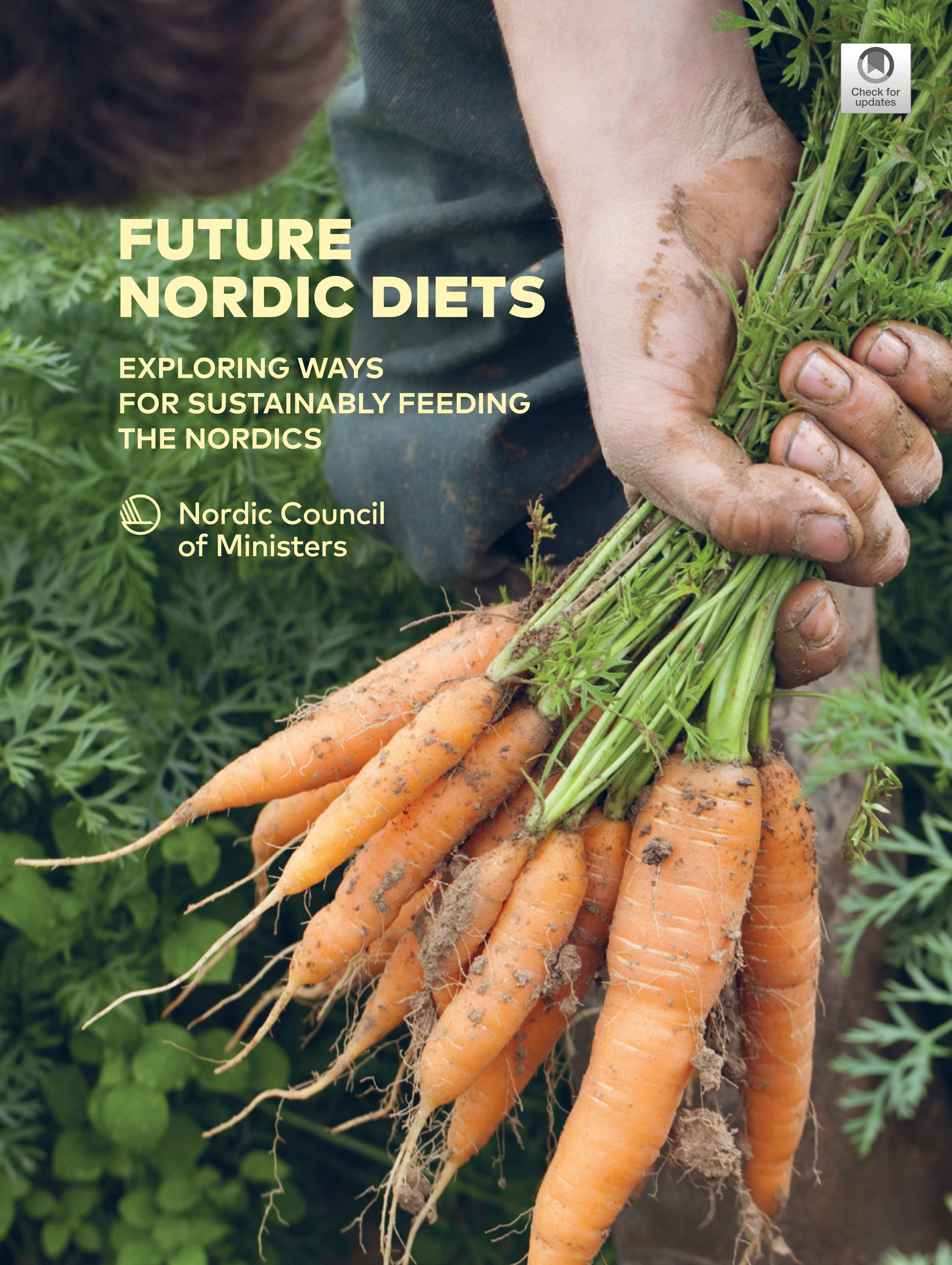

FUTURE NORDIC DIETS

EXPLORING WAYS FOR SUSTAINABLY FEEDING THE NORDICS

Nordic Council
of Ministers

Future Nordic Diets

Exploring ways for sustainably feeding the Nordics

Johan Karlsson, Elin Röös, Tove Sjunnestrand, Kajsa Pira, Malin Larsson,
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Preface

Farming is the foundation of our food system. While the pre-requisite to farming is a clean environment, development over recent decades has pushed for ever-increasing production and intensification at the expense of quality. This has led to enormous impacts on the environment including 12 percent of the greenhouse gas emissions[1] and around 90 percent of the nitrogen emissions in Finland, Denmark, Norway and Sweden (henceforth referred to as the Nordic countries) originating from farming (Antman et al., 2015).

Many of the studies (e.g. Gerber et al., 2013) done on climate mitigation and reducing nitrogen emissions from agriculture have taken a highly technical approach, assuming that the diets of people will be the same in the future, or extrapolating current dietary trends. The studies show that there is some potential for emission reductions through technical measures and changed practices, but not to the degree needed for the sector to sufficiently contribute to the long-term goal of the Paris agreement – a future in which the increase in global average temperature is kept well below 2 °C above pre-industrial levels.

We believe that the planetary boundaries (Steffen et al., 2015) and human nutritional needs should be the starting point for any serious discussion of a future agriculture and food system.

The scenarios developed in this report show that it is possible to feed a population of up to 37 million people in the Nordic countries of Denmark, Finland, Norway and Sweden with a healthy diet, while keeping greenhouse gas emissions on a level compatible with staying below 2 °C warming by the end of this century.

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[1] The contribution of agricultural methane and nitrous oxide emissions to total greenhouse gas emissions (excluding LULUCF) in the Nordic countries is eight percent and nine percent in Norway and Finland respectively, whereas this figure is as high as 13 percent in Sweden and 19 percent in Denmark. If carbon dioxide emissions from land use, land use changes, transport and energy consumption were included, the figure would be significantly higher and would increase further if emissions related to imported fertilizers and animal fodder were included.

The scenarios also show that this would require major changes to current diets, including reductions in meat consumption by 81–90 percent, depending on the assumptions of the scenarios.

It is noteworthy that animal products nevertheless constitute an important contribution to the diets in these scenarios, since animals can convert resources that humans cannot benefit from directly. Grazing animals also play an important role in the management of natural and semi-natural pastures that contain a high share of valuable species in the Nordic flora and fauna.

These models give us a rough estimate of what is possible given certain assumptions. The scenarios do not rule out the possibility that a completely vegan diet or a diet containing slightly more animal products could meet the same criteria, if other assumptions were made for variables such as availability of local fish stocks, extent of grasslands and rangelands, and the use of novel proteins and crops that are grown in the Nordic countries only to a limited extent today. It has also been difficult to fully consider the great variation in agricultural structure, topographic and climate conditions, land use and production figures both between and within the countries.

The results in the first part of the report, chapters 1–5, are limited to what can be understood from a natural science perspective. We therefore also organized four workshops with stakeholders in which we discussed these issues from political, economic and social perspectives (chapter 6).

The scenarios in this report should not be seen as the perfect recipe for a future food and farming system, but more of an indication of which direction we need to be heading in. Like many other areas of human activity, we cannot continue to believe that business as usual is just fine. We hope that this report can contribute to a more enlightened debate that continues to examine the opportunities we have for a truly sustainable food system.

We hope you will find our approach enlightening.

Summary

The global food system causes large emissions of greenhouse gases and other pollutants into the environment. Livestock are responsible for a large part of these emissions and take up most of the agricultural land for grazing and feed production while only making a more limited contribution to the global food supply. In this project, we have used an agricultural mass flow model to assess two future food system scenarios for the Nordic countries Denmark, Finland, Norway and Sweden (hereafter "the Nordic countries"). In these scenarios, livestock feed production competes less with human food production and the majority of food is produced within the Nordic countries using organic farming practices.

In the first scenario (SY) the number of ruminants was limited to the minimum number needed to graze all semi-natural pastures, while monogastric animals (poultry, pigs and aquaculture fish) were limited to available food processing byproducts.

In the second scenario (EY) the number of ruminants was increased to utilize all ley grown in organic crop rotation and byproduct feed for monogastric animals was supplemented with some feed crops grown on arable land. This enabled more food to be produced from Nordic agriculture, thus feeding a larger population.

The results show that the scenarios would be able to produce enough nutritious food for 31 (SY) and 37 (EY) million people in the Nordic countries. The scenarios would thus be able to support the projected population in 2030, albeit with changes in consumption patterns. Consumption of meat decreased by 90 percent (SY) and 81 percent (EY) from current consumption levels; substituted by cereals, legumes and vegetable oil. The scenarios also included more vegetables than currently consumed in order to comply with the Nordic nutrition recommendations.

Estimates of current greenhouse gas emissions from the agricultural production of food consumed in the Nordic countries range between 1,310 and 1,940 kg CO_2-eq per person per year. The greenhouse gas emissions from agricultural production in the scenarios were estimated at 310–700 kg CO_2-eq per diet per year.

Workshops held in each of the four participating Nordic countries with stakeholders provided further perspectives on the viability of the scenarios. These discussions

highlighted among other things the complexity of consumer choices, the potential for policy action, farmers’ needs and the importance of creating a positive narrative.

1. Introduction

This report is one of the main outputs of the project "Pathways to a Nordic food system that contributes to reduced emissions of greenhouse gases and air pollutants". The project is financed by the Nordic Council of Ministers and began in 2013.

The outset of the project was the recognition that agriculture was responsible for a significant part of both greenhouse gas emissions and air pollutants. But few efforts were being made to achieve any further cuts in emissions. The emission reductions seen in the past were to a great extent structural changes that led to lower number of animals and indirect effects of legislation that had the primary purpose to reduce waterborne emissions.

In 2015, we published a baseline and system analysis report "Nordic agriculture air and climate" and in 2016 a policy brief "Paths to a sustainable agricultural system" based on the same report.

One of the preliminary recommendations from the first part of the project was to:

> "Strive towards a paradigm shift in how we perceive agricultural production, food systems and consumption, with a view to striking a balance between various dilemmas and conflicts in the production systems, the import/export balance, consumption patterns, and how we perceive efficiency in the farming sector and take into account environmental and climate impact factors."

It was decided that the second part of the project would include a scenario for a future Nordic food system in order to inspire a more holistic debate around sustainability, by envisioning what could be possible, given some certain criteria. A prerequisite for the scenarios was that they must contribute to: reducing greenhouse gas emissions; reducing global hunger and poverty and assuring access to healthy and nutritious food and drink for the world's population. At that time several scenarios had been proposed for sustainable energy and transport systems in Europe, but we had seen no corresponding work for food and agriculture.

A vision for the scenario work was decided by the steering group in 2015:

> "To develop a new Nordic agricultural and food system that will contribute to global sustainable food systems and climate mitigation also taking into account the agroecological approach".

The Swedish University of Agricultural Sciences, which had previously produced other future scenarios with a focus on sustainability, was contracted to do modelling work. They also had the opportunity to contribute additional funds to support the project, including the involvement of Mälardalen University to evaluate the nutritional quality of the diets.

There has been close and effective collaboration between the project's steering group and the researchers, including regular discussions in order to refine and adjust the scenarios to fulfil our vision in the best possible way.

1.1 Project group

Table 1: Participants in the steering group

Organization	Contact person	Contact details
Miljøbevægelsen NOAH and Frie Bønder – Levende land	Bente Hessellund Andersen	bente@noah.dk
Miljøbevægelsen NOAH	Jacob Sørensen	jacob@noah.dk
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Norsk Bonde- og Småbrukarlag	Stein Brubæk	stein359@gmail.com
The Air Pollution and Climate Secretariat	Kajsa Pira	kajsa.pira@airclim.org
The Air Pollution and Climate Secretariat	Malin Larsson	malin.larsson@airclim.org

Besides the steering group a few other people have contributed data, projections and views, including Anne Antman (The Finnish Society for Nature and Environment) and Jenny Teerikangas (Uusimaa Region of Finnish Association for Nature Conservation).

Our steering group represents conservation and environmental organizations as well as farmers' organizations. Miljøbevægelsen NOAH (NOAH) is a Danish registered association and the first environmental organization in the country. NOAH works for equal access to the earth's resources without overloading the environment. Frie Bønder – Levende Land is a Danish association that speaks for the interest of farmers and works to improve the relationships between rural and urban areas. Uusimaa Region of Finnish Association for Nature Conservation (FANC) is a Finnish registered association. FANC is the largest non-governmental organization for environmental protection and nature conservation in Finland. Norsk Bonde- og Småbrukarlag (NBS) is a Norwegian registered association and is a politically independent organization that works to improve the economic and social framework of agriculture. The Air Pollution and Climate Secretariat (AirClim) is a non-profit organization and joint venture between four Swedish organizations: Nature and Youth Sweden, Friends of the Earth Sweden, Swedish Society for Nature Conservation and World Wide Fund for Nature Sweden. AirClim's chief purpose is to promote awareness of the problems associated with air pollution and climate change.

The organizations represented by the steering group have also published:

- The report Nordic agriculture air and climate – Baseline and system analysis report 2015
- The policy brief: Paths to a sustainable agricultural system – Pathways to a Nordic agricultural and food system with reduced emissions of greenhouse gases and air pollutants 2016

1.2 Researchers

Table 2: Researchers in the project

University	Contact person	Contact details
Swedish University of Agricultural Sciences	Elin Röös	elin.roos@slu.se
Swedish University of Agricultural Sciences	Johan Karlsson	johan.o.karlsson@slu.se
Mälardalen University Sweden	Tove Sjunnestrand	tove@sjunnestrand.se

Elin Röös is a researcher at the Swedish University of Agricultural Sciences who focuses on sustainable food production and sustainable land use from a system perspective. Johan Karlsson is a PhD student at the Swedish University of Agricultural Sciences and Tove Sjunnestrand is a research assistant in public health at Mälardalen University Sweden.

1.3 Project outline

The current production and consumption of food in the western world is unsustainable. Globally, food systems are estimated to account for almost one third of anthropogenic greenhouse gas emissions, of which agricultural production is responsible for over 80 percent (Vermeulen et al., 2012). More than one third of the world's total arable land is used to grow feed crops for animals and, when pasture land is included, livestock occupies 70 percent of all agricultural land (Foley et al., 2011). A large part of the original energy in animal feed is lost in the metabolic processes of animals (Godfray et al., 2010). If a larger proportion of feed crops were used directly as human food, more food could be made available without the need for more agricultural land (Smith, 2013; Stehfest et al., 2009). If livestock are fed resources that are not in direct competition with human food, livestock production can provide important services to society, and in some cases also to ecosystems (Röös et al., 2016; Schader et al., 2015). For example, the semi-natural pastures in Europe have developed over hundreds of years of human influence through grazing livestock, and today boast a diversity of plant and animal species (Jordbruksverket, 2016). Semi-natural pastures can generally be defined as permanent pastures that have evolved from long-term, low-intensity traditional farming and where no recent reseeding or heavy fertilization have taken place. Grazing animals are needed to preserve the values in these landscapes. Further, byproducts from food production, such as low-grade vegetables or residues from vegetable oil production, can be used to feed animals that provide meat and other livestock products to human diets without requiring land for feed production.

This project aims to explore scenarios for future food systems in the Nordic countries that build on the principle of limiting livestock production to resources that do not compete with human food, as well as principles of organic farming. By doing so we try to answer the question whether the Nordic population could by 2030 be supported by local organically produced food resources and what these diets could comprise. Furthermore, the project aims to evaluate the impacts of the resulting agricultural production on land use and on the environment. The livestock feed resources that are assumed not to be in competition with human food were:

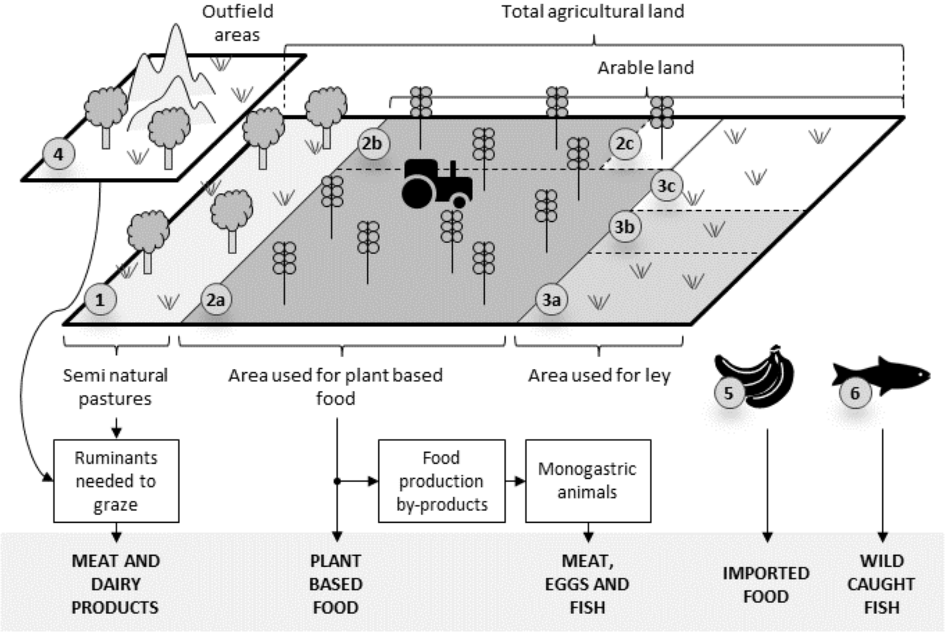
- semi-natural pastures where annual cropping is unfeasible and grazing promotes biodiversity;
- byproducts unfit or undesirable for human consumption; and
- ley grown with the primary purpose of providing green manure and/or pest control.

The scenario diets were based on the Swedish nutrient recommendations translated into food items (SNÖ). This is an exemplified diet similar to the current Swedish dietary pattern that also fulfils the Nordic Nutrient Recommendations (NNR) (Nordic Council of Ministers, 2014). This "base-line" diet was used to promote resulting diets with high acceptability (i.e. using similar food items as in current diets) and adequate nutritional values. Limiting livestock to non-food-competing resources results in reduced consumption of animal protein, fat and energy, which was substituted with cereals, legumes and vegetable oil in the scenarios. Two scenarios were modelled, with different numbers of livestock. For each scenario, estimates were made of the maximum number of people that could be supported by Nordic agriculture. Land was allocated to grow all food in the diets except for tropical fruits, nuts, tea and coffee, which were imported in amounts equal to current consumption. Figure 1 shows how the available agricultural land was used in the scenarios.

A first scenario (*Sufficiency*, *SY*) was developed using a stringent interpretation of the principles. The number of ruminant animals (cattle and sheep) was limited to the minimum number of animals needed to graze available semi-natural pastures in each country. Byproducts were fed to monogastric animals (poultry, pigs and aquaculture fish) and used to supplement the ruminant feed. Only byproducts and grass were allowed in the livestock diets and apart from ley no additional feed was grown.

A second scenario (*Efficiency*, *EY*) was developed to increase the utilization of available land resources. In this scenario the ruminants were allowed to graze pastures on arable land to a larger extent, and more grass was used for winter feed in order to make use of the ley that was grown in the crop rotations. Some feed that was cultivated on arable land was also included in the feed rations, as long as this contributed to the aim of feeding more people from local resources. This scenario allowed a larger number of livestock to be kept in each country and more animal products to be retained in the diets.

Figure 1: Illustration of the basic rationale used for designing the scenario diets and allocating the available agricultural land to different land uses and activities



1 The amount of semi-natural pastures available for grazing sets a limit on the number of ruminants needed to keep these areas grazed. The ruminants provide meat and dairy products for the diets.

2a Arable land was allocated to produce most of the plant-based food in the diets. Food processing generates byproducts that were used to supplement the ruminant feed and feed monogastric animals (poultry, pigs and aquaculture fish). The monogastric animals provide additional meat, eggs and fish to the diets.

2b To compensate for a reduced consumption of meat and other animal products, additional arable land was allocated to grow supplementary plant-based food (legumes, cereals and vegetable oil).

3 To provide green manure and pest control, ley was grown for at least two years in a six-year crop cycle. All crops except greenhouse horticulture and fruit orchards were grown in a crop rotation that included ley.

3a Some ley was allocated to provide winter feed for ruminants and pasture for dairy cows that were assumed to be able to graze semi-natural pastures only to a limited extent.

3b Slaughter and food waste, manure and, to some extent, straw were used to produce bioenergy for heat, electricity and fuel use on the farms. If additional energy was needed, ley was harvested to produce bioenergy. The digestate was returned to the soils as organic fertilizer.

3c Ley that was not used for 3a or 3b was not harvested in scenario SY. In scenario EY this land was used to provide more pasture and winter feed for a larger number of ruminants.

4 In the EY scenario, Norwegian outfield areas were also included because of their importance in Norway's animal husbandry. This provided additional pasture for ruminants, especially sheep.

5 Some plant-based food (tropical fruits, nuts, tea and coffee) was imported and included in the diets.

6 A global "fair share" of wild-caught fish was included in the diets.

2. Development of scenarios

The normative decisions proposed by Röös et al. (2016) in this report were extended to the Nordic case in discussion with representatives of the steering group in the project. An initial workshop with the steering group and researchers from the Swedish University of Agricultural Sciences and Mälardalen University was held in Oslo on 31 October 2016. During early spring 2017, a workshop was held in each country and these were attended by various stakeholders (farmer unions, politicians, environmental organizations etc.). Preliminary results were presented and discussed during these workshops. Comments from the participants and lessons learned were then fed back into the process of formulating the normative decisions and the modelling work. The final decisions and their implications for the modelled systems are found in Table 3 and reflect the NGOs' views and opinions on the future of agriculture in the Nordic countries. Based on these decisions, the scenarios for future Nordic diets were developed. The comments from the four workshops were compiled by the steering group in chapter 6: stakeholder consultation.

Table 3: Normative decisions decided by the five NGOs in consultation with the researchers and their implications for the modelled systems

Normative decisions	Implications
1. Diets should seek to resemble current eating patterns and fulfill Nordic Nutrient Recommendations (NNR).	– The Swedish nutrient recommendations translated into food items (SNÖ) was used as the "base-line" diet from which the scenario diets were. produced (Enghardt and Lindvall, 2003). – No novel foods (insects, synthetic meat, algae etc.) were included.
2. Future diets should facilitate equitable consumption that is based on local resources and arable land should primarily be used to grow food for humans, not feed for livestock or bioenergy crops.	– On the available arable land and semi-natural pastures food was produced for as many people as possible. – Arable land was allocated to grow most plant-based food needed for a nutritionally adequate diet (SNÖ). – A global "fair share" of wild-caught fish was included in the diets.
3. The Nordic countries should provide as much food as possible from local production, but be able to import food products that are not possible[a] to produce locally.	– The amount of greenhouse-grown vegetables (cucumbers, lettuce and tomatoes) was reduced by half compared to SNÖ and replaced with vegetables and roots able to grow on open fields. – Tropical fruits, nuts and coffee/tea were imported according to current consumption. Increased consumption of fruits in the scenario diets was covered by local production.
4. The food should be produced in an organic farming system, acknowledging agro-ecological principles.	– At least 33% of arable land in rotation was allocated for ley production (i.e. in a six-year crop rotation ley is grown for two years) to provide green manure. – The frequency of rapeseed and grain legume cultivation was limited to 17% and 10% respectively to avoid build-up of pests and soil-borne pathogens. – Current yield levels were factored using literature values for the yield gap between organic and conventional farming. – Livestock production follows organic practices with respect to time spent on pastures, growth rates, feed, etc.
5. Food waste should be reduced by half compared to current levels.	– Avoidable food waste in the retail and consumer stage of the food chain is halved compared to current levels.
6. Some land currently used for annual crop production is unsuitable for this and should be left for nature conservation.	– Drained and cultivated peatlands were excluded from the available arable area. – In Denmark 15% of the arable area was set aside to promote nature conservation.
7. Semi-natural pastures should be grazed by livestock to promote biodiversity and preserve the cultural landscape.	– Ruminants (dairy cattle and sheep) were included in numbers needed to graze all semi-natural pastures. – In the EY scenario, Norwegian outfield areas were also grazed by ruminants.
8. Durable breeds of ruminants should be used to allow grazing of semi-natural and outfield areas in rough terrain.	– A milk yield from dairy cows of 6,000 kg energy-corrected milk per year was assumed, which is low compared to modern breeds of dairy cows.

Normative decisions	Implications
9. Byproducts[b] from food production are best used as feed for livestock.	– Available byproducts are fed to livestock and aquaculture producing meat, eggs, dairy products and fish.
10. Agriculture should be self-sufficient in energy, but should not provide energy for other parts of society.	– Manure, food and slaughter waste were used as substrate in a biogas reactor to produce heat, electricity and, through upgrading, fuel for agricultural machinery. Some straw was also burned to heat stables and greenhouses. – The digestate and straw ash was applied to the arable land as fertilizers. – If needed, ley was harvested and used as substrate in the biogas reactor.

Note: [a)] What can be produced locally is largely dependent on the amount of resources (e.g. working hours, energy, irrigation etc.) one is willing to invest. In this work those products traditionally grown on arable land and in greenhouses in the Nordic countries were considered as possible to produce locally.

[b)] Byproducts were defined as leftovers from food production that are unfit or undesirable for human consumption. This includes low-grade potatoes and roots, excess cereal bran, byproducts from sugar and vegetable oil production, and fishmeal from gutting and cleaning.

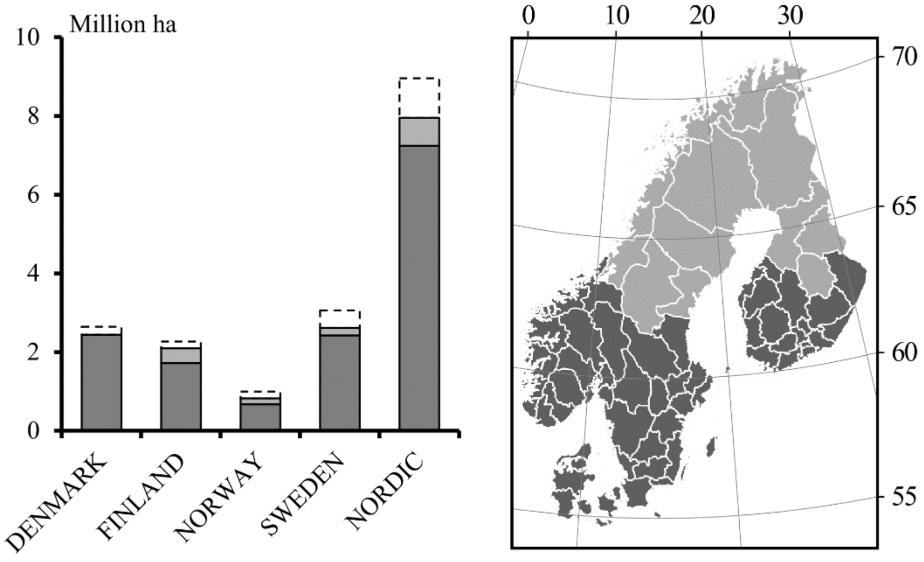
The scenarios were applied to the cases of Denmark, Finland, Norway and Sweden, using national statistics on available arable land and semi-natural pastures, crop yields and nutrient leaching. An aggregated Nordic diet was also modelled.

2.1 Crop cultivation

The arable land needed to produce the plant-based products in the diets (i.e. cereals, legumes, vegetables, roots etc.) was calculated using national statistics on different crop yields. Statistics on yields from organically farmed crops were not available for all crop types in all countries. Statistics for conventional yields were therefore used and factored using literature values from de Ponti et al. (2012) for the yield gap between conventional and organic farming practices for the different crops. Furthermore the ley yields were adjusted for statistical bias by multiplying the yields by 1.7 for Finnish, Norwegian and Swedish yields. No correction was applied to the Danish ley yields. (See Appendix B)

The proportion of rapeseed and grain legume cultivation was limited to 17 percent and 10 percent of arable land respectively, corresponding to, on average, rapeseed cultivation every sixth year and grain legumes every tenth year in the crop rotation. These limitations were justified by the need to avoid build-up of pests and soil-borne pathogens that may affect these crops if grown too often in the same location, as well as the assumption that all arable land might not be suitable for grain legume cultivation. In organic farming systems, ley cultivation is important to maintain soil fertility. All crops except greenhouse horticulture crops and apples were therefore assumed to be grown in a crop rotation containing at least 33 percent ley, corresponding to, on average, ley cultivation every third year. If needed, more ley was added to the crop rotations to avoid exceeding the limitations on rapeseed and grain legume cultivation. For climatic reasons, it was assumed that no cultivation of rapeseed or grain legumes would take place in the northern parts of the Nordic countries, approximately above 63°N (Figure 2). The restriction of cultivation areas for this group of crops was based on the fact that these crops cannot overwinter (for winter rapeseed crops) or reach maturity in the strong winters and short growing seasons of the northern regions. Further guidance on the restriction of areas was taken from national statistics on cultivation areas and crop yields. The restricted area represents 9 percent of the total arable area, ranging from zero in Denmark to 19 percent in Norway.

Figure 2: (left) Total agricultural area used for each country divided between semi-natural pastures (dashed) and arable areas with (dark grey) and without (light grey) assumed cultivation of rapeseed and grain legumes. (right) Map showing the studied region divided between areas with (dark grey) and without (light grey) assumed cultivation of rapeseed and grain legumes



In the EY scenario, Norwegian outfield areas were also included for grazing animals since they are an important part of the country's animal husbandry, especially for sheep but also for larger ruminants. Currently around two million sheep and 230,000 cattle are released to graze Norwegian outfields yearly (Rekdal, 2008).

Table 4: Current and projected populations, available arable land and semi-natural pastures used in the modelled scenarios. Dry matter yields (kg dm ha^{-1}) were used in the scenarios. Yields were retrieved from national statistics and factored using literature values for the yield gap between conventional and organic farming for different crop types

	Denmark	Finland	Norway	Sweden	Nordic
Population (million)					
2015	5.7	5.5	5.2	9.8	26.2
2030	6.0	5.7	5.9	10.8	28.4
Agricultural area (ha)					
Arable land	2,520,682	2,078,300	813,353	2,590,100	7,729,335
Semi-natural pastures	273,100	195,400	175,840	449,800	1,094,333
Yields (kg dry matter ha-1)					
Fodder crops					
Ley	12,304	7,230	7,778	6,976	
Temporary pastures	7,383	4,338	4,667	4,185	
Semi-natural pastures	1,777	1,116	655	1,144	
Cereals	3,637	2,282	2,453	3,177	
Grain legumes	2,684	1,677	1,445	2,272	
Food crops					
Rapeseed	2,210	1,016	1,384	1,584	
Cereals	3,772	2,166	2,958	3,591	
Grain legumes	3,258	1,623	1,084	1,301	
Potatoes	4,032	1,278	2,838	3,353	
Sugar beet	15,670	10,024	7,560	15,658	
Cabbage	2,122	1,588	1,972	1,995	
Onion	3,384	1,937	2,292	3,520	
Roots	5,376	4,510	3,441	6,000	
Apples	1,808	798	701	1,436	
Berries	428	277	367	407	
Lettuce, tomato, cucumber	10,971	19,570	15,219	15,898	

2.2 Livestock production

The numbers of livestock in the different scenarios were found using the generalized reduced gradient (GRG) method bundled with Microsoft Excel Solver. This is an optimization algorithm for solving non-linear problems. When the solver converges to a solution it means that no other feasible solution that is more optimal can be found close to the current solution (a locally optimal solution). It is however possible that other more optimal solutions might exist further away from the current solution (Fylstra et al., 1998).

The solver was set up with the number of livestock, feed rations and number of people the diets could supply, as variables. Constraints were put on feed composition (described in more detail below), land use, percent ley, rapeseed and grain legumes in the crop rotations and macronutrient composition in the resulting diets. The variable to optimize was the number of people the diets could supply. To ensure solutions close to the true optimum, each solution was manually checked for the following criteria: (i) all arable land used, (ii) all byproducts used, and (iii) no over-feeding. If the solution was found to be lacking in any of these criteria the starting values were changed and the solver run again until a satisfactory solution was found. This process ensured a feasible solution as close as possible to the optimal solution, but it cannot be ruled out that other more optimal solutions exist.

The relative numbers of cattle and sheep in the scenarios were based on the consumption of beef and lamb meat in each country (i.e. the scenario diets have the same proportion of beef and lamb meat as current consumption). An exception from this was the Norwegian EY scenario, where more lamb meat was included in the diet to utilize outfield areas.

Livestock production parameters (yields, growth rates, time on pastures, mortality, etc.) for the different livestock species were compiled from different sources and set to reflect organic livestock rearing practices. It was decided to use dual purpose poultry, where the cockerels are grown for meat (rather than being killed immediately after being hatched as is usual practice today) due to the ethical appeal of this concept. The dairy cattle were reared in extensive systems with a large proportion of feed from pastures and relatively low milk yields. Beef was produced as a byproduct from dairy production, rearing male calves and heifers not entering the milk production for meat, and no specialized beef units were used in the scenarios. Lamb meat was produced in extensive systems where the lambs are grown on pastures during the summer months and slaughtered before the ewes are moved to the stables. Growing pigs and sows were kept on pastures in rotation in the summer. The aquaculture fish were grown in land-based aquaculture systems and the species used was *Nile Tilapia*.

Current practice nutrition recommendations for each livestock species were used to compile feed rations based on the available byproducts, grass resources and, in the EY scenario, grown feed. For cattle and sheep the recommendations were derived from Spörndly (2003), using recommendations for metabolizable energy (ME), amino acids absorbed in the small intestine, protein balance in the rumen and crude fat. For pigs, recommendations from Simonsson (2006) were used, taking ME and digestible amino acids into account. Recommended maximum inclusion rates of different feedstuffs were also considered. Feed rations for poultry were derived from *Nutrient requirements of poultry* (1994) together with productivity parameters for dual purpose poultry from Leenstra et al. (2010). Poultry feed rations were designed using recommendations for ME and crude protein. The aquaculture (*Nile Tilapia)* feed rations were designed using ME, crude protein and crude fat contents from Goda et al. (2007). Nutrition parameters for the different feedstuffs were acquired from the online feed tables provided by the Department of Animal Nutrition and Management at the Swedish University of Agricultural Sciences.

For the wild-caught fish in the diets a global "fair share" was calculated based on the World Bank report "Fish to 2030" (The World Bank, 2013). Values were adopted from Scenario 5 where global fish stocks are harvested at levels permitting the maximum sustainable yield. Under this scenario fisheries would supply a total of 65,880,000 tons of food fish in 2030 which, divided by the global population projections, gives a "fair share" of 3.5 kg of wild-caught fish per person per year, which was included in all scenario diets.

2.3 Food waste

The food losses throughout the food chain were accounted for using factors for estimated food losses in different commodity groups (FAO, 2011). Avoidable food waste at the retail and consumer stages of the food chain was assumed to be halved in the scenarios compared to current levels.

The food production byproducts assessed in this study were rapeseed cake from vegetable oil production, low-grade roots and potatoes, residue cereal bran, bakery wastes, spent grains from beer production, fibre and molasses from sugar production and fishmeal from gutting and cleaning. Byproducts from roots, potatoes, cereals, bakery waste and rapeseed oil were estimated from current food losses from FAO (2011). Byproducts from sugar production were calculated from Flysjö et al. (2008). For fish meal all inedible fractions of the wild-caught and aquaculture fish were assumed to be processed into fishmeal, apart from 41 percent of the fish which was assumed to be sold fresh.

2.4 Energy used on the farm

Eighty percent of the food waste at the consumer stage was assumed to be digested together with slaughterhouse waste, manure, and straw used for bedding, to produce bioenergy for heating, electricity and fuel use on the farms. If needed, ley was also harvested and digested together with the other feedstocks to meet the farms' energy needs. Literature values for energy use in stables and greenhouses were used to calculate the energy needed.

2.5 Diet nutrient composition

The nutritional content of the diets was analysed using the program DietistNet. The program is based on national and international food databases (e.g. Swedish National Food Agency, United States of Agriculture and Swedish food companies), and contains information on 107 nutrients. In this study, only the food database of the Swedish National Food Agency was used to ensure consistent nutrient analysis of the foods.

For meat products, nutrient analyses for raw products were used to minimize the calculation error from raw to cooked products, since the weight yield factors differ a lot within this product group. Where nutrient analyses for raw products were lacking (i.e. for legumes, pasta and couscous), weight yield factors (Table 5) were used to convert the mass of raw products to cooked equivalents.

Table 5: Weight yield factor (i.e. the weight ratio from uncooked to cooked product) for each food item used in the nutritional calculations. Adopted from Bognár (2002)

Product	Weight Yield Factor
Cereals	
Pasta	2.5
Couscous	3.4
Legumes	
Beans	3.6
Peas	3.0
Lentils	2.8

The types of food in the different food groups used in the nutrition calculations were distributed as follows: Cereals were assumed to consist of 39 percent wheat (bread, flour, couscous, pasta), 38 percent rye (bread), 12 percent oats (breakfast cereals) and 11 percent barley (beer); legumes were assumed to consist of 50 percent peas (chickpeas, green peas and yellow peas), 30 percent lentils (red and green) and 20 percent beans (kidney, black beans and brown beans); roots were equally distributed between carrots, parsnips and celeriac; the cabbage group was equally distributed between broccoli, cauliflower and cabbage; the onion group was equally distributed between red and yellow onions; and vegetables were equally distributed between lettuce, tomato and cucumber.

The nutritional values for current consumption were derived from national dietary surveys (Amcoff et al., 2012; Helldán et al., 2013; Pedersen et al., 2015; Totland et al., 2012). Since food and food groups are presented differently and with various accuracy in the surveys, the national food agencies in respective countries were contacted to collect additional information. Where additional information was lacking, assumptions had to be made. For instance, the category meat was presented as red meat, fish and poultry, and no consumption data was available for subgroups (i.e., beef, pork and lamb). To estimate the distribution of intake of beef, pork and lamb, consumption statistics from national statistical databases were used (StatBank Denmark, Statistisk sentralbyrå Norway, Luke Luonnonvarakeskus Finland and Jordbruksverket Sweden). The consumption statistics derived from these institutes are based on production and imports minus exports, i.e. what is sold within the country and not the actual consumption. The Nordic Nutrition Recommendations 2012 (NNR 2012) were used as the reference values for recommended daily intake (RDI) of macronutrients, vitamins and minerals (Nordic Council of Ministers, 2014).

3. Impact Assessment

The environmental impact of the diets was assessed using indicators for global warming, eutrophication and acidification. Emissions were assessed from soil to farm gate and included emissions related to land management, livestock and manure management, farm energy and fuel use, biogas generation and fuel consumption by the fishing fleet. For global warming, emissions related to importing food were also included. Processing, packing, storage and transport of food and feed were excluded, as well as the environmental impact of other farm equipment and material. The data sources used for the impact assessment included (but were not limited to) IPCC 2006 Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), national inventory reports and published life cycle assessment studies. Emission factors and methods used for the different activities are described in more detail in the appendix.

3.1 Global warming

Global warming is caused by the release of gases into Earth's atmosphere that increase the absorption of infrared radiation, commonly known as greenhouse gases. The global warming impact of the diets were assessed as global warming potential over a hundred-year time frame (GWP_{100}), expressed as carbon dioxide equivalents (CO_2eq). To weigh the varying climate impact of different greenhouse gases, GWP_{100} characterization factors were used to relate the radiative forcing of the instantaneous release of one kg of a particular compound to the release of one kg of carbon dioxide Table 6 shows the compounds used in the assessment and their associated activities together with GWP_{100} factors for each compound.

Table 6: Compounds included in the global warming assessment, the activities associated with their emission and their respective GWP_{100} factor

Assessed compound	Associated activities	GWP_{100} [a] (kg CO_2eq/kg)
Carbon dioxide (CO_2)	Emissions from combustion of fossil fuels and changes in cropland soil carbon stocks.	1
Methane, bio (CH_4)	Enteric fermentation, manure management, bioenergy production and use.	34
Methane, fossil [b] (CH_4)	Emissions from combustion of fossil fuels.	36
Nitrous oxide (N_2O)	Direct emissions from crop residues and manure application. Indirect emissions through ammonia emissions and nitrogen leaching.	298

Note: a) Source: (Stocker et al., 2013, Table 8.7).
b) Includes CO_2 from methane oxidation.

3.1.1 Changes in soil carbon stocks

Soil carbon stock changes were assessed with the Introductory Carbon Balance Model (ICBM). The ICBM can either be used to model the steady state carbon pool following certain management and climatic conditions, or used to model changes over time from a defined starting value. The driving variables in the model are organic carbon input to the soil (e.g. crop residues, manure and biogas digestate) and climate. Since a calibrated model was only available to us for Swedish agricultural soils it was not possible within the scope of this study to assess soil carbon changes for the other countries.

In this study the steady state carbon pool in a business-as-usual (BAU) scenario was modelled for all arable soils using data on current land use and livestock numbers. The calculated steady-state carbon pools were then used as the initial state when modelling changes in soil carbon over time under the two different scenario diets.

3.2 Eutrophication

Eutrophication is caused by an excess of macronutrients, mainly nitrogen (N) and phosphorus (P), in the environment. This can lead to shifts in species composition and increased biomass growth and subsequent depression of oxygen levels in aquatic environments. The eutrophying impact of the diets were assessed by their eutrophication potential (EP), expressed as phosphate equivalents ($PO_4^{3-}e$). This method is based on the Redfield ratio (i.e. that the average relative proportion of N:P in algal biomass is equal to 16:1). It is therefore assumed that one mole of P and 16 moles of N will contribute equally to the production of biomass and to eutrophication (Guinée et al., 2002).

Generic EP factors were used to translate compounds that contribute to eutrophication into $PO_4^{3-}e$. These factors do not take into account whether a particular nutrient is limiting in the local environment or not, but give a general metric for the EP if no other nutrient is limiting the biomass growth Table 7 shows the compounds used in the assessment and their associated activities, together with generic EP factors for each compound.

Table 7: Compounds included in the eutrophication assessment, the activities associated with their emission, and their respective generic EP factor

Assessed compound	Associated activities	AP [a] (kg SO_2e/kg)
Sulphur dioxide (SO_2)	Emissions from combustion of bio- and fossil fuels.	1.00
Nitrogen oxides (NOX)	Emissions from combustion of bio- and fossil fuels.	0.70
Ammonia (NH_3)	Emissions from manure management and application, crop residues and biogas production.	1.88

Note: a) Source: (Guinée et al., 2002, Table 4.3.10.2).

3.3 Acidification

Acidification is caused by pollutants acting as acids in the natural environment, and has a variety of impacts on both terrestrial and aquatic ecosystems as well as on building materials. The acidifying impact of the diets were assessed by their acidification potential (AP), expressed as sulphur dioxide equivalents (SO_2e). The acidification potential is based on a pollutant's ability to release hydrogen ions (H^+) into the environment and is defined as the number of H^+ ions released per kg of substance, relative to SO_2 (Guinée et al., 2002).

Generic AP factors were used to translate emissions of acidifying substances into SO_2e. These factors do not take the buffering capacity of the local environment into account, but express the maximum AP of the substances. Table 8 shows the compounds used in the assessment and their associated activities together with generic AP factrs for each compound.

Table 8: Compounds included in the acidification assessment, the activities associated with their emission and their respective generic AP factor

Assessed compound	Associated activities	AP [a] (kg SO_2e/kg)
Sulphur dioxide (SO_2)	Emissions from combustion of bio- and fossil fuels.	1.00
Nitrogen oxides (NOX)	Emissions from combustion of bio- and fossil fuels.	0.70
Ammonia (NH_3)	Emissions from manure management and application, crop residues and biogas production.	1.88

Note: a) Source: (Guinée et al., 2002, Table 4.3.10.2).

4. Results

4.1 Diets and food supply

In all scenario diets the consumption of meat decreased substantially. Compared to current levels, meat consumption (incl. chicken) decreased on average by 90 percent in SY and 81 percent in EY, to a weekly consumption of 80 and 149 grams respectively. Consumption of fish in both scenario diets was around half of current consumption; around one serving weekly compared to the two servings currently consumed in the Nordic countries. Consumption of milk was slightly less than half of current consumption for SY while it was on the same level as current consumption for the EY scenario (Table 9).

Comparing the different countries, it was noticed that the Norwegian scenario diets were generally higher in meat due to extensive pasture resources, while arable land was limited and crop yields comparably low. However, the Norwegian scenario diets were not able to support the projected population in 2030. On the other side of the spectrum, the Danish diets were lower in meat and milk, since the Danish scenarios were able to support a large population due to high crop yields, while pasture resources were limited leading to a larger fraction of vegetable products in the diets.

To compensate for reduced consumption of animal products, plant-based protein in the form of cereals and legumes increased. For SY the consumption of legumes was about four times the current level, and for EY it increased by 156 percent. Consumption of cereals increased by 67 percent and 51 percent for SY and EY respectively.

In total, it would be possible to supply an estimated 30.9 and 37.0 million people respectively with the SY and EY scenario diets. The 2015 population in the Nordic countries totalled 26.2 million and is projected to grow to 28.4 million by 2030. In other words, the scenario diets could feed the Nordic population in 2030 and potentially provide food for an additional 2.5–8.6 million people. Looking at each country individually the SY scenario had the potential to support the 2030 population in Denmark and Sweden, while the EY scenario could also support the Finnish population from local resources. None of the scenarios proved to be able to support the Norwegian population from national resources.

Table 9: Current (CC), SY and EY scenario diet consumption (kg cap^{-1} year^{-1}) of different food items. The figures represent the uncooked amounts actually consumed after all losses and waste have been deducted. ↑ or ↓ indicates increased or decreased consumption compared to the current level. Where data on current consumption was not available the corresponding cell is marked with "nd"

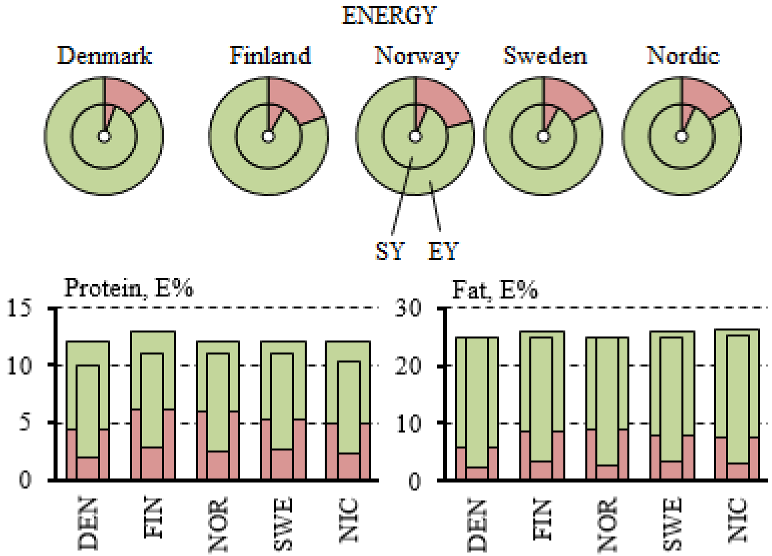
	Denmark			Finland			Norway			Sweden			Nordic	
	CC	SY	EY	CC	SY	EY	CC	SY	EY	CC	SY	EY	SY	EY
Livestock products														
Meat	49	↓ 4.1	↓ 5.7	44	↓ 3.9	↓ 7.9	36	↓ 4.7	↓ 17.5	35	↓ 4.2	↓ 7.9	4.1	7.7
Beef	14	↓ 1.7	↓ 5.1	11	↓ 2.8	↓ 6.9	6.9	↓ 1.9	↓ 6.9	8.8	↓ 2.5	↓ 6.1	2.2	5.9
Lamb	0.9	↓ 0.1	↓ 0.3	0.4	↓ 0.1	↓ 0.2	9.6	↓ 0.9	↓ 6.8	1.1	↓ 0.4	↓ 1.0	0.3	1.1
Pork	25	↓ 2.1	↓ 0.0	20	↓ 0.8	↓ 0.0	11	↓ 1.6	↓ 3.0	17	↓ 1.0	↓ 0.0	1.5	0.2
Poultry meat	9.5	↓ 0.2	↓ 0.3	12	↓ 0.2	↓ 0.8	8.2	↓ 0.2	↓ 0.8	8.0	↓ 0.2	↓ 0.8	0.2	0.6
Eggs	8.8	↓ 2.9	↓ 3.8	6.9	↓ 2.8	↑ 10	9.1	↓ 2.9	↑ 10	5.1	↓ 2.8	↑ 10	2.8	7.4
Offal and blood	2.1	↓ 0.6	↓ 1.0	0.3	↑ 0.6	↑ 1.3	4.0	↓ 0.7	↓ 2.8	1.5	↓ 0.7	↓ 1.3	0.7	1.3
Fish	14	↓ 7.1	↓ 6.2	12	↓ 7.6	↓ 10.3	22	↓ 7.3	↓ 4.8	14	↓ 7.5	↓ 6.3	7.3	6.8
Dairy products														
Milk and milk products [a]	98	↓ 30	↓ 92	149	↓ 51	↓ 124	105	↓ 35	↑ 124	88	↓ 46	↑ 110	39	106
Cheese and cheese products	16	↓ 2.2	↓ 6.7	14	↓ 3.7	↓ 8.9	16	↓ 2.5	↓ 8.9	9.1[1]	↓ 3.3	↓ 7.9	2.8	7.6
Cream	11	↓ 1.3	↓ 3.9	7.8	↓ 2.1	↓ 5.2	8.0	↓ 1.4	↓ 5.2	2.9	↓ 1.9	↑ 4.6	1.6	4.4
Butter	nd	(-) 0.9	(-) 2.8	5.5	↓ 1.5	↓ 3.8	2.6	↓ 1.1	↑ 3.8	0.4	↑ 1.4	↑ 3.3	1.2	3.2
Other dairy products [b]	2.3	↑ 18	↑ 54	nd	(-) 30	(-) 73	nd	(-) 20	(-) 73	nd	(-) 27	(-) 65	23	62
Plant products														
Cereals	80	↑ 123	↑ 113	49	↑ 120	↑ 106	96	↑ 122	↑ 105	69	↑ 120	↑ 109	121	110
Legumes	nd	(-) 14	(-) 10	3.1	↑ 13	↑ 7	5.2	↑ 14	↑ 6	4.4	↑ 13	↑ 8	13	9
Vegetable oil	nd	(-) 18	(-) 15	nd	(-) 17	(-) 14	nd	(-) 18	(-) 13	nd	(-) 17	(-) 14	18	15
Potatoes	33	↑ 72	↑ 72	28	↑ 72	↑ 72	24	↑ 72	↑ 72	36	↑ 72	↑ 72	72	72
Vegetables and roots	73[2]	↑ 99	↑ 99	58	↑ 99	↑ 99	56	↑ 99	↑ 99	64	↑ 99	↑ 99	99	99
Apples and berries	nd	↑ 130	↑ 130	29	↑ 130	↑ 130	22	↑ 130	↑ 130	12	↑ 130	↑ 130	130	130
Sugar	14[3]	↓ 12	↓ 12	16	↓ 12	↓ 12	22[4]	↓ 12	↓ 12	17	↓ 12	↓ 12	12	12
Imported food [c]	nd	(-) 36	(-) 36	46[5]	↓ 36	↓ 36	37[6]	↓ 36	↓ 36	40[5]	↓ 36	↓ 36	36	36

Note: a) Includes milk, sour milk and yoghurt; b) Includes whey and buttermilk; c) Includes tropical fruits, nuts, cocoa, coffee and tea.
1) Cheese in ready meals not included; 2) Also includes consumption of legumes; 3) Sugar in sweetened beverages not included;
4) Estimated from intake of food items containing sugar; 5) Cocoa not included; 6) Cocoa and nuts not included.

4.2 Diet nutrient composition

Figure 3 shows the composition of macro nutrients in the scenario diets and the relative contribution of plant and animal sources. For SY around 8 percent of the energy was supplied from animal sources while the same figure for EY was 18 percent. The reduced consumption of animal products in the scenario diets was replaced with cereals, legumes and vegetable oil containing on average less protein and fat per unit of energy. This resulted in the carbohydrate content of the diets being slightly above the recommended range (45–60 E%) for all countries for both the SY and EY diets, ranging from 61–65 E% (while currently, the consumption of carbohydrates is slightly below recommended in all countries, ranging from 42–44 E%). The total fat content was within the recommended range (25–40 E%) in all scenarios, as was protein (10–20 E%). The fat quality was improved in all the scenario diets, being well below the recommended maximum level for saturated fat of <10 E%, while current consumption in all countries is above that. The content of dietary fibre is also greatly increased in the scenario diets in comparison with current levels, which do not reach recommended levels. The results show a slightly higher total energy content in the scenario diets compared to current consumption. This was however attributed to underreporting of energy intake in the diet surveys while the scenario diets were based on energy requirements. In the Danish, Norwegian and Swedish diet surveys, energy intake was significantly underreported by 20, 16 and 19 percent of participants respectively, especially from foods considered unhealthy (Amcoff et al., 2012; Pedersen et al., 2015; Totland et al., 2012)

Figure 3: Fraction of energy intake from plant (green) and animal sources (red) (top). Percent of energy from protein (bottom left) and fat (bottom right) divided between plant and animal sources indicated by colour. Thin bars/ inner circles represent the SY scenario and thick bars/ outer circles represent the EY scenario



As for vitamin and mineral content, all scenario diets in all countries were below recommendations for the following micronutrients: vitamin A, B_{12} (only the SY diets) and D, riboflavin, calcium (only the SY diets), iodine, iron (only the EY diets) and selenium. Of these, the following are also low in current consumption patterns: Vitamin D, riboflavin, iron and selenium (except Finland). As for folate, the scenario diets provided above recommended minimum values and considerably more than current consumption patterns in all countries, which are all currently below recommendations.

Vitamin A exists in two forms: retinol, the active form that is found in animal products, and carotenoids, the inactive form (i.e. it must be converted to retinol in the body) found in plant sources. Because carotenoids are an inactive form of the vitamin they must be consumed in larger quantities than retinol. The content of carotenoids differs greatly between different plant sources (e.g. 862 µg per 100 g in carrots, 0.2 µg per 100 g in parsnips), hence there is potential to increase the content of vitamin A in the scenario diets if a greater proportion of, for instance, carrots are produced and consumed, however, different plant foods contribute various nutrients and a diverse intake is therefore desired.

Iodine is mainly found in lean fish and shellfish, but the main contributor to iodine in the population of the Nordic countries is salt and dairy products, which is due to fortification of salt and cow feed (Nyström et al., 2016). The selenium content in food varies due to the occurrence of selenium in soil, which differs greatly between geographical areas and is low in the Nordic region in general. Thus, plant foods grown there are unreliable sources of this element (Allen et al., 2006). Animal products represent the main source of selenium in these countries partly due to bioaccumulation of selenium in animals and partly due to selenium fortification of feed in some countries. In Denmark and Sweden, the current consumption of selenium is below recommended intake, but this is not the case for Finland (Table 10). Selenium has been added to fertilizers in Finland since 1984, which has significantly improved the selenium levels of the population (Allen et al., 2006). Just like vitamin A, the content of iodine and selenium differs greatly between different foods in the same category.

Riboflavin and calcium are mainly found in animal products, but considerable amounts are also available in plant-sources such as mushrooms (riboflavin), nuts (riboflavin and calcium) and green leafy vegetables (calcium). Furthermore, riboflavin and calcium are usually fortified in plant-based dairy options such as oat milk, which therefore constitute a good source of these nutrients for vegans.

All scenario diets reach the RDI for zinc and all the SY diets also reach the RDI for iron due to the large proportion of cereals included in the diets; zinc and iron are usually critical nutrients when meat and dairy are reduced in the diet (Craig, 2009). In the EY diet, the iron content is slightly below recommended levels due to a lower proportion of cereals and legumes compared to the SY diet. A larger proportion of whole-grain products would increase the iron content. However, iron derived from plant sources (non-heme iron) has lower bioavailability than iron derived from animal sources (heme iron). In addition, there is a large difference in recommended intake of iron between sexes (9 mg/d for men, 15 mg/d for women of reproductive age), and although the content in the scenarios is enough to cover the RDI for men, none of the scenarios meet the RDI for women.

As previously mentioned, plant-based sources contain little if any vitamin D, B_{12} and n-3 fatty acids, and it may therefore be problematic to meet these requirements on a diet that contains little animal-based food. However, despite the limited amount of meat and dairy in both scenarios, n-3 fatty acids reach the RDI in all countries, as does vitamin B_{12} for the EY diets. All diets are low in vitamin D, but no lower than in current consumption patterns, with the exception of Finland. In Finland, fortification of vitamin D is more extensive than in the other Nordic countries, and this has resulted in a sufficient intake of the vitamin in the Finnish population.

In summary, due to a heavy reduction in animal products in the scenario diets, these are associated with some nutritional challenges. Hence, the choice of products within broader food groups should be made with care, and fortification strategies for some critical nutrients must be considered.

Table 10: Nutrient content in the different diets, Sufficiency (SY) and Efficiency (EY), compared to estimated intake of current consumption (CC). ***Italic*** **numbers indicate deviation from Recommended Daily Intake (RDI) according to the Nordic Nutrition Recommendations 2012 (NNR 2012) given for men and women, age span 18–74 years. (ND=No data available.)**

Nutrient	Denmark			Finland			Norway			Sweden			RDI
	CC	SY	EY	CC	SY	EY	CC	SY	EY	CC	SY	EY	NNR 2012
Macronutrients													
Energy (MJ/d)	9.8	10.3	10.4	8.0	10.4	10.4	9.4	10.4	10.4	8.3	10.3	10.4	-
Protein (E%)	16	10	12	17	11	13	18	11	12	17	11	12	10–20
Carbohydrates (E%)	*42*	*65*	*63*	*44*	*64*	*61*	*44*	*64*	*63*	*44*	*64*	*62*	45–60
Total fat (E%)	36	25	25	35	25	26	34	25	25	34	25	26	25–40
SFA^1 (E%)	*14*	3	6	*14*	4	7	*13*	4	6	*13*	4	6	<10
MUFA^2 (E%)	13	13	12	13	12	12	12	13	12	13	13	12	10–20
PUFA^3 (E%)	6	7	6	6	6	5	6	6	6	6	6	6	5–10
n-3 fatty acids (E%)	ND	1.8	1.6	1.5	1.7	1.4	ND	1.8	1.6	1.2	1.7	1.5	>1
n-6 fatty acids (E%)	ND	4.7	4.1	5	4.5	3.9	ND	4.6	4.1	4.2	4.5	4.0	-
Dietary fibre (g/d)	*22*	54	49	*21*	52	46	*24*	53	49	*20*	52	46	>25–35
Vitamins													
Vitamin A (RE^4)	1,326	*375*	*483*	835	*406*	*588*	886	*399*	*483*	821	*400*	*569*	800
- Men	1,556	ND	ND	915	ND	ND	1,011	ND	ND	812	ND	ND	900
- Women	1,110	ND	ND	760	ND	ND	769	ND	ND	829	ND	ND	700
Vitamin B$_6$ (mg/d)	1.6	2.2	2.2	1.6	2.2	2.3	1.7	2.2	2.2	2	2.2	2.3	1.4^5
Vitamin B$_{12}$ (µg/d)	6.8	*1.3*	3.0	5.9	*1.9*	4.4	7.4	*1.6*	3.0	5.5	*1.8*	3.9	2
Vitamin C (mg/d)	114	178	178	111	178	178	108	178	178	95	178	178	75
Vitamin D (µg/d)	*5*	*6*	*7*	10	*7*	11	*6*	*6*	*7*	*7*	*7*	*8*	10
Vitamin E (mg/d)	9	18	16	10	17	16	11	18	16	12	18	17	9^6
Folate (µg/d)	*349*	494	501	*247*	497	517	*254*	495	501	*259*	495	511	350
- Men	370	ND	ND	*263*	ND	ND	*279*	ND	ND	*266*	ND	ND	300
- Women	*329*	ND	ND	*227*	ND	ND	*231*	ND	ND	*253*	ND	ND	400
Niacin (NE^7)	35	25	27	33	26	29	ND	26	27	35	26	28	16^8
Riboflavin (mg/d)	*1.8*	*0.9*	*1.3*	*1.8*	*1.1*	*1.6*	*1.8*	*1.0*	*1.3*	*1.5*	*1.0*	*1.5*	2.4
Thiamine (mg/d)	1.4	1.4	1.4	1.3	1.4	1.4	ND	1.4	1.4	1.2	1.4	1.4	1.2^9

Nutrient	Denmark			Finland			Norway			Sweden			RDI
	CC	SY	EY	CC	SY	EY	CC	SY	EY	CC	SY	EY	NNR 2012
Minerals													
Calcium (mg/d)	1111	546	932	1104	675	1131	920	598	932	875	643	1041	800
Copper (mg/d)	ND	ND	ND	1.3	ND	ND	ND	ND	ND	ND	ND	ND	0.9
Iodine (µg/d)	247	43	65	202	50	82	ND	45	65	ND	48	78	150
Iron (mg/d)	11.5	12.8	12.0	11.0	12.5	11.9	11.0	12.8	12.0	10.4	12.6	12.0	12.3
- Men	13	ND	ND	12.2	ND	ND	13.0	ND	ND	11.5	ND	ND	9
- Women[10]	10	ND	ND	9.9	ND	ND	9.9	ND	ND	9.4	ND	ND	15
Magnesium (mg/d)	382	406	411	371	409	414	391	408	411	331	407	409	315[11]
Sodium (g/d)	3.8	1.4	1.4	2.9	1.4	1.5	3.0	1.4	1.4	3.1	1.4	1.4	<2.4
Phosphorus (mg/d)	1577	1369	1604	1520	1449	1474	ND	1404	1604	1374	1426	1689	600
Potassium (g/d)	3.6	3.6	3.9	3.7	3.7	4.1	3.8	3.7	3.9	3.1	3.7	4.0	3.3[12]
Selenium (µg/d)	*53*	*29*	*30*	68	*29*	*40*	ND	*29*	*30*	*46*	*29*	*35*	55
- Men	61	ND	ND	74	ND	ND	ND	ND	ND	*50*	ND	ND	60
- Women	*46*	ND	ND	57	ND	ND	ND	ND	ND	*42*	ND	ND	50
Zinc (mg/d)	12	10	11	11	10	12	ND	10	11	11	10	12	8[13]

Note:
1) Saturated fatty acids;
2) Monounsaturated fatty acids;
3) Polyunsaturated fatty acids;
4) Retinol Equivalents;
5) Average value of the requirement for men and women (men 1.5 mg/d, women 1.2 mg/d);
6) Average value of the requirement for men and women (men 8 mg/d, women 10 mg/d);
7) Niacin Equivalents;
8) Average value of the requirement for men and women (men 18 NE, women 14 NE);
9) Average value of the requirement for men and women (men 1.3 mg/d, women 1.1 mg/d);
10) Women of reproductive age, recommended intake for post-menopausal women is 9 mg/d;
11) Average value of the requirement for men and women (men 350 mg/d, women 280 mg/d);
12) Average value of the requirement for men and women (men 3.5 g/d, women 3.1 g/d);
13) Average value of the requirement for men and women (men 9 mg/d, women 7 mg/d).

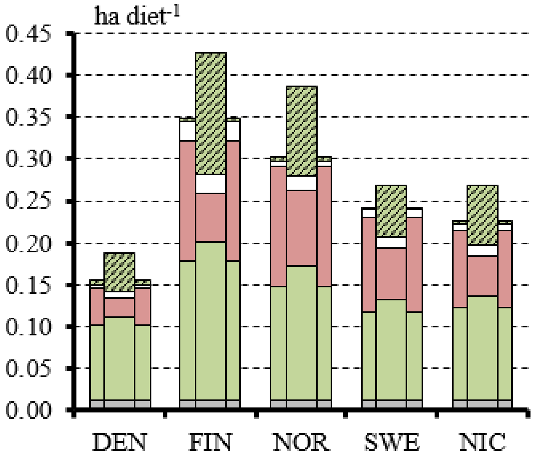
4.3 Agricultural production and land use

The total agricultural area needed per diet including land used abroad for imported food was 0.27 ha diet^{-1} for SY and 0.23 ha diet^{-1} for EY (Figure 4). This can be compared to the planetary boundary for land use change proposed by (Rockström et al., 2009), which states that no more than 15 percent of global land cover should be converted to cropland. This amounts to some 1,951 Mha of safe operating space for global agricultural production. Dividing by the projected global population in 2030 gives us 0.23 ha cap^{-1}, hence the EY diet ends up just on the planetary boundary for land use change while the SY diet overshoots the boundary.

The variation in land use per diet between the individual countries was large. The Finnish diets used more than twice as much land as the Danish diets.

The results show, somewhat counterintuitively, that a relative increase in arable land allocated to livestock in the EY scenario compared to the SY scenario, had the potential to feed more people from Nordic agriculture. To produce the SY and EY diets 7 percent and 34 percent of the arable land would respectively be used for livestock feed production and grazing. Adding the semi-natural pastures, these numbers increase to 18 percent and 43 percent of total agricultural land.

Figure 4: Total use of agricultural land per diet for SY (thin bars) and EY (thick bars) divided between land used abroad for imported products (grey), crops for direct human consumption (green), feed crops and pastures (red), bioenergy crops (white) and green manure crops (green hatched)



In comparison with current land use, a lower proportion of Nordic arable land would be needed for cereal production in the scenario diets (due to less feed production), while higher proportions would be used for grain legumes, rapeseed and other food crops (Figure 5). The proportion of arable land used for ley cultivation would decrease in all countries except in Denmark, where ley cultivation is currently relatively limited, and for the Finnish SY scenario.

Figure 5: Percent use of arable land for different crops under current land use (C) and for the two scenario diets. The current land use represents current use of arable land in each country and is not directly related to the currently consumed diets

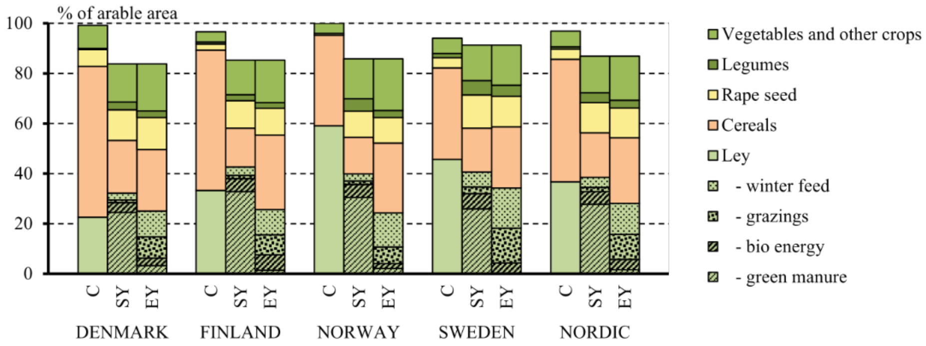


Table 11 shows the total number of animals needed in the different scenarios. In the SY scenario the number of ruminants was kept at the minimum number required to maintain all semi-natural pastures, resulting in a 74 percent reduction in cattle and a 71 percent reduction in sheep and goats compared to current numbers. It was assumed that dairy cows would be able to graze semi-natural pastures only to a limited extent because these are not always easily accessible or are too far away from the farm. Some ley was therefore needed as pasture for dairy cows and also for winter feed. To avoid exceeding the limitations on rapeseed and grain legumes in the crop rotations, additional ley cultivation was introduced to the rotations. This led to an overproduction of ley in this scenario that was not needed for the limited number of ruminants. Some of this ley was used for bioenergy while the rest was left on the fields as green manure. In the EY scenario, more ruminants were allowed in order to make use of the excess ley for food production. In the Norwegian case, ruminants were also allowed to graze the outfield areas. The total number of ruminants in this scenario increased to almost the same level as current numbers in the Nordic countries, resulting in a 17 percent reduction in cattle and a 35 percent increase in sheep and goats compared to current numbers.

In the Norwegian EY scenario, 254,000 cattle and 839,000 ewes with 1,451,000 lambs spent on average 90 (cattle) and 135 (sheep) days on the outfields every year. In total, grazing in the outfields accounted for 6.8 PJ ME or 495 MJ ME per hectare of outfield area. (Rekdal, 2017) has estimated that a total of 137,462 km^2 of outfield has sufficient vegetation growth to be grazed by livestock with a maximum average density of 65 ewes with lambs or 13 cattle per km^2. The EY scenario would then utilize 24 percent of available feed from the outfields. However, (Rekdal, 2017) assumed that 10 per cent of the estimated outfield area will be too steep or otherwise impossible to use for livestock, and that competition from wild fauna and reindeers would reduce the available feed by an equivalent of 1,408,500 ewes with lambs. Accounting for this, the EY scenario would utilize some 32 percent of available outfield resources. Utilizing more of the feed resources in the outfields would require larger areas of arable land to provide winter feed for the larger number of ruminants, and thus compete with the production of food in the scenario.

Monogastric animals were limited to the number that could be supported with available byproducts and, in the EY scenario, some feed grown on arable land. The number of pigs was reduced by 92 percent and 98 percent for SY and EY respectively, while the number of poultry decreased by 84 percent and 50 percent compared to current numbers in the Nordic countries. A shift from more pigs in the SY scenario to more poultry in the EY scenario was noticed. This can be attributed to: first, that the byproducts were not well suited for poultry feed, limiting their use in the SY scenario, while in the EY scenario the poultry feed was supplemented with cereals enabling more poultry in this scenario; second, the large increase in ruminants in the EY scenario reduced the amount of byproducts available for pig feed, limiting the number of pigs in this scenario.

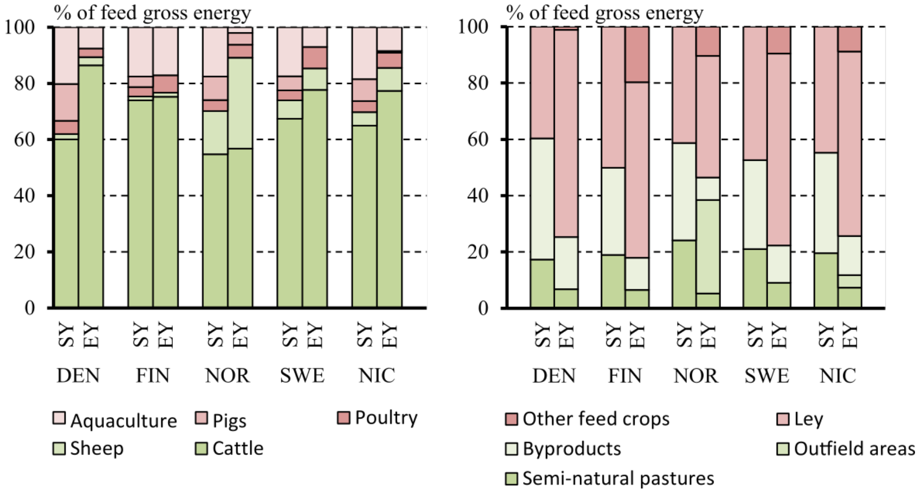
The amount of farmed fish was relatively constant between the two scenarios and around 60 percent lower than currently produced volumes from aquaculture. Around two-thirds of the fish in the diets was supplied from aquaculture while the rest was wild-caught fish. The amount of wild-caught fish corresponded to 7–9 percent of the current volumes landed in the Nordic countries. This resource could arguably provide more food, especially in Norway with its access to large coastal fishing grounds. Incorporating more fish in the diets could potentially increase the number of people who could be supported by the scenario diets. It is however questionable whether the current landed volumes are sustainable, and fish currently caught in international waters can hardly be considered a local resource. Within the scope of this project it was not possible to estimate sustainable yields from coastal and inland fisheries around the Nordic countries. Instead a global "fair share" was used, resulting in a small contribution of wild-caught fish in the scenario diets, although it is likely that more wild-caught fish could be included from sustainable Nordic coastal and inland fisheries.

Table 11: Number of livestock in the scenarios in each country expressed as total number of animals, and yearly fish production from aquaculture and catches from fisheries expressed as live weight in kilotonnes. Current livestock numbers and fish production were compiled from the Eurostat database for the most resent years for which complete data was available (Livestock and Aquaculture: 2014, Fisheries: 2015)

	Livestock (1,000 heads)				Fish (kilotonne live weight)		
	Cattle	Sheep & goats	Poultry	Pigs	Total	Aquaculture	Fisheries
Denmark							
2014	*1,564*	*153*	*18,274*	*12,332*	*903*	*34*	*869*
SY	398	137	4,615	653	303	202	101
EY	1,505	517	7,454	0	317	193	124
Finland							
2014	*914*	*142*	*7,633*	*1,245*	*167*	*13*	*153*
SY	250	48	1,669	93	121	84	37
EY	747	142	7,308	0	210	164	46
Norway							
2014	*839*	*2,348*	*5,186*	*831*	*3,479*	*1,332*	*2,146*
SY	84	241	844	93	57	38	19
EY	389	2,290	3,808	226	45	21	24
Sweden							
2014	*1,493*	*589*	*8,371*	*1,377*	*216*	*13*	*203*
SY	525	521	3,920	284	278	191	87
EY	1,418	1,406	15,638	0	258	159	98
Nordic							
2014	*4,811*	*3,233*	*39,464*	*15,784*	*4,764*	*1,392*	*3,371*
SY	1,257	946	11,048	1,123	760	515	244
EY	4,058	4,355	34,208	226	830	538	292

The amount of feed available for animal consumption was around three times greater in the EY scenario than in the SY scenario. This increase was mainly in the form of ley that was not utilized in the SY scenario, but also from the inclusion of Norwegian outfield areas and feed cultivated on arable land. The majority of feed energy (70% in SY and 86% in EY) was used by ruminant animals, since the available feed mainly constituted of grass resources not suitable for monogastric animals. For SY, 20 percent of feed energy was from semi-natural pastures, 45 percent from ley and 36 percent from byproducts. For EY, 11 percent was from semi-natural and outfield areas, 65 percent from ley, 14 percent from byproducts and the remaining 9 percent from other feed grown on arable land. For the Norwegian EY scenario, outfield areas provided 78 percent of the sheep's and 14 percent of the cattle's total feed consumption on a gross energy basis (Figure 6). Straw was harvested to provide bedding material for the livestock and to be burned for heating stables and greenhouses. 37 percent and 40 percent of the total available straw was harvested in the SY and EY scenarios respectively, and the rest was left on the fields. Out of the harvested straw 58 percent and 73 percent was used as bedding material and the rest was burned.

Figure 6: Proportion of feed used for different livestock species and aquaculture (left) and proportion of feed from different sources (right) in the SY and EY scenarios, expressed as percent of total gross energy available for animal feed



The soil nutrient balance on the arable land was estimated for the two scenarios. Digestate from food and slaughter house wastes, manure and ley was assumed to be applied to arable soils as organic fertilizer. Nitrogen (N) fixation by legumes was estimated from Frankow-Lindberg (2003). Ley, green manure ley, temporary pastures and grain legumes were assumed to fix 18, 8, 16 and 44 kg of N per ton of harvested dry matter respectively[2]. All scenarios showed a nitrogen and phosphorus (P) deficit that would need to be compensated by N and P application from additional sources. For SY the deficit was 20 kg N and 5 kg P and for EY it was 28 kg N and 7 kg P per hectare per year. Nutrient content in the diets that could potentially be retrieved from human excreta corresponded to 16 kg N ha^{-1} and 2 kg P ha^{-1} for SY and 22 kg N ha^{-1} and 3 kg P

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[2] The N fixation in green manure ley is lower than in ley since these leys are not harvested, and thus add N to the soils. This inhibits N fixation in the legumes. The total addition of N to the soil is however larger in the green manure leys since no N is removed with harvested biomass.

ha^{-1} for EY. The majority of N deficits could thus be compensated for by recirculation of human excreta to the fields. However other sources of nutrients for arable soils would also be needed for the long-term sustainability of the farming system.

4.4 Environmental impacts

Figure 7 shows the environmental impacts of the scenario diets. The SY and EY scenario diets would give rise to 0.36 and 0.48 ton CO_2-eq per diet and year respectively, mainly comprising methane emissions from ruminant feed digestion and nitrous oxide emissions from soils. The global GHG emission space has been estimated for pathways with a 'likely' chance of staying below 1.5°C global warming compared to preindustrial levels (Sanderson et al., 2016). These pathways require annual GHG emissions to drop to around 27 Gton CO_2-eq (3.2 ton CO_2-eq cap^{-1} $year^{-1}$) by 2030 and reach 6 Gton CO_2-eq (0.6 ton CO_2-eq cap^{-1} $year^{-1}$) by 2050, while long-term emissions need to settle at close to zero or net negative emissions. The estimated emissions from agriculture in the scenarios would occupy 11–15 percent of the 2030 emission space and 58–78 percent of the 2050 emission space. Considering that agriculture is presently estimated to account for around 15–25 percent of global emissions (Vermeulen et al., 2012) the scenarios can be considered in line with the pathways in the short term (up until 2030) while deeper reductions would be necessary further on.

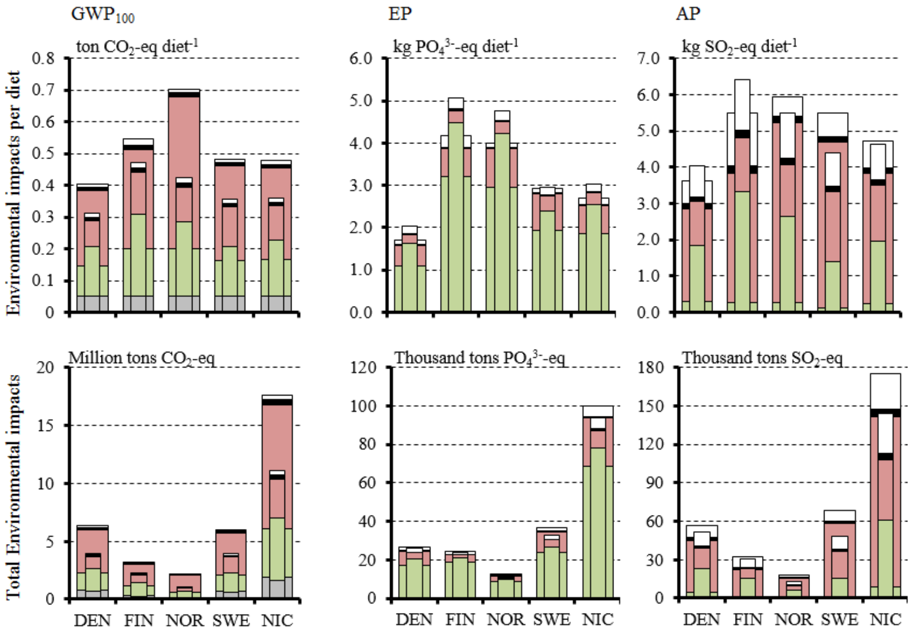
Leaching of nitrogen and phosphorus from arable soils accounted for roughly two thirds of the diet's total eutrophication potential (EP). The remaining third was mainly attributed to ammonia volatilization related to manure management, and for the SY scenario also to ammonia volatilization from non-harvested ley residues. The EP per diet was slightly higher in the SY scenario compared to EY, primarily since the latter scenario provided more diets without using more arable land.

Volatilization of ammonia was the main contributor to acidification potential (AP) in the scenario diets, accounting for 97 percent of total AP. Fewer animals in SY compared to EY resulted in less volatilization of ammonia from manure. This was however counterbalanced by increased volatilization from crop residues due to extensive areas of ley being used for green manure in the SY scenario. Agricultural practices play an important part in ammonia volatilization from crop residues and immediate incorporation of the residues into the soil could potentially reduce ammonia volatilization (de Ruijter et al., 2010). Alternative uses of the ley, such as biogas production, could also reduce these emissions.

Scientists have established critical loads for eutrophying and acidifying air pollutants as well as guidelines for critical levels regarding health impacts. These data cannot, however, be converted into maximum allowable emissions per capita because the impacts of air pollutants vary depending on several factors, such as the location of the emissions, the sensitivity of the ecosystems and the number of people exposed.

Both scenarios (SY and EY) would bring noticeable reductions in the emissions of ammonia. As agriculture is responsible for around 90 percent of total national ammonia emissions, these emission cuts would result in significant environmental and health improvements through less nitrogen deposition and lower concentrations of inhalable secondary fine particles with a diameter of 2.5 µm or less ($PM_{2.5}$). The emission reductions for NOx, SO_2, and CH_4 would further contribute to these improvements.

Figure 7: Estimated annual Global Warming Potential (GWP_{100}), Eutrophication Potential (EP) and Acidification Potential (AP) from agricultural production and fisheries fuel consumption for the SY (thin bars) and EY (thick bars) scenario diets. The impacts are divided between imports (grey), crop production (green), livestock production and manure management (red), energy use (black) and bioenergy production (white). Only GWP_{100} was estimated for the imported products. The total impacts are largely dependent on the total number of people who could be fed in the different case countries, leading for example to relatively high emissions from the Danish scenarios, since it would be possible to feed substantially more people from Danish resources than the current number of inhabitants



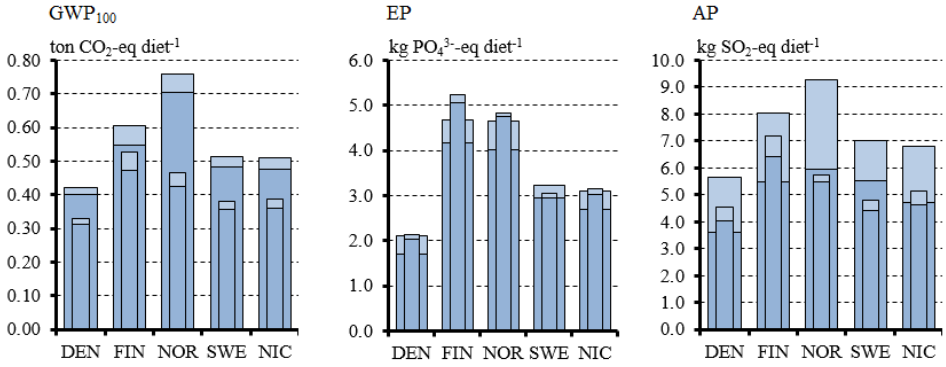
4.4.1 *Farm energy use*

In all scenarios food and slaughter house wastes together with manure were digested to produce biogas for energy use on the farms. After these resources had been exploited there was still energy use that was unaccounted for. Some ley was therefore harvested and digested to make farms self-sufficient in energy. Hence agricultural production in the scenarios was fossil-free and was supplied with energy from the agri-food system itself. However diesel was assumed to be used as fuel for the fishing vessels that provided the wild-caught fish for the diets.

To be logistically feasible, the digestion of manure and ley would need to be performed in small-scale biogas digesters at the farm or regional level. Although technically feasible there may be economic and infrastructural challenges with realizing this on a large scale. A sensitivity analysis was therefore performed to test the effect of excluding ley and manure from biogas production. Instead of being digested, manure was assumed to be composted prior to field application. The ley was assumed to be left on the fields as green manure. In the sensitivity analysis, food and slaughter house wastes were still digested to produce biogas. These substrate streams do not have the same logistical concerns and are extensively used today to produce biogas in the Nordic countries. Missing heat and electricity were assumed to be supplied by the Nordic electricity mix, and fuel for agricultural machinery was assumed to be diesel.

The exclusion of ley and manure from biogas generation resulted in increases in all environmental impact indicators (Figure 8). GWP_{100} was 28 (+8%) and 31 (+7%) kg CO_2-eq diet^{-1} higher for SY and EY respectively. This was mainly due to the changes in the energy system, but increased nitrous oxide emissions from manure management also contributed. The increase in GWP_{100} was somewhat counterbalanced by spared methane losses along the biogas chain. For EP, increases of 0.11 (+4%) and 0.40 (+15%) kg PO_4^{3-}-eq diet^{-1} were observed and attributed to changes in manure management resulting in increased ammonia volatilization. This also affected the AP, which increased by 0.48 (+10%) and 2.1 (+43%) kg SO_2-eq diet^{-1}.

Figure 8: Estimated annual Global Warming Potential (GWP_{100}), Eutrophication Potential (EP) and Acidification Potential (AP) from agricultural production and fisheries fuel consumption for the SY (thin bars) and EY (thick bars) scenario diets. Darker shades indicate the impact potential for scenarios where ley and manure were digested for bioenergy and lighter shades where ley and manure were excluded

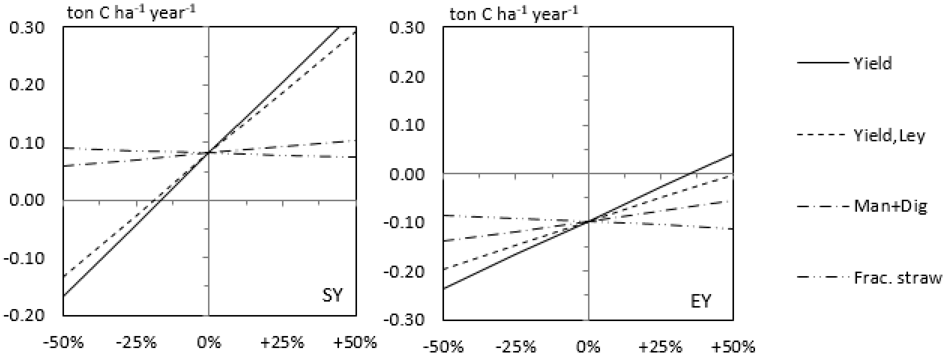


4.4.2 *Changes in soil carbon stocks*

Changes in soil carbon stocks are presented for Swedish agricultural soils in the following section but have not been included in any previously mentioned figures for GWP. Since a calibrated model was only available to us for Swedish agricultural soils it was not possible within the scope of this project to assess soil carbon changes for the other countries. In the SY scenario, soil carbon increased compared to business as usual (BAU) with an average of 82 kg C ha^{-1} $year^{-1}$ over a 100-year time frame. Expressed as CO_2-eq per produced diet this equals a net sequestration of 59 kg CO_2-eq $diet^{-1}$ $year^{-1}$. This was attributed to extensive areas of ley that were not harvested, thus adding carbon to the soils in the form of green manure. This was counteracted by lower input of carbon from crop residues and manure compared to BAU. In the EY scenario, carbon stocks decreased by 97 kg C ha^{-1} $year^{-1}$ over a 100-year time frame compared to BAU. Per produced diet this equals net emissions of 62 kg CO_2-eq $diet^{-1}$ $year^{-1}$. In this scenario a smaller fraction of arable land was cultivated with ley and all ley was utilized as animal feed or substrate for biogas production, resulting in less carbon input from crop residues.

A sensitivity analysis was performed by varying the overall crop yields, ley yield, carbon input from manure and biogas digestate, and the fraction of straw that was harvested and removed from the fields (Figure 9). Modelled carbon stock changes were most sensitive to changes in the overall yields since these govern the amounts of crop residues and root biomass produced by the crops. The sensitivity to ley yields was also high, especially in the SY scenario, showing that ley biomass that was left on the fields in this scenario contributes largely to the modelled carbon sequestration. The fraction of straw that was harvested and removed from the fields had a slight negative impact on modelled carbon sequestration by reducing the amount of crop residues left on the fields.

Figure 9: Sensitivity of modelled changes in arable soil carbon stocks over a 100-year time frame for the Swedish SY (left) and EY (right) scenario. Positive numbers indicate a net sequestration in arable soils and negative numbers net emissions. The sensitivity analysis was performed on Overall yields (Yield), Ley yields (Yield, Ley), input of carbon from manure and digestate (Man+Dig), and on the fraction of straw harvested and removed from the fields (Frac. straw)



In soil organic carbon stocks were also modelled for the two alternative scenarios where ley and manure were excluded from biogas production. In these scenarios the ley was instead left on the fields as green manure, and farmyard manure was composted prior to field application. More carbon was sequestered in arable soils resulting in a net flux of +110 and -75 kg C ha^{-1} year^{-1} for SY and EY respectively. Expressed per diet this equals a net sequestration of 77 kg CO$_2$-eq diet^{-1} year^{-1} for the SY scenario and net emissions of 48 kg CO$_2$-eq diet^{-1} year^{-1} for the EY scenario.

5. Discussion

A recent assessment of European food consumption revealed that the GWP of the average European diet was 1,445 kg CO_2-eq per year, of which around 70 percent was attributed to agricultural production (Notarnicola et al., 2017). Few studies were found that assess the impact of food consumption in the Nordic countries. One Finnish study suggests that the average Finnish diet has a GWP of 2,811 kg CO_2-eq per year, of which agricultural production accounted for 69 percent (Virtanen et al., 2011). The Swedish Environmental Protection Agency presents yearly figures for the GWP of food consumption in Swedish households, and in 2014 these emissions were estimated at 2,169 kg CO_2-eq per year per inhabitant (Naturvårdsverket, 2017). Röös et al. (2015) estimated emissions from Swedish food consumption to be 1,875 kg CO_2-eq per year per diet. Assuming that 70 percent of the total GWP from food consumption can be attributed to agricultural production these estimates range between 1,313–1,939 kg CO_2-eq per diet and year emitted by the agricultural sector. The scenario diets GWPs were estimated at 311–703 kg CO_2-eq per year, and would thus represent a major reduction in the carbon footprint of producing food for the Nordic population. In comparison with emission pathways compatible with keeping global temperature rise below 1.5 °C it was shown that the scenario diets would be in line with these pathways up until year 2030 while deeper emission reductions would be necessary further on.

Organic farming systems have been observed to have a positive influence on carbon sequestration and soil carbon stocks (Gattinger et al., 2012). The drivers for this are not well understood, but crop rotations, increased use of organic amendments such as manure, and a larger allocation of biomass to roots in organic systems have all been suggested as important drivers (Gattinger et al., 2012; Kong and Six, 2010). The present study indicated a net sequestration of carbon in soils for the SY scenario and net carbon emissions for the EY scenario. The modelled carbon stock changes in this study did not take into account any increased allocation of biomass to roots, which may lead to an underestimation of the actual potential to sequester carbon in arable soils in the scenarios.

Both scenarios showed deficits in the soil nutrient balances, which need to be compensated by further N and P inputs to arable soils. This could partly be alleviated by recovering nutrients present in human excreta, but other sources would also be needed for the long-term sustainability of the farming systems. Leaching of nitrogen and phosphorus accounted for around 40 percent of N losses and all P losses from arable land in the model. These calculations were based on national estimates of leaching from arable soils. In organic farming systems leaching could potentially be lower per hectare compared to conventional systems (Hansen et al., 2000) and leaching was therefore presumably somewhat overestimated in the model.

National statistics on the productivity of pastures and leys were sparsely available and contained large uncertainties and biases. Some effort was made to account for bias in the data but this is still a source of uncertainties in the results.

Within the scope of this study it was not possible to assess the local sustainable fish and seafood yields from coastal and inland waters around the Nordic countries. A global "fair share" of wild-caught fish was instead included in the diets, which does not reflect local access to coastal and inland fishing waters. Further studies would be needed to assess the potential volumes of food that could be sustainably harvested from marine and lake ecosystems within the Nordic countries.

The scenario diets in this report explore paths towards a Nordic food system that contributes to reducing greenhouse gas emissions and minimizing the reliance on imported food. This is possible through changes in dietary patterns, especially drastic reductions in meat consumption. This would impose large changes on the overall Nordic food system. The livestock sector, which currently accounts for the largest share of economic value in Nordic food production, needs to give way to extended domestic plant-based food production. Grain legumes and oil crops in particular need to be grown much more frequently in the scenarios compared to the current situation in the Nordic countries.

The results from this study indicate that more extensive agriculture in the Nordic counties could provide food for a large population albeit with changes in consumption patterns, most notably a large reduction in meat consumption. There was however considerable variation between the countries. The Finnish SY scenario and the Norwegian SY and EY scenarios could not feed the projected 2030 population with the scenario diets.

In conclusion, this report takes a holistic approach that links dietary patterns to the food system as a whole and to agricultural production. This resulted in one possible vision of a more sustainable food system in the future, in which organic agriculture and diets containing traditional food items were used in a way that reduces the environmental and climatic burden of Nordic food consumption. The results are highly dependent on the normative decisions made (Table 1) and on the vision for the future of Nordic agriculture. Other paths towards more sustainable food systems can and should also be explored. Developments in technology and production methods, plant and animal breeding and further intensification of agriculture can perhaps increase how efficiently we produce food and reduce the input needed in the form of arable land, fertilizer and water per unit of food produced. Or perhaps innovations in novel food and feed, such as artificial meat, algae or insects, will lead the food system towards a more sustainable future. This can lead to increased food production or smaller environmental impact or, at best, both.

6. Stakeholder consultations

In early 2017, we organized workshops in each of the countries:

- 22 February, Stockholm, Sweden
- 28 February, Copenhagen, Denmark
- 2 March, Helsinki, Finland
- 16 March, Oslo, Norway

Participants included representatives from farmer's unions, producers, retailers, governmental agencies, and environmental organizations. They all had the opportunity to read a draft report beforehand. During the workshop, they were given a presentation of the results that was followed by discussions.

Many of the comments given led to improvements in the modelling work. However, one purpose of the workshop was also to gather views on economic, political and social issues related to the scenarios. Below we have summarized the different views that came up. Naturally, not everyone shared the same opinions. On the contrary, discussions were sometimes lively. We have attempted to write in a way that shows whether an opinion was shared by many or only a few participants.

6.1 Consumers and changes in diets

During the workshops, it was stated that consumption patterns are driven by several factors, such as price, norms, culture, availability, trends, how food is presented, what well-known gastronomes do, as well as habits.

The diets in the scenarios consist of less meat and a higher proportion of plant-based foods compared to the present consumption. This kind of change would probably be perceived by many consumers as a deterioration in the standard of living if it occurred overnight.

The participants suggested several ways to increase the acceptance of a low-meat diet. Plant-based foods need to be given a higher status and become trendier. We will need new and innovative food products. Some companies have already started making new meat-like products, for example sausages in which some of the meat is replaced with root vegetables. There are also several on-going projects aimed at producing more legumes domestically.

One example that was mentioned was a restaurant that has started to put the vegetarian lunch meal at the top of the menu, above meat and fish. The result was that more guests ordered the vegetarian meal instead of meat and fish. This shows how consumers can make the move towards new diets with less meat without having to make active choices, so called "nudging". Retailers can also apply such simple changes by furnishing their stores and advertising products in ways that influence buying habits.

Several participants argued for the need to develop and promote new dishes and recipes with vegetables of the season and recipes that contain more pulses. It is possible to get inspiration from both traditional and foreign recipes where meat is used more as a flavour than the main ingredient in the meal.

It was suggested that a successful way to market a diet with less animal products could be to highlight, not only the environmental and climatic benefits it would bring, but also the health benefits – both towards the public and towards decision-makers, who are facing increasing costs in the health system due to welfare diseases.

Many of the participants argued that it is important that the debate about agricultural and future diets reaches out to the public. Young adults who have moved away from home but not yet started a family were recognised as a particularly important target group. People in that age group experiment with new lifestyles and new eating habits and can be inspired to cook in a completely different way than the previous generation. These habits are likely to continue for the rest of their lives. A growing number of young people eat radically different diets than the same age group only a few years ago, moving towards a more sustainable diet.

The study does not consider seasonal variation in detail and what products we have available at different times of the year. Even if the climate in the Nordic countries is not ideal for food production during winter, a great thing about root vegetables, is that they are easy to store and can be used for cooking throughout the year.

If imports are decreased, some of the products that we find in our supermarkets today will disappear. The reduced selection of products could partly be compensated by a greater variety of locally produced food. To support such development, efforts are needed to develop new ways of marketing. Trends affect how we eat and encourage us to change our eating habits quite rapidly.

Consumers should be made aware that they have a responsibility in what they buy and that by making active choices they can influence how and what food is produced. Farmers and retailers also have a responsibility for and impact on what consumers buy. Consumers can make better decisions if they have the right information, but information is not enough. There is also a need for stronger economic incentives so that consumers can make those right decisions.

Changing people's habits and diets is a major social and psychological mission, which requires that the distance between food production and consumers need to shrink. Mutual dialogue between farmers and society can create greater acceptance from society, but also encourage the farmer to consider more environmentally friendly farming methods. If consumers are closer to where the food is produced they are also more likely to have a better understanding about production conditions. Community Supported Agriculture is one way to get consumers more involved in production and this could increase understanding of organic food production. Retailers also play an important role in consumers' choices. Increased contact between farmers and retailers can help to raise interest in more environmentally friendly food production and reinforce the connection between agriculture and the rest of society. Together, this could contribute to increased acceptance of higher food prices among consumers.

The scenarios would likely result in higher food prices. Meat will be transformed from a main ingredient in every meal to a more exclusive product for special occasions and as a side dish and additional flavour in vegetable-based meals. This will require that consumers find a new way of valuing food. This shift in values has already begun to happen. More and more consumers demand organic and locally produced food, and desire greater food integrity, and similarly, a growing proportion of the population are vegan or vegetarian.

6.2 Consequences for farmers

One of the most recurring views was that farmers must be able to survive economically on their farms or we will have no agriculture. The scenarios only describe what could be produced given the physical and natural conditions in each country. To ensure economic sustainability for farmers, there is a need for new policy instruments as well as new business models.

The scenarios involve an increase in the production of pulses and vegetables in the Nordic countries. However, these are more sensitive crops, and weather-related risks are greater compared to growing ley for livestock production. On the other hand, the revenue per hectare is higher and organic vegetable production is more labour intensive and will create new jobs. Diversified agriculture could also be a way to reduce risks in a changing climate.

Many participants argue that the big industrial farms that are best adapted to the current policy will have the hardest time to convert to a new system. If you own or are employed in large-scale livestock production, you may be more concerned about economics than running a social utility or environmentally friendly agriculture. Young farmers' knowledge and way of thinking are changing, in reaction to an agricultural system that today is largely about companies and is based on extremely large loans.
A few participants pointed out that issues of ownership of land and rights to use land are of importance for the development of farming. Today it is difficult for young people to start a farm, because it requires such a high start-up capital.

Existing infrastructure, not only at farm level but also in related businesses, such as dairies and slaughterhouses, has a conservative effect on where animal production takes place. To promote change, it is important to identify such barriers, and find ways to make best use of what is available while supporting the construction of new infrastructure needed to process locally grown produce into good quality products. It was suggested that the cooperative movement, if revitalised, could play a part in this process.

6.3 Self-sufficiency versus international trade

The scenarios illustrate a future in which each country is almost self-sufficient in food. High self-sufficiency in food products has many advantages, for example:

- Less transport
- Closer distance between producers and consumers, which could lead to better food quality, greater food diversity, better taste, improved customer satisfaction as well as a better understanding of environmental protection and nature conservation

- Potential to close nutrient cycles
- Potentially more jobs
- Increased resilience, for example to climate changes, economic crises and in case of a global energy crisis (if agriculture also produces its inputs)
- Democracy is strengthened. When trading of food happens over long distances, production is removed from genuine democratic influence

To implement such a high degree of self-sufficiency, free trade would need to be limited. Leaving aside the political difficulties of implementing this, it would increase the price of food, and many products that consumers are accustomed to would disappear from the shelves. Restrictions of free trade could also have implications for the national economy, especially in countries like Denmark where agricultural products make up a rather large share of exports. It is also possible that some products that can be grown in the Nordic countries would require less resources and result in less emissions per kilogram of product if grown elsewhere.

There is also the obvious limitation that Norway will have difficulties feeding its future population as land availability per capita is limited (currently less than 0.2 ha per capita). There is however some potential to supply more food from coastal fisheries and potentially also by extending areas for rangeland pastures although this would also require more arable land for winter feed cultivation. There is also the problem of extreme weather and the risk of crop failure. The common Nordic scenario of regional trade can be considered as more feasible. It is reasonable to believe that it would be possible to design a system in which self-sufficiency is increased significantly compared to today, but which minimizes the disadvantages of reduced trade.

6.4 New policy instruments

The scenarios described in the report involve a radical transformation of the agricultural system we have today. The present situation is a result of, among other things, our economic system, consumption patterns, trade and agricultural policies. During the workshops, several participants called for transformational changes such as abolishing current free trade agreements, scrapping the Common Agricultural Policy and adapting our economy to zero growth. However, there were also more reformist proposals that could lead to great improvements compared to the present situation. The one does not need exclude the other; it is possible to criticize the systems while working to make changes in the systems that are in place today.

A recurring view shared by most participants was that the cost of the environmental impact of food, especially meat, must be included in the price. One way would be to introduce consumption taxes on food with large environmental footprints. Another possibility would be to tax environmentally damaging practices in production. Support to farmers should focus on sustainability.

Farmers must have incentives to convert to organic and other, more sustainable, forms of production. Taxation could generate a revenue that could finance economic incentives, however policy makers would have to abandon their reluctance for "earmarked" revenues.

Another possible area for action is to improve already existing standards and regulation, e.g. rules for public procurement.

In an open market, like the European Union, it is preferable if more demanding rules for agriculture are implemented in all countries simultaneously.

Several participants mentioned more soft policy measures, like improving recommendations and guidance to consumers and developing sustainable food strategies at national and regional level.

Another related issue that was highlighted was that farmers must get a fair price for their products. Policy makers must consider that many farmers today are struggling with a strained economy.

One tool used today is organic and other types of sustainability labelling. That means producing food to higher environmental standards, while farmers usually get better prices for their yields than conventional farmers. The requirements for organic farming were also discussed and it was suggested that they would need to be raised – above all, in order to provide better conditions for recycling nutrients.

In developing new policy, it is important that politicians work in close cooperation with farmers and get help from each other's knowledge and experience. To achieve this, it may be necessary to develop new models for consultation.

The conditions for cultivation vary widely within a country. In the scenario work, it has only been considered whether a certain crop can be grown or not, but yields might be so low that is not economically feasible when competing with more high-yielding regions in the same country. This could be compensated for by offering regionally differentiated support to farmers.

6.5 Potentials to improve the food system

In the scenarios, the model for production is existing organic farming, not because this is necessarily the most optimal from a sustainability perspective, but because there are data available. During the workshops, there were many suggestions on how to improve the food system further:

- To become more self-sufficient, fruit and vegetable production needs to increase significantly and there is a huge need to focus on education in organic horticulture rather than agriculture;
- To increase the share of local food in our diets all year around we need to improve storage techniques;
- Food waste should be reduced and used as efficiently as possible; one example is a project in which maggots are grown on food waste to feed poultry;
- Using traditional breeds could be a way to graze areas that are not grazed today;
- It is crucial that we find ways to close phosphorus and nitrogen cycles;
- To increase carbon storage in the agricultural landscape, we need more perennials, trees and shrubs, as well as less intensive soil management;
- To reduce the pressure on wild-caught fish from the oceans, we must become better at fish and mussel farming, and take better care of our lakes and coastal areas. There is a potential to develop new foods like algae and novel proteins.

It was suggested that if agro-ecological methods become wide-spread, it might lead to the natural development of improvements in productions systems and methods. Agro-ecology requires that the individual farmer has good knowledge of the local conditions, crop rotations etc. to maximise yields.

People who work in retailing, distribution, catering and restaurants, as well as consumers, must also get a better understanding of the origin of food and gastronomic options.

6.6 Other ideas

It was suggested that a narrative about the scenarios could reduce their complexity and show that we can live well and still work and earn money. Examples of positive synergies that could be included in a positive narrative are:

- Improved health, e.g. a better mix of fats (more rapeseed oil and less animal fats) would decrease heart diseases
- New jobs and business opportunities in the agricultural and food sectors
- Better animal welfare, with a high share of grazing livestock
- Building a stronger sense of community between us as a population is a very positive social aspect. By helping each other and involving new people in the agricultural sector, we get to know each other and help each other.
- More diversified agriculture creates resilience
- Environmental protection and nature conservation through effective, sustainable production of food.

To convert the food sector, it is important to build networks and co-operations. A Nordic agro-ecological network could be a way to mobilize and spread knowledge between the countries.

Local networks are also of importance for change. Samsø in Denmark is a good example of a place in which they created a great new network. Among other things they are on their way to rebuilding the island's old slaughterhouse and dairy. The residents have organized themselves and have collectively determined that if the community is to survive, they need to support initiatives that help to preserve jobs in the local area.

Much transformation is rooted among enthusiasts, e.g. when they find new ways to start a farm by providing start-up capital. Such individuals often come from urban areas, and thus help to connect urban and rural areas. We can learn much from these examples, and encourage more enthusiasts to choose to engage in future farming systems. Besides enthusiasm we will need to spread knowledge and gain more experience of new production systems.

Agricultural programs must be changed so that students get a whole new way of thinking. No one has a definitive answer to the future of agriculture, but, in education, there should be introduced a new way of thinking and horticulture should play a more prominent role when more food is to be based on vegetables.

7. Conclusions

From our scenario work, we can conclude that the four Nordic countries, Denmark, Finland, Norway and Sweden, when seen as a unity, can become largely self-sufficient (in 2030) and even supply food for more people, based on mainly regional, organic production, if the consumption of animal products is reduced. The two scenarios we have investigated are:

- the *Sufficiency* scenario (*SY*), where the number of ruminant animals (cattle and sheep) is limited to the minimum number of animals needed to graze available semi-natural pastures in each country and where byproducts are fed to monogastric animals (poultry, pigs and aquaculture fish) and used to supplement the ruminant feed, and
- the *Efficiency* scenario (*EY*), where ruminants graze pastures on arable land to a larger extent, more grass is used for winter feed in order to make use of the ley that is grown in the crop rotations. Some feed cultivated on arable land may also be included in the feed rations as long as this contributes to the aim of feeding more people from local resources.

In other words, in the *SY scenario*, only byproducts and grass are allowed in livestock diets and, apart from ley, no additional feed is grown, whereas in the *EY scenario*, more cultivated feed is allowed to be grown and therefore there is room for a larger number of livestock and more animal products can be part of the diet.

The results show, somewhat counterintuitively, that a relative increase in arable land allocated to livestock in the *EY* scenario compared to the *SY* scenario means that the *EY* scenario has the potential to feed more people from Nordic agriculture.

When comparing the two scenarios we found that the maximum number of people that can be supported with the basic food items by Nordic agriculture is largest in the *EY scenario*, namely 37 million people, which is 8.6 million more than the 28.4 million projected to live in the Nordic countries by 2030, while the *SY* scenario is able to support

30.9 people, i.e. 2.5 million more than the projected population. However, the figures for additional people to be supported would in reality be lower, since tropical fruits, nuts, tea and coffee, are imported in amounts equal to current consumption in both scenarios.

The total agricultural area needed per diet including land used abroad for imported food was 0.27 hectare per diet for *SY* and 0.23 hectare per diet for *EY*.

The variations between the individual countries in both the diets and the land use per diet are large, reflecting the big geographical and climatic differences. For example, the Finnish diets used more than twice as much land as the Danish diets.

In both scenario diets the consumption of meat decreased substantially. Compared to current levels, meat consumption decreased on average by 90 percent in the *SY* scenario and 81 percent in the *EY scenario*, to an average weekly consumption of 80 and 149 grams respectively. Consumption of fish in both scenario diets was around half of current consumption; around one serving weekly compared to the two servings currently consumed in the four Nordic countries. Consumption of milk was slightly less than half of current consumption for SY while it was at the same level as current consumption for the EY scenario.

Regarding the nutritional value of the scenario diets, a "base-line" diet was used to promote resulting diets with adequate nutritional values, where the reduced consumption of animal protein, fat and energy was substituted with cereals, legumes and vegetable oil in the scenarios. This led to some vitamin and mineral deficiencies in the scenario diets of which some are also present in the current diets in the Nordic countries. However, the vitamins A and B_{12} as well as the minerals calcium and iodine are below recommendations in the scenario diets (B_{12} and calcium only in the **SY** diets), while they are not below recommendations in the current diets. Vitamin D, riboflavin, iron and selenium are below recommendations today (except for selenium in Finland) as well as in the scenario diets (iron only in the *EY* diet).

Regarding the climatic impacts of the scenario diets, the *SY* and *EY* scenario diets would give rise to 0.36 and 0.48 tonnes CO_2-eq per person per year respectively, mainly due to methane emissions from ruminant feed digestion and nitrous oxide emissions from soils. Emissions in the *SY* scenario are lower because fewer livestock result in lower methane emissions and more carbon is stored when most of the ley is left on the fields.

Contrarily, the potential for reducing eutrophication was higher for the **EY** scenario compared to *SY*, primarily since the *EY* scenario provided more diets without using more arable land. Leaching of nitrogen and phosphorus from arable soils accounted for roughly two-thirds of the diet's total eutrophication potential. The remaining third was mainly attributed to ammonia volatilization related to manure management, and for the SY scenario also to ammonia volatilization from non-harvested ley residues.

Volatilization of ammonia was the main contributor to acidification potential in the scenario diets, accounting for 97 percent of total AP. Fewer animals in SY compared to EY resulted in less volatilization of ammonia from manure. This was however counterbalanced by increased volatilization from crop residues due to extensive areas of ley being used for green manure in the SY scenario.

The present study indicated a net sequestration of carbon in soils for the SY scenario and net carbon emissions for the EY scenario. However, the modelled carbon stock changes in this study did not take into account any increased allocation of biomass to roots, which may lead to an underestimation of the actual potential to sequester carbon in arable soils in the scenarios.

Summarising, when comparing the two scenarios, we can conclude that the *SY scenario* is best from a climate perspective. On the other hand, the *EY* scenario causes less eutrophication per diet and can feed more people. Another conclusion to be drawn is that it is possible to feed more than the projected Nordic population in 2030 on mostly regionally grown organic food while increasing the consumption of plant-based food items and reducing consumption of animal products. Thus, the recurrent criticism of organic farming that it is a threat to food security is proven wrong, at least at the regional level in the Nordic countries. Although there is some uncertainty regarding the results for carbon sequestration, the results indicate that a transition to organic farming, and the production described in the scenarios, would not significantly increase carbon storage and could even lead to net emissions. The Paris Agreement requires that anthropogenic greenhouse gas emission sources and sinks are balanced by the second half of this century. For this to be possible we will need other types of actions and management methods than those described in this report.

8. Recommendations

A transition towards a more extensive organic farming system of the type described in the scenarios, where livestock feed production competes less with human food production, would result in significantly lower emissions of greenhouse gases, acidifying pollutants and eutrophying pollutants. In other words, the opportunity to reduce emissions from food production is around the corner. The knowledge to grow organic food is already there. These farming systems would benefit from further development, but no technical miracles are required.

Organic farming systems have been observed to have a positive influence on carbon sequestration and soil carbon. The drivers for this are not well understood, but crop rotations, increased use of organic amendments such as compost, straw, green manure and deep litter manure, and a larger allocation of biomass to roots in organic systems may all contribute to this. We recommend further exploration into these aspects of organic farming, including the role of grazing animals in farming. This goes hand in hand with the aim of the Paris Agreement to achieve net zero carbon emissions by 2050, where the potential and best methods for carbon sequestration in agriculture needs to be explored further.

A holistic perspective on our food and farming system is necessary if we want to achieve real emission reductions. In this study, we show that a transition to organic and extensive farming is beneficial to the climate, even if the emissions per kilogram of product are equivalent or even higher than for conventional cultivation, since this would go along with changes in our diets. In order for such a perspective to permeate policies and support systems, these need to undergo a profound reformulation, not least the EU’s common agricultural policy.

We believe that efforts need to be made to promote more sustainable diets. This can be done through general recommendations, guidelines for public meals, policy decisions within companies and other private institutions that serve food to employees or customers. The results can serve as a basis for such recommendations for sustainable diets. E.g. a reasonable level of meat consumption is one or two servings of meat per week.

To increase Nordic self-sufficiency towards the levels described in the scenarios, we will need to grow other crops. In particular, grain legumes and oil crops need to be more widespread compared to current production in the Nordic countries.

In order to promote an informed debate on food and agriculture, we want to encourage the development of more future scenarios for sustainable agriculture, exploring aspects that we have not included here, e.g. developments in technology and production methods, plant and animal breeding, sustainable fisheries, energy efficiency, innovations in novel food and feed, such as artificial meat, algae or insects. We would also like similar work to be carried out for other regions to increase our knowledge about how local conditions (geology, demography, climate etc.) affect the opportunities for increased regional self-sufficiency.

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Sammanfattning

Det globala livsmedelssystemet orsakar stora utsläpp av växthusgaser och andra miljöföroreningar. Djurhållningen står för en stor del av dessa utsläpp och kräver merparten av världens jordbruksmark för betes- och foderproduktion, men bidrar endast begränsad del till den globala livsmedelsförsörjningen. I detta projekt har vi använt en massflödesmodell för att analysera två framtida livsmedelsscenarier för de nordiska länderna Danmark, Finland, Norge och Sverige (fortsättningsvis kallat ”Norden”).

Dessa scenarier bygger på mindre konkurrens mellan djurfoderproduktion och livsmedelsproduktion, och huvuddelen av maten produceras i Norden med hjälp av ekologiska jordbruksmetoder. I det första scenariot (SY) begränsades antalet idisslare till det minsta antal som krävdes för att beta alla seminaturliga betesmarker, medan enkelmagade djur (fjäderfä, grisar och uppfödd fisk) var begränsade till tillgängliga biprodukter från livsmedelsindustrin.

I det andra scenariot (EY) ökades antalet idisslare i syfte att utnyttja all vall som odlas i ekologisk växtodlingsrotation. Dessutom kompletterades biproduktfoder för enkelmagade djur med visst vegetabiliskt foder odlat på åkermark. Detta gjorde det möjligt att odla mer mat i Norden och därmed föda en större befolkning.

Resultaten visar att scenarierna skulle kunna producera tillräckligt med näringsrik föda för 31 (SY) respektive 37 (EY) miljoner människor i de nordiska länderna. Scenarierna skulle således kunna försörja den beräknade befolkningen år 2030, dock med förändringar av dieten. Konsumtionen av kött minskades med 90 procent (SY) respektive 81 procent (EY) jämfört med nuvarande konsumtionsnivåer och ersattes med spannmål, baljväxter och vegetabilisk olja. I scenarierna ingår också en större andel grönsaker än nuvarande konsumtionsnivåer för att motsvara de nordiska näringsrekommendationerna.

Uppskattningar av nuvarande växthusgasutsläpp från jordbruksproduktionen av de livsmedel som konsumeras i Norden varierar mellan 1 310 och 1 940 kg CO_2-ekv per person och år. Växthusgasutsläppen från jordbruksproduktionen i scenarierna uppskattas till 310–700 kg CO_2-ekvivalent per diet och år.

I vart och ett av de fyra deltagande nordiska länderna anordnades workshops med intressenter som gav ytterligare perspektiv på scenariernas genomförbarhet. Diskussionerna betonade bland annat komplexiteten i konsumentval, möjligheter till politiska åtgärder, jordbrukarnas behov och vikten av att skapa en positiv berättelse.

Appendix A

A.1 Methane emissions

A.1.1 Enteric fermentation

For ruminant animals the IPCC (2006) Tier 2 method was used. Gross energy intake was calculated for dairy cows, heifers, steers, ewes and lambs individually from the feed rations using gross energy content of the different feedstuff, obtained from Feedipedia (equation 1). Y_m values were set to 6.5 percent for all ruminants except lambs, for which a Y_m of 4.5 percent was used (IPCC, 2006). For pigs and sows the IPCC (2006) Tier 1 method was used with EF equalling 1.5 kg CH_4 head^{-1} year^{-1}. No emissions of methane through enteric fermentation were assumed from poultry and aquaculture.

$$EF = \frac{GE \cdot \left(\frac{Ym}{100}\right) \cdot 365}{55.65} \qquad (1)$$

EF = emission factor, kg CH_4 head^{-1} year^{-1}
GE = gross energy intake, MJ head^{-1} day^{-1}
Y_m = methane conversion factor, percent of gross energy in feed converted to methane

A.1.2 Manure management and biogas

For ruminant animals the excretion of volatile solids (VS) was calculated according to IPCC (2006) Tier 2 methodology using GE and digestibility of the feed rations (equation 2). For monogastric animals, generic factors for VS excretion were used. A VS excretion rate of 0.02, 0.01, 0.46 and 0.30 kg VS head^{-1} day^{-1} was used for laying hens, cockerels, sows and slaughter pigs respectively (IPCC, 2006). The manure collected in stables was assumed to be digested together with ley and slaughter house and food waste. The fractions of VS in these substrates were 0.88, 0.83 and 0.85 kg VS (kg dm)$^{-1}$ respectively (Carlsson and Uldal, 2009).

$$VS = \left[GE \cdot \left(1 - \frac{DE\%}{100}\right) + UE \cdot GE\right] \cdot \left(\frac{1-ASH}{18.45}\right) \qquad (2)$$

VS = volatile solids excretion, kg VS head^{-1} day^{-1}
GE = gross energy intake, MJ head^{-1} day^{-1}
DE% = feed digestibility, percent
UE = urinary energy expressed as a fraction of GE = 0.04
ASH = ash content of manure, expressed as a fraction of dry matter feed intake = 0.08

Methane emissions were calculated by summing all VS excreted by animals in stables and VS present in waste and ley (equation 3). For biogas digestate, values of B_0 = 0.095 m^3 CH_4 (kg VS)$^{-1}$ and MCF = 3.5 percent were used (Tufvesson et al., 2013). For manure deposited outside stables, Bo was set to 0.24, 0.14, 0.25 and 0.45 m^3 CH_4 (kg VS)$^{-1}$ for dairy cows, other cattle, sheep and pigs respectively (IPCC, 2006). MCF for manure deposited outside stables was set to 1 percent based on (IPCC, 2006).

$$EF = VS_{tot} \cdot (B_o \cdot \frac{MCF}{100} \cdot 0.67) \qquad (3)$$

EF = emission factor, kg CH_4 year^{-1}
B_0 = maximum methane-producing capacity, m^3 CH_4 (kg VS)$^{-1}$
MCF = methane conversion factor, percent

Methane losses along the biogas production chain were assumed to be 0.61 percent of produced biogas used for tractor fuel and 0.50 percent of produced biogas used for electricity and heating, based on Tufvesson et al. (2013).

A.2 Nitrous oxide emissions

A.2.1 Direct emissions from soils

Emissions of nitrous oxide from soils were calculated as 1.0 percent of total N added to the soils (IPCC, 2006). Added N included N in manure, biogas digestate, crop residues and additional nitrogen needed to balance the nitrogen deficits on arable soils in the scenarios. The amount of additional N (Nadd) needed was found by balancing equation 4. Denitrification was calculated from the N_2O emissions and an assumed N2-N:N_2O-N ratio. In the literature this ratio ranged between 3.6 – 26 (Fowler et al., 2013; Nieder and Benbi, 2008; Sutton et al., 2011). N2-N:N_2O-N = 10 was used in the calculations.

$$N_{man} + N_{dig} + N_{add} + N_{dep} + N_{fix} = N_{har} + N_{leach} + N_{N2O} + N_{N2} + N_{NH3} \qquad (4)$$

N_{man} = manure deposited on arable soils; N_{dig} = biogas digestate; N_{dep} = atmospheric deposition; N_{fix} = N fixation in leguminous crops; N_{har} = N removed with harvested crops and straw; N_{leach} = N leaching; N_{N2O} = N_2O-N emissions from soils; N_{N2} = denitrification losses; N_{NH3} = NH_3-N volatilization from manure, biogas digestate and crop residues.

A.2.2 Indirect emissions

Indirect emissions of nitrous oxide were calculated as 0.75 percent of total leached N plus 1.0 percent of NH_3-N volatilized from manure, biogas digestate and crop residues (IPCC, 2006).

A.3 Ammonia emissions

A.3.1 Manure and biogas digestate

NH_3 volatilization from manure deposited on pastures was calculated as 8.0 percent of total N in manure (Cederberg et al., 2009). For manure deposited in stables, 20%, 15%, 35% and 25% of total N in manure was assumed to be volatilized through the ventilation (Swedish Environmental Protection Agency, 2014) before the manure was sent to the biogas digester.

Data on ammonia volatilization during storage and field application of biogas digestate were sparse. NH_3 volatilization was estimated at 4 percent of N-tot during storage and 15 percent of NH_4-N during field application based on data for liquid manure (Karlsson and Rodhe, 2002). Berg (2000) reported storage losses of 17 percent of total N after 5 months storage and 50–58 percent losses of NH_4-N during field application.

A.3.2 Crop residues

Volatilization of ammonia from crop residues was calculated using equation 5 from (Ruijter and Huijsmans, 2012).

$$NH_3 - N = 0.40 \cdot N_c - 5.08 \qquad (5)$$

NH_3-N = ammonia-nitrogen volatilization, percent of applied N in crop residues
N_C = N content in applied crop residues, g N (kg dry matter)$^{-1}$

A.4. Emissions from fuel combustion

Emission factors used for the combustion of different fuels are found in Table 12.

Table 12: Emissions from combustion of different fuels per MJ of produced electricity+heat, heat or motor power

Fuel	CO_2 (g)	CH_4 (mg)	N_2O (mg)	SO_2 (mg)	NO_X (mg)	NH_3 (mg)	Source
Biogas, electricity+heat	0	**	-	2.0	32	-	(Börjesson and Berglund, 2003)
Biogas, vehicle fuel	0	**	-	0	560	-	(Börjesson and Berglund, 2003)
Straw, heat	0	1.7	0.64	0.34	50	2.0	(Gode et al., 2011)
Diesel*, vehicle fuel	253	112	6.8	56	2330	-	(Gode et al., 2011)

Note: * Includes production and distribution.
** Methane losses through the biogas production and consumption chain were calculated as 0.50% (Göthe, 2013) of produced biogas for biogas used for electricity generation and 0.61% (Tufvesson et al., 2013) for biogas used as vehicle fuel.

A.5 Changes in soil carbon stocks

Changes in soil carbon stocks were modelled with the introductory carbon balance model (ICBM). The steady-state carbon pool (C_{SS}) was modelled for a business-as-usual (BAU) scenario using national statistics on crop production and livestock numbers. C_{SS} was given by equations 6 (Andrén et al., 2004).

$$Y_{SS} = \frac{i}{k_Y r_e} \; ; \; O_{SS} = h\frac{i}{k_O r_e} \; ; \; C_{SS} = Y_{SS} + O_{SS} \qquad (6)$$

$k_Y = 0.8$ year^{-1}
$k_O = 0.009$ year^{-1}
i = carbon input from crop residues, green manure, manure and biogas digestate, ton C ha^{-1} year^{-1}
h = humification coefficient, -
re = external influence on k_Y and k_O, -

Input of carbon from crop residues was calculated using national statistics on areas cultivated with different crops (Table 13) and corresponding harvest yields and the regression model in Andrén et al. (2004) relating above ground (AG), below ground (BG) and straw residues from different crop groups to harvest yields. Input from farmyard manure was calculated from national statistics on livestock numbers (Table 14) together with manure excretion rates according to NIR (Swedish Environmental Protection Agency, 2014). Carbon losses from manure during storage were calculated as 50 percent of the original carbon content for solid and deep-litter manure (Tiquia et al., 2002). For other forms of manure storage it was assumed that equal amounts of CO_2 and CH_4 are released from storage, and carbon losses were thus calculated based on methane emission factors according to IPCC (2006).

Table 13: Areas cultivated with different crop groups and dry matter yields used in the BAU scenario

Crops	Area ha	Yield kg dm ha^{-1}
Cereals	1,034,234	5,180
Grain legumes	58,698	3,300
Rapeseed	101,622	3,406
Roots	42,544	34,908
Ley	1,089,678	10,634
Other	99,860	18,202

Table 14: Number of different livestock and manure production used in the BAU scenario

Livestock	Number heads	C in manure kg C head^{-1} year^{-1}
Cattle		
Dairy cows	339,823	914
Suckler cows	184,438	407
Heifers, bulls and steers	488,462	287
Calves	467,335	97
Sheep	288,675	55
Pigs		
Sows	140,249	67
Boars	1,548	102
Pigs	830,257	64
Piglets	383,973	6.5
Poultry		
Hens	7,571,087	3.6
Chickens	10,285,688	1.8
Horses	355,500	292

Humification coefficients for different carbon sources were adopted from Kätterer et al. (2011) and are found in Table 15. The humification coefficient for biogas digestate was approximated with farmyard manure. The aggregated humification coefficient was calculated using equation 7.

Table 15: Humification coefficients used in the ICBM model. Adopted from (Kätterer et al., 2011)

Carbon source	Humification coefficient (h)
AG residues	0.15
BG residues	0.35
Green manure	0.12
Farmyard manure	0.27

$$h = \frac{\sum h_i \cdot i_i}{\sum i_i} \qquad (7)$$

hi = humification coefficient from carbon source i,-

ii = carbon input from source i, ton C ha-1 year-1

The annual change in soil carbon stocks over a 100-year time frame under the different scenarios was calculated using equations 8 through 10. Carbon inputs and humification coefficients were calculated following the same methodology as for the BAU scenario.

$$Y(t) = \frac{i}{r_e k_Y} + \left(Y_0 - \frac{i}{r_e k_Y}\right) e^{-r_e k_Y t} \tag{8}$$

$$O(t) = h\frac{i}{r_e k_O} + \left(O_0 - h\frac{i}{r_e k_O}\right) e^{-r_e k_O t} \tag{9}$$

$$SOC_{change} = \frac{Y(100) + O(100) - Y(0) - O(0)}{100}$$

Appendix B

B.1 Crop parameters

The national statistics on ley productivity in Finland, Norway and Sweden are based on questionnaires filled in by farmers, and in Denmark on questionnaires filled in by crop consultants. For individual farmers it is often difficult to make accurate estimates on weight, volume and dry matter content of harvested ley, which makes the statistics uncertain. Furthermore, it is often common practice to take one or two harvests before using the remaining regrowth for grazing. The latter is not included in the national statistics, which leads to an underestimation of actual productivity on leys. To account for this we compared Swedish national statistics to field studies (Gunnarsson et al., 2014). The yields from the field studies were reduced by 20 percent to resemble practical farming, after which a correction factor was calculated. This factor ranged between 1.5 – 2.1 depending on region and number of harvests. The yields from Finnish, Norwegian and Swedish national statistics were factored by the average value of 1.7 to account for the underestimation of ley productivity in the statistics. For temporary pastures, no national statistics were available. Here it was assumed that 60 percent of the productivity of the leys would be utilized by the grazing animals.

B.2 Livestock parameters

Table 16: Assumed live weight, slaughter age, mortality and meat yields for the different animal species

	Cattle			Sheep		Poultry		Pigs		Fish	
	Dairy cows	Steers	Heifers	Ewes	Lambs	Laying hens	Cock-erels	Sows	Pigs	Aqua-culture	Wild
Live weight, kg	6441,2	6381,3	5661,3	705	505	2.0	1.8	225	115	0.3	n/a
Age at slaughter, months	691	291	281	525	4.95	18	3.2	24	6	n/a	n/a
Mortality,%	2	2	2	2	95	5	3.5	1.5	1.56	0.5	n/a
Slaughter rejects,%	n/a	n/a	n/a	n/a	n/a	1.35	1.35	0.296	0.296	n/a	n/a
Dressed weight ,% of l.w.	472,3	503	503	455	455	59	70	75	75	35	35
Bone-free meat, % of d.w.	754	754	754	705	705	764	764	58	56	n/a	n/a
Offal, % of l.w.	3	3	3	25	25	5	5	3	3	n/a	n/a
Blood, % of l.w.	3	3	3	3	3	7	7	3	3	n/a	n/a

Source: 1 (Gård & Djurhälsan, 2016).
2 (Jokinen, 2005).
3 (Clason and Stenberg, 2016).
4 (Hallström et al., 2014).
5 (Sjödin et al., 2008).
6 (WinPig, 2015).

A low milk yield of 6,000 kg ECM per year was assumed for the dairy cows to enable adequate feed rations from the available byproducts, ley and pasture resources and to account for the presumed need for more durable breeds in some regions.

Feed rations for the different animal species were calculated based on currently used recommendations, and accounted for energy, protein and fat intake (Table 17). Nutrition parameters for the different feedstuffs were acquired from the online feed tables provided by the Department of Animal Nutrition and Management at the Swedish University of Agricultural Sciences. Maximum recommended inclusion rates of some feedstuff were also accounted for.

Tabel 17: Energy, protein and fat in feed rations for the different livestock and aquaculture

	Cattle			Sheep		Poultry		Pigs		Fish
	Dairy cow	Steers	Heifers	Ewes	Lambs	Laying hens	Cock-erels	Sows	Pigs	Aqua-culture
Energy, MJ head^{-1} year^{-1}	56,172[1]	23,887[1]	21,402[1]	5,205[1]	1,756[1]	481[3]	92[3]	19,572[5]	4,272[5]	10.6[7]
Protein, kg head^{-1} year^{-1}	427[2]	161[2]	144[2]	39[2]	12[2]	4.4[4]	1.4[4]	166[6]	49[6]	0.189[7]
Fat, kg head^{-1} year^{-1}	<50g/kg[2]	<50g/kg[2]	<50g/kg[2]	<50g/kg[2]	<50g/kg[2]	n/a	n/a	n/a	n/a	0.057[7]

Note: 1 Metabolizable energy, calculated from Spörndly (2003).
2 Amino acids absorbed in the small intestine, calculated from Spörndly (2003). Protein balance in the rumen and maximum crude fat content (50 g [kg feed]$^{-1}$) were also considered when formulating the ruminant diets.
3 Metabolizable energy, recommendations from (*Nutrient requirements of poultry*, 1994) and FCR from (Leenstra et al., 2010).
4 Crude protein, recommendations from (*Nutrient requirements of poultry*, 1994) and FCR from (Leenstra et al., 2010).
5 Metabolizable energy calculated from Simonsson (2006).
6 Standardized ileal digestible amino acids calculated from Simonsson (2006).
7 *Nile Tilapia* feed conversion ratio and feed metabolizable energy, crude protein and crude fat from Goda et al. (2007). Maximum crude protein content was however increased to 35% since the available byproducts were generally high in protein.

B.3 Energy production and use

Manure together with straw used for bedding, ley, slaughter house and food waste were digested to produce bioenergy. Biogas yields used are found in Table 18.

Table 18: Biogas yields and biogas methane content from different substrates

	Manure			Ley[1]	Straw[2]	Slaughter house waste[2]	Food waste[2]
	Cattle and sheep[1]	Poultry[1]	Pigs[1]				
Biogas yield, Nm3 CH_4 (ton VS)$^{-1}$	185	230	250	300	200	430	460
Methane content in biogas, %	57	64	64	55	70	63	63

Source: 1 (Edström et al., 2008).
2 (Carlsson and Uldal, 2009).

Biogas production process heat and electricity needs were assumed to be 14 percent and 4 percent of total produced energy according to Edström et al. (2008) which was deducted from the total energy produced. For biogas that was upgraded for use as tractor fuel an additional 8 percent was deducted to account for energy use in the upgrading process (Edström et al., 2008).

Energy use for field operations in cereal, grain legume and rapeseed cultivation were calculated from (Flysjö et al., 2008) based on annual plowing, sowing, manure application and harvesting. To account for mechanical weed control in organic farming additional harrowing was included. Energy consumption per hectare for the different crops is found in Table 19.

Table 19: Energy used by tractors for field operations cultivating different types of crops

Crop	Energy use (GJ ha-1 year-1)	Source
Ley	1.7	(Flysjö et al., 2008)
Cereals	3.7	(Flysjö et al., 2008)
Grain legumes	3.2	(Flysjö et al., 2008)
Rapeseed	3.7	(Flysjö et al., 2008)
Potatoes	5.3	(Röös et al., 2010)
Sugar beats	5.3*	(Röös et al., 2010)
Roots	8.9	(Röös and Karlsson, 2013)
Cabbage	8.4	(Davis et al., 2011)
Onion	9.6	(Davis et al., 2011)
Apple	6.2	(Davis et al., 2011)
Berries	0.6	(Davis et al., 2011)

Note: * Approximated with potatoes.

Electricity and heating energy use in agricultural production buildings is found in Table 20. Electricity and heat were supplied from small-scale biogas cogeneration plants with a total efficiency of 80 percent, of which 30 percent was electricity and 50 percent heat (Börjesson and Berglund, 2003). Fuel use in the fishing fleet providing the wild-caught fish in the diets was assumed to be diesel.

Table 20: Use of heat and electricity in stables, greenhouses, aquaculture tanks and fuel use in the fishing fleet

Livestock	Energy use, MJ (Electricity/Heating)
Dairy cows, per kg ECM, incl. recruitment animals	0.3/- [1]
Other cattle, per head per year	230/- [2]
Sheep ewes, per head per year, including lambs	140/- [3]
Laying hens, per kg eggs	0.5/- [4]
Cockerels, per head per year	0.5/2.8 [4]
Pigs, per head per year	233/- [4]
Aquaculture *Nile Tilapia*, per produced fish	1.9/3.7 [5]
Greenhouse grown vegetables, per hectare	1,241/6,482 [6]
Fishing fleet fuel consumption, per kg live weight	0.24 litre diesel [7]

Source: 1 (Flysjö, 2012).
2 (Edström et al., 2005).
3 (Wallman et al., 2011).
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Appendix C
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FUTURE NORDIC DIETS

Farming is the foundation of our food system. While the prerequisite for farming is a clean environment and a diverse nature, agriculture is currently the cause of major environmental problems, including greenhouse gas and nitrogen emissions. The challenge to protect our environment and feed the world sometimes seem insurmountable, but solutions might be just around the corner.

This report describes two food system scenarios for Denmark, Finland, Norway and Sweden, where the majority of food is produced within the region using organic farming practices and where livestock is mainly fed on grass and by-products not suitable for human consumption.

The results show that we could feed the projected Nordic population in 2030 on organic food, mostly grown within the region, while reducing the climate and nitrogen footprints of our food system.

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