Designing a future food vision for the Nordics through a participatory modeling approach

Johan O. Karlsson, Georg Carlsson, Mikaela Lindberg, Tove Sjunnestrand, Elin Röös

Agronomy for Sustainable Development (2018) 38: 59
https://doi.org/10.1007/s13593-018-0528-0

RESEARCH ARTICLE

Designing a future food vision for the Nordics through a participatory modeling approach

Johan O. Karlsson [1] · Georg Carlsson [2] · Mikaela Lindberg [3] · Tove Sjunnestrand [1] · Elin Röös [1]

Accepted: 22 August 2018 / Published online: 23 October 2018

Abstract
The development of future food systems will depend on normative decisions taken at different levels by policymakers and stakeholders. Scenario modeling is an adequate tool for assessing the implications of such decisions, but for an enlightened debate, it is important to make explicit and transparent how such value-based decisions affect modeling results. In a participatory approach working with five NGOs, we developed a future food vision for the Nordic countries (Denmark, Finland, Norway and Sweden) through an iterative process of defining the scenario, modeling, and revising the scenario, until a final future food vision was reached. The impacts on food production, land use, and greenhouse gas emissions, and the resulting diets in the food vision, were modeled using a mass flow model of the food system. The food vision formulated was an organic farming system where food is produced locally and livestock production is limited to "leftover streams," i.e., by-products from food production and forage from pastures and perennial grass/clover mixtures, thus limiting food-feed competition. Consumption of meat, especially non-ruminant meat, was substantially reduced compared with current consumption in the Nordic countries (−81%). An estimated population of 37 million people could be supplied with the scenario diet, which uses 0.21 ha of arable land and causes greenhouse gas emissions of 0.48 tCO_2e per diet and year. The novelty of this paper includes advancing modeling of sustainable food systems by using an iterative process for designing future food visions based on stakeholder values, which enables results from multidisciplinary modeling (including agronomy, environmental system analysis, animal and human nutrition) to be fed back into the decision-making process, providing an empirical basis for normative decisions and a science-based future vision of sustainable food systems.

Keywords Food system · Local · Organic · Livestock · Leftovers · Food-feed competition · Default livestock · Land use · Greenhouse gas emissions · Agriculture

1 Introduction

Agriculture faces a massive dual challenge in feeding a growing and increasingly affluent global population, while at the same time reducing its negative environmental impacts. Food systems affect the environment through agricultural land expansion, where agriculture extends into other biomes with negative impacts on biodiversity, soils and stored carbon, and through intensification, with increased water withdrawal, perturbation of nutrient cycles, and increased energy use (Foley et al. 2011). Up to 29% of global anthropogenic greenhouse gas (GHG) emissions can be attributed to food systems (Vermeulen et al. 2012), where livestock products, especially red meat, are GHG-intensive and responsible for a large part of the GHG impact of diets (Hallström et al. 2015). While the goal for future food systems is clear, i.e., to produce enough nutritious food accessible to everyone while reducing negative environmental impacts, the paths suggested to reach this goal are numerous and sometimes opposing.

Some experts call for further improvements in efficiency, to produce more from existing land through increased and more efficient use of inorganic fertilizers, pesticides, and other amendments and modern technologies, in order to increase

✉ Johan O. Karlsson
johan.o.karlsson@slu.se

[1] Department of Energy and Technology, Swedish University of Agricultural Sciences, Uppsala, Sweden

[2] Department of Biosystems and Technology, Swedish University of Agricultural Sciences, Alnarp, Sweden

[3] Department of Animal Nutrition and Management, Swedish University of Agricultural Sciences, Uppsala, Sweden

the per-hectare yields. This strategy is often called "sustainable intensification" (e.g., Burney et al. 2010). However, as the historical focus on higher productivity has come at a cost to the environment (Foley et al. 2011), and has not been able to end global food insecurity, others see high-input modern farming itself as the problem. They call instead for reduced external inputs, improved nutrient cycling, and a greater dependence on local resources, as in organic farming (Reganold and Wachter 2016). This approach has been criticized in turn for not providing an answer as to how the world's population can be fed without causing further expansion of agricultural land, as yield per area in low-input organic farming is usually lower (Connor 2008).

It is also becoming increasingly clear that a dietary change away from diets high in animal products towards more plant-based foods and reductions in food waste are needed to reach, e.g., climate targets (Bajželj et al. 2014). In addition, re-allocation of crops from animal feed to direct human food production could substantially increase food supply worldwide, as one third of global cereal production is currently used to feed animals (Mottet et al. 2017).

A range of different approaches will arguably be needed to transform the current food system into one that sustainably produces enough food for everyone. However, the future is uncertain, food systems are highly complex, and optimal solutions are highly context-specific. The composition of future human diets and the environmental and social impacts they cause will depend on the type of approach invested in, which in turn will depend on general visions of "good," faith in technology, and beliefs about what can be changed (Garnett 2014; Smith 2013). Modeling of future food systems can increase knowledge of possible implications of different choices in the evaluation of more sustainable food systems. The process of designing such futures to model is inevitably associated with unavoidable normative decisions at different levels that have to be taken in a democratic and transparent process by key stakeholders rather than researchers. It is crucial that such stakeholder decisions are taken in an unprejudiced way, based on the best empirical evidence available (Muller et al. 2017). Participatory research, where knowledge is co-created through collaboration between researchers and non-academic stakeholders, markets, and government institutions, has been proposed as a fruitful endeavor in research on complex sustainability transition problems (Mauser et al. 2013; Volkery et al. 2008). Direct involvement of stakeholders and inclusion of goals, norms, and visions will be needed to create deeper legitimacy, ownership, and accountability regarding the problem and proposed solutions.

In the present study, we worked with a group of non-government organizations (NGOs) in a participatory scenario development process to jointly define a future food vision for the Nordic countries (Denmark, Finland, Norway, and Sweden), based on the values and views of these NGOs. The aim of this paper is to describe this process and the modeled results in terms of food production (including nutritional aspects), land use (i.e., how many people can be provided with a complete diet from the Nordic land base), and the climate impact of this future food vision. In the following sections of this paper, we illustrate and discuss how normative decisions and assumptions made during scenario development influenced the results of the modeling.

2 Materials and method

2.1 The Nordic food system

The Nordic countries are part of a highly globalized food system with resource-intense consumption patterns, e.g., meat consumption in the Nordic countries is around double the global average. Due to the large Danish pork industry, the region is also a net exporter of meat. Within the region, Denmark is the only country with net export of agricultural commodities, while the other countries are net food importers (FAO 2017). A relatively small proportion of the total land area (3–8%) is used for agricultural production in all countries except Denmark (~ 50%). Specialist dairy farming (Fig. 1) is the most economically important farm enterprise in Finland, Norway, and Sweden, while specialist pig production is the most prominent enterprise in economic terms in Denmark. Due to the harsh weather and topography in Norway, specialist sheep farms are also common, utilizing remote pastures in hilly areas. All the Nordic countries have experienced an increase in average farm size in recent decades due to smallholders ceasing operations and merging into larger farms (Eurostat 2016). However, smallholders are still relatively important in Norway. At the national level in all countries, only 2–3% of the total workforce is employed in agriculture. The emissions of methane and nitrous oxide from agriculture constitute a considerable part of total national greenhouse gas emissions; 8, 9, 13, and 19% in Norway, Finland, Sweden, and Denmark, respectively. Ammonia emissions, mainly from livestock manure, account for approximately 90% of total ammonia emissions in the Nordic countries (Antman et al. 2015). The Baltic Sea, which Sweden, Finland, and Denmark border, is heavily affected by eutrophication due to nutrient pollutants lost from agriculture.

2.2 Stakeholder engagement process

Based on the methodologies presented by Volkery et al. (2008) and Mauser et al. (2013), an iterative stakeholder integration process was employed to design and model the future food vision for the Nordic countries. The process followed the three principal steps suggested by Mauser et al. (2013) to define normative decisions describing the food vision and

Fig. 1 Dairy calves grazing in the central Swedish lowlands with extensive cultivation of grass leys in the background which is typical for many parts of the Nordic region. Photo: Jannie Hagman, SLU

translate these decisions into quantitative model inputs. The NGOs provided the creative input when defining normative decisions, while the researchers were responsible for translating the normative decisions into quantitative model inputs and running the model. The process was iterated until a compelling and reasonable set of decisions and model outputs was obtained.

The group of NGOs participating in the study was a rather homogeneous group consisting of five environmental and small-scale farmers' organizations: *Miljøbevægelsen NOAH* (Denmark), *Frie Bønder - Levende Land* (Denmark), *Uusimaa Region of Finnish Association for Nature Conservation* (Finland), *Norsk Bonde-og Småbrukarlag* (Norway), and *The Air Pollution and Climate Secretariat* (Sweden) (hereafter "the NGOs"). They had previously worked together on food system sustainability (see Antman et al. 2015) and had already started to define common interpretations of problems and potential solutions in the area. With this said, each NGO entered into the process with different agendas and local knowledge.

The first step in the process involved initial communications between the researchers and the NGOs in which the overall aim, framing, and initial pre-conditions for the work were decided (see Sect. 2.3). This was followed by collaborative data acquisition and method development (see Sect. 2.4). Collection of data was facilitated by the NGOs' networks in their home countries. In late October 2016, a first workshop involving the researchers and representatives of the NGOs was held in Oslo, where the researchers presented the methodological approach and preliminary model results. Questions regarding what a future sustainable food system should comprise were discussed and key normative decisions were determined (see Sect. 2.3). During this workshop, each NGO provided insights into the political discourse in their respective home country, information which was used to frame the work in a way that was relevant for each of the participating NGOs. Furthermore, the NGOs provided local knowledge on agricultural practices and particularities in their respective home country.

The first workshop was followed by continued method development and modeling work where the decisions made were fed back into the model. This resulted in a draft project report containing the methodology and results.

In early 2017, the NGOs organized four workshops, one in each of the case countries, and invited participants from a broad spectrum of stakeholders, including representatives from farmers' unions, producers, retailers, government agencies, and environmental organizations. The participants had the opportunity to read the draft project report beforehand. During the workshops, they were given a presentation on the main results, which they were asked to discuss and respond to. After the workshops, the researchers and NGOs reviewed the outcomes and lessons learnt, which were fed back into the process of framing the work. Some methodological issues identified during the workshops were also discussed and resolved.

A final step in the participatory process is co-dissemination of results, where findings are openly discussed among participants and other stakeholder groups, and results are published through channels relevant for all participating parties (Mauser et al. 2013). This was done through a co-authored report published by the Nordic Council of Ministers in late 2017 (Karlsson et al. 2017), and the findings were also discussed at the COP 23 meeting in Bonn in November 2017. At the time of writing, a series of debate articles in the different countries has been authored by the NGOs and submitted to relevant newspapers and a final workshop is planned.

2.3 Normative choices in developing the future food vision

This section provides some details on the background to the normative decisions made and the discussions leading to these. The aim is to give an understanding of the ideological views and opinions behind the decisions which shaped the results and conclusions of this modeling study. Key normative decisions and their implications on the modeled scenario are summarized in Fig. 2 and further details can be found in Karlsson et al. (2017).

Early in the process, it was decided that the food vision should depict a future where food is produced mainly through agriculture and not in highly technical landless systems (Muller et al. 2017). Furthermore, one key concept used by the NGOs was that of agroecology (Wezel et al. 2009). One important aspect of agroecology as interpreted by the NGOs

Fig. 2 The main normative decisions resulting from an iterative stakeholder process and how these decisions were implemented in the modeling. The normative decisions are grouped according to which area of the food system they concern, although many span multiple food system areas

was to attempt to re-establish the link between available local resources, food production, and diets consumed. From this, it emerged that food systems need to be re-localized and the reliance on food imports reduced. However, limited imports of tropical fruits, tea, coffee, and chocolate were included in the scenario, as these cannot be produced in the region. Livestock, especially grazing livestock, were considered a vital component in re-localizing the food system, through their ability to utilize local pasture resources, and also by-products from food processing, to produce food. Livestock production should hence not be reliant upon imported feed or compete with local plant-based food production, but instead rely on "leftover streams," i.e., biomass not consumed by humans, a concept referred to as "default livestock" (Van Zanten et al. 2018). The leftover streams available as livestock feed in this study were

1. Semi-natural pastures and Norwegian outfield areas (i.e., forest and mountainous pastures, not counted as agricultural land), where grazing can promote biodiversity and annual cropping is unfeasible
2. Perennial grass or grass/clover mixtures (referred to as ley) grown in crop rotations to facilitate biological nitrogen fixation and control of weeds
3. By-products from food processing unfit or unwanted for human consumption

In Norway, pasture resources outside the areas defined as agricultural land (outfield areas) were considered a resource base for grazing livestock. Outfield areas are currently an important part of Norway's animal husbandry and were considered by the NGOs to be a vital domestic resource that should be utilized for food production.

Together, these leftover streams represented the base upon which livestock production was performed in the future food vision. This limited meat, milk, and egg production to regionally available resources that were not in competition with plant-based food production. However, to enable a large utilization rate of pasture resources and by-products, this normative choice necessitated animal production systems with low productivity compared with current levels.

Another aspect of agroecology suggested for inclusion in the future vision by the NGOs was use of organic farming practices, such as exclusion of synthetic fertilizers and pesticides. This decision led to modeled crop rotations with a large share of grass-legume leys to supply biological nitrogen fixation and to limit pests and weeds, limitations on some crops prone to disease if grown too frequently and also reduced per hectare crop yield (for most crops) compared with current conventional farming practices.

To promote biodiversity in agricultural landscapes, the NGOs decided to set aside 15% of arable land in Denmark for nature conservation. In the other countries, agriculture is a minor land user, which is why this was only applied to the Danish case. The NGOs also decided that semi-natural pastures should be grazed by livestock to prevent them from reverting to natural vegetation, an outcome which would lead to loss of many endangered species that are dependent upon semi-natural pastures.

It was decided that the diets should be based on the type of food currently consumed in the region and seek to fulfill Nordic nutrition recommendations (Nordic Council of Ministers 2014). Therefore, a sample diet produced by the Swedish National Food Agency (Enghardt-Barbieri and Lindvall 2003) was used as a "baseline" diet from which the scenario diets were developed. This baseline diet was based on current Swedish consumption patterns but adjusted to conform to nutrient recommendations. Reduced consumption of animal products compared with the baseline diet was replaced with plant-based counterparts (i.e., cereals, grain legumes, and vegetable oil) to provide the same amount of energy and to meet fat and protein requirements according to the Nordic nutrition recommendations. Dietary carbohydrate content and intake of 20 vitamins and minerals were also assessed and compared to recommendations.

The current levels of food waste were considered unsustainable, and it was agreed that future scenarios for food production should include reduced food waste. Avoidable food waste at the retail and consumer stage of the food chain was therefore assumed to be halved compared with current levels of waste, which is also in line with the United Nations Sustainable Development Goal 12, Target 12.3.

Regarding the energy system, it was decided that the vision should depict fossil-free agriculture. This was enabled through the use of non-food biomass (i.e., wastes, manure, straw, and grass legume leys) for bioenergy production. There was some skepticism among the NGOs about the use of agricultural biomass for bioenergy production and some had previously campaigned actively against the use of arable land for energy production, due to its competition with food production. However, they agreed that limited bioenergy production to cater for energy needs within the agricultural sector was acceptable.

In light of a changing climate and uncertainties in future agricultural productivity in many parts of the world, it was agreed that, instead of restricting food production to the need of the local population, the focus should be on the maximum food production potential based on local resources, in order to feed as many as possible.

2.4 Modeling the future food vision

An adapted and extended version of the bottom-up agricultural mass flow model from Röös et al. (2016) was used to model the impacts of the future food vision on (1) food production including nutrient content in resulting diets, (2) land use, and (3) GHG emissions. Modeling was performed separately for each country. The model tracks mass flows between four main subsystems (crop production, animal production, bioenergy production, and food processing and consumption) and includes 16 crop groups (e.g., cereals, rapeseed, cabbage, potatoes, ley, etc.), 5 animal species (dairy cattle, sheep, pigs, poultry, and aquaculture), and 32 different food items (e.g., cereals, vegetable oil, cabbage, cheese, fish, etc.). The nutrient content of the resulting diets was analyzed with the DietistNet software, using the Swedish National Food Agency's food database. The global warming potential (GWP) was calculated for the GHG methane, nitrous oxide, and carbon dioxide over a 100-year timeframe, according to the 5th IPCC assessment report (IPCC 2013).

Emissions were assessed from cradle to farm gate, thus excluding emissions generated in post-harvest transport, processing, and storage. Changes in soil carbon stocks in arable soil were modeled using the Introductory Carbon Balance Model (ICBM, Andrén et al. 2004) for the Swedish case only due to data limitations and presented separately. Average carbon sequestration (or emission) rates were calculated over a 100-year timeframe. Agricultural energy expenditure was accounted for in the model, and biomass was allocated for bioenergy to provide for farm energy needs. Farmyard manure, food, and slaughterhouse wastes, together with straw and ley, were used as feedstocks, and the digestate was used as fertilizer. For a more detailed description of the model and impact assessment, please see Karlsson et al. (2017).

The area needed to produce all plant-based food in the baseline diet and the bioenergy crops, feed crops, and additional food crops needed to replace reduced consumption of animal products was calculated using national statistics on crop yields. Since data were not available for organic production of all crop groups in all countries, conventional yields were used and the yield gap between conventional and organic farming was accounted for using literature values from de Ponti et al. (2012). Land use for imported food was calculated using global average yield levels according to FAOSTAT.

All crops (except greenhouse horticulture and apple orchards) were grown in crop rotations containing at least one-third grass-legume leys (i.e., ley grown for 2 years in a 6-year rotation), which is recommended for good nitrogen supply and for preventing agricultural pest problems (i.e., weeds, arthropods, and diseases). Ley yield data were taken from national statistics and adjusted for statistical bias using results from Swedish ley field experiments. Limitations in terms of harsh winters and short growing seasons in the northern parts of the Nordic countries and how often specific crops can be incorporated in the crop rotation to avoid build-up of pests were accounted for by limiting cultivation of rapeseed and grain legumes to the southern parts of the countries and restricting their cultivation frequency.

Food chain by-products unfit or unwanted for human consumption were used as animal feed. These were rapeseed cake from vegetable oil production, low-grade roots and potatoes, residue cereal bran, bakery wastes, spent grains from beer production, fiber and molasses from sugar production, and fishmeal from gutting and cleaning.

Livestock herd structures and allocation of feed resources (by-products, grass feed, and feed grains grown on arable land) were identified using a non-linear optimization algorithm described in Karlsson et al. (2017). The model included five livestock systems: (1) low-yielding dairy systems relying on pasture resources to a large extent, (2) lamb production where lambs are reared on pastures during summer and slaughtered in the autumn, (3) organic pork production with access to pastures on arable land, (4) dual-purpose poultry producing eggs and also meat by rearing cockerels, and (5) land-based fish farming using Nile tilapia that can be reared on plant-based feed. For details, see Karlsson et al. (2017).

3 Results and discussion

3.1 Contribution of the Nordic countries to food security

The future food vision formulated has the potential to provide complete diets for an estimated 37.0 million people. The current population in the Nordic countries is 26.5 million and is expected to reach 28.4 million by 2030 (United Nations 2017). However, the aggregated Nordic case masks large differences between the individual countries, e.g., in the Norwegian case, the future vision could only support the dietary requirements of some 51% of its projected 2030 population; in the Danish case, it could provide diets for a much larger population (262% of its projected 2030 population); and in the case of Sweden and Finland, it could provide 102 and 116%, respectively, of the projected 2030 population with the food they require. These differences arose directly from differences in available arable land and average crop yields in the four countries. Thus, our results indicate that a local food system at the national level is not feasible for all Nordic countries. However, via exchange of food between and within the different countries in the region, this would be possible.

3.2 Scenario diets and nutrition

The weekly diets (Fig. 3) were composed of 110–340 g of meat (including poultry), 70–190 g of eggs, 90–200 g of fish, 3100–3400 g of dairy products, 2000–2200 g of cereals, 120–190 g of legumes, 260–390 g of vegetable oil, 1400 g of potatoes, 2400 g domestically grown vegetables, roots and fruits (partly in the form of beverages), and 680 g of imported fruits, tea, and coffee. Currently, a large amount of cereals and legumes grown in the Nordic regions is fed to animals, e.g., approximately 60% of Swedish grain is used as animal feed. The decision to limit livestock production to available leftover

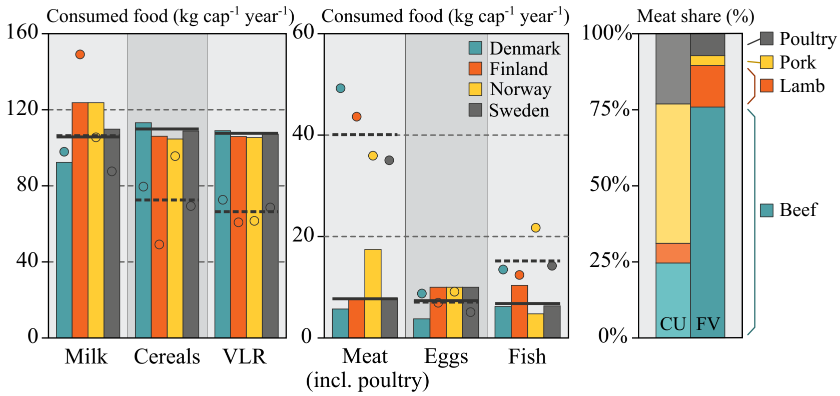

Fig. 3 (Left and center) Yearly per-capita consumption of milk products, cereals, vegetables, legumes and roots (VLR), meat (incl. poultry), eggs, and fish in the future food vision diets (bars) and in current diets (circles). Solid lines represent the aggregated Nordic case for the scenario and dotted lines current average consumption in the Nordic countries. (Right) Share of beef, lamb, pork and poultry meat in the current case (CU) and future vision (FV) of total meat consumption

streams had dramatic impacts on meat supply. Compared with current levels, meat consumption decreased on average 81%, to weekly per-capita consumption of 150 g. The decrease was largest for non-ruminant meat (− 97%), while for ruminant meat, the reduction was "only" 44%. The scenario diets ended up well below the 500 g of red meat a week recommended by the World Cancer Research Fund (WCRF 2007). The high share of ruminant meat compared with non-ruminant meat remaining in the diets was a consequence of both the "default livestock" approach and the choice to base cropping on organic practices. Ruminants are better utilizers of leftover streams, especially ley, which was cultivated on large areas in the future food vision (Fig. 4) due to its importance in organic cropping systems, thus feeding more ruminant animals.

To replace dietary energy, protein, and fat following reduced consumption of animal products, additional cereals, grain legumes, and vegetable oil had to be cultivated and incorporated into diets. These replacement foods contained on average less protein and fat per unit energy, which resulted in carbohydrates constituting 61–63% of dietary energy (E%) in the scenario diets, exceeding the Nordic nutrition recommendation of 45–60 E% but staying within the range recommended by the WHO of 55–75 E% (Amine et al. 2003). In our calculations, we did not include any processing of leguminous food prior to consumption, but processing could be performed to increase the protein and fat-to-energy ratio, addressing the high carbohydrate content in the scenario diets. The protein content (12–13 E%) and total fat content (25–26 E%) were both within the Nordic (10–20 E% protein and 25–40 E% fat) and WHO recommended range (10–15 E% protein and 15–30 E% fat). The scenario diets complied with recommendations on saturated fatty acids and dietary fiber, while current diets exceed the recommendation for saturated fat and provide insufficient amounts of fiber.

The scenario diets did not meet the Nordic nutrition recommendations for 6 of 20 micronutrients assessed. These were vitamins A and D, riboflavin, iodine, iron, and selenium. Of these, vitamin D, riboflavin, iron, and selenium (except in Finland) are also low in current diets. For folate, the scenario diets met the recommendations, while current diets are below recommendations. For both iodine and selenium (only in Finland), the recommendations are met in the current diets mainly through fortification, which is also a viable option for the food vision diets. For other nutrients such as vitamin A and iron, selection of foods within broader groups is important. For vitamin A, increased consumption of carrots and

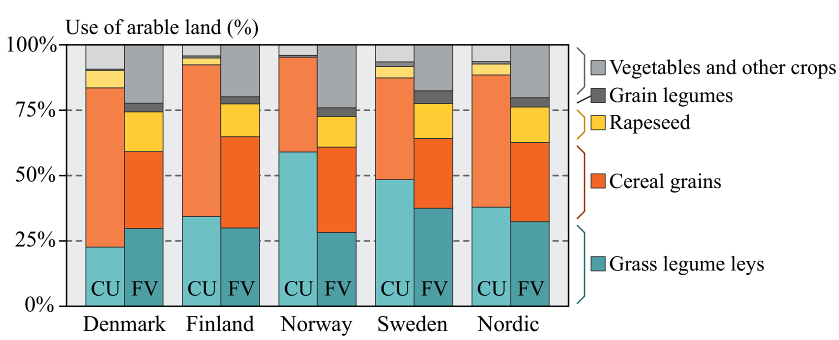

Fig. 4 Share of arable land used for (from bottom to top): grass legume leys, cereal grains, rapeseed, grain legumes, and vegetables and other crops, including horticultural crops, roots, and apples. The left bars show current (CU) land use according to national statistics and the right bars show land use in the future food vision (FV)

other vegetables rich in carotene is an option, while for iron increasing, the fraction of whole grain cereals could improve nutrition. Vitamin D is mainly found in oily fish and (due to fortification) in milk and some plant-based milk alternatives, but intake is still inadequate for a large part of the population (Nordic Council of Ministers 2014). In summary, the scenario diets were associated both with nutritional benefits and challenges that would need to be handled by, e.g., choice of products within broader food groups and fortification strategies for some critical nutrients.

3.3 Land use and climate impact

For the Nordic countries on aggregate, a total of 0.21 ha of agricultural land was needed to produce a per-capita diet and an additional 0.01 ha was needed outside the Nordic countries to produce the imported foods. Semi-natural pastures made up 11% of the total agricultural area, and the rest, 0.19 ha, was arable land. The global land availability per capita in 2030 based on currently available agricultural land would be 0.57 ha of agricultural land, of which 0.19 ha would be arable (FAO 2017). Thus, if global arable land were to be shared equally, the scenario diets would be just on this threshold, while the total use of agricultural land would be well below the global per-capita availability.

The choice in this study to rely on local food systems and produce most foods within the region meant that agriculture in the Nordic countries had to diversify substantially, which is also consistent with previous findings on regional food self-sufficiency (Pradhan et al. 2014). Compared with the current use of arable land in the Nordic countries, cereal cultivation had to be drastically reduced (− 46%) and cultivation of grain legumes (+ 242%), oilseed crops (+ 188%), fruit and vegetables (+ 258%), and potatoes (+ 134%) had to increase substantially.

A total of 34% of arable land in the future vision was used for livestock feed production and grazing, while 7% was used for bioenergy production and the rest to produce food for direct human consumption, of which 6% was used to grow supplementary plant-based foods (i.e., legume grains, cereals, and vegetable oil) to compensate for reduced consumption of animal products (Fig. 4).

In total, 60 PJ of biogas was produced to provide electricity and heating for production buildings and propellant for agricultural machinery. Thirty-five percent was supplied from harvested leys and the rest from manure and slaughter house and food waste. Apart from the biogas, straw was burned to produce an additional 9.3 PJ of heat and 2.6 PJ diesel was used by the fishing fleet. The climate impact from field to farm gate was estimated to be 0.48 tCO_2e per diet and year, comprising mainly methane emissions from enteric fermentation and nitrous oxide emissions from soils (Fig. 5). To our knowledge, no previous study has assessed the climate impact of diets currently consumed in the Nordic region, but two studies have

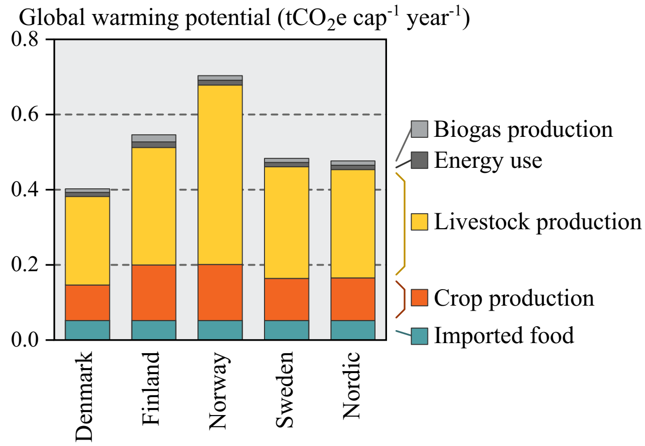

Fig. 5 Estimated climate impact per diet and year of the future food vision for the different case countries and the Nordic region. Emissions are divided between (from bottom to top): Emissions outside the region, related to imported food; emissions directly from crop production; emissions related to livestock production and manure management; emissions from combustion of fossil and biofuels; and emissions from biogas production and storage of biogas digestate

estimated that the Swedish and Finnish diet cause emissions of 1.8 and 2.8 tCO_2e, respectively, of which around 70% is attributable to agricultural activities (Röös et al. 2015; Virtanen et al. 2011). The climate impact can also be compared to emission pathways with a "likely" chance of keeping global temperatures below + 1.5 °C compared with pre-industrial levels, which require global anthropogenic GHG emissions to drop to around 27 $GtCO_2e$ $year^{-1}$ by 2030 (3.2 tCO_2e cap^{-1} $year^{-1}$), 6 GtCO2e $yr.^{-1}$ by 2050 (0.6 tCO_2e cap^{-1} $yr.^{-1}$) and reach zero or net negative emissions in the long term (Sanderson et al. 2016). The GHG emissions from the future Nordic diets corresponded to 11–15% of the 2030 per-capita emissions space and 58–78% of the 2050 emissions space. Considering that the food system currently accounts for some 29% of global emissions (Vermeulen et al. 2012), the scenarios can be considered in line with the near-term pathway (i.e., up until 2030), without increasing the food system's share of the emission space. However, later on in this century, greater reductions would be necessary, or other sectors would need to take more responsibility for greenhouse gas mitigation, allowing food systems to use a larger share of the available emission space in the future.

Changes in soil carbon stocks on arable land were modeled for the Swedish case and resulted in net emissions of 0.06 tCO_2e per diet and year compared with a situation in which current land use continues. The modeled soil carbon losses followed mainly from lower yields and reductions in ley cultivation. Adoption of organic farming practices has previously been associated with increased soil carbon stocks (Gattinger et al. 2012) while our results suggest the opposite. One explanation for this could be that it is already common to include grass and legume leys in crop rotations in Swedish agriculture, and thus the organic crop rotations assumed in this study did not involve increased cultivation of leys, while modeled yields were lower, resulting in a reduced carbon input compared with the current situation.

3.4 Key normative decisions and their impacts on results

The three most important normative choices that determined the outcome in terms of the number of people that could be fed, the food in diets, the land use, and the climate impact were (i) basing production on organic farming and agro-ecological principles, (ii) limiting livestock production to feeds based on leftover streams, and (iii) relying on local food systems. Producing all food in an organic system would most likely lead to lower per-hectare crop yields compared with conventional farming, but this was compensated for by reduced cultivation of feed grains in the future food vision, enabling a large food output. To account for reduced yields, we used data on observed yield gaps for different crop groups in field trials comparing organic and conventional practices. Observed organic yields were on average 20% (de Ponti et al. 2012) lower than conventional yields at field level. However, it is not certain that these yields would be achieved at the food system level, which would affect both the total food output and food composition in the future food vision.

In the future food vision, animals were an integral part of the farming system, utilizing the grass from leys and biomass from outfield areas to produce highly valued food (milk and meat) but inevitably also emitting GHGs. Another food future could have been to promote a completely plant-based diet. Vegan diets have been shown to have the lowest climate impact (Hallström et al. 2015), which would have decreased GHG emissions even further, but possibly slightly increased land use (Van Zanten et al. 2018). However, due to the agro-ecological approach chosen by the stakeholders, a totally plant-based vision was not seen as a viable alternative. Yet another approach could have been to model a more moderate reduction in meat consumption, referring to what might be considered a more "realistic" goal in terms of dietary change (e.g., a reduction in meat consumption of 50% following an international contraction and convergence strategy, as suggested by McMichael et al. (2007)) and a strong reduction in ruminants (to cut methane emissions) in favor of more efficient fish and poultry production. However, while such an approach would have been in line with the aim of the NGOs to reduce GHG emissions drastically, fish and poultry would not have been able to utilize biomass from the leys.

Another important decision that affected the results was feeding as many people as possible using agricultural land in the Nordic countries. An alternative could have been to divide the amount of produce by the projected Nordic population in 2030, which would have yielded diets with higher amounts of animal products, higher land use, and higher GHG emissions per capita. The decision to share the Nordic agricultural production over more people was taken by the NGOs based on the moral responsibility of the Nordic region to supply as much food as possible, as this region is one of few that will potentially experience more favorable growing conditions due to climate change.

The results also depend on the assumed decrease in food waste of 50% from current levels. If such a decrease could not be achieved, the number of people that could be fed in the future vision would decrease. It was decided to use ley mainly for animal feed and only to a limited extent for bioenergy production. Allocating more ley to bioenergy production would have led to fewer ruminants and diets with lower GHG emissions and also enable substitution of fossil fuels in other sectors, but would also lead to diets with even less animal products and with higher land requirements, thus feeding fewer from Nordic agriculture. Furthermore, bio-refinement, i.e., extracting macro- or micronutrients to produce human food directly, may become a viable option for many of the resources considered as leftovers here, thus bypassing the need for livestock. However, it was decided here that the future food vision diet should be based on foods currently consumed in the region.

4 Conclusions

This is the first paper to describe a process in which researchers in agronomy, animal science, nutrition, and systems analysis and stakeholders with a desire to promote more sustainable food consumption and production in the Nordic countries worked together in an iterative manner to sketch out, model, and evaluate a future food vision for Sweden, Norway, Denmark, and Finland. This future food vision, based on organic local food production and designed to avoid food-feed competition, involves a drastic reduction in meat consumption, greatly diversified agriculture, land use that can be considered "fair" from a global perspective, and a climate impact in line with emission pathways compatible with the Paris agreement. The study provides important insights into both the process of designing food futures with stakeholder engagement and the outcomes in terms of food production and environmental impacts of unavoidable normative decisions taken when designing the food vision. Implementation of such a vision requires strong support and collaboration on several societal levels, including changes in agricultural practices, food processing, policies, and consumer behavior, aspects that were not investigated here but are important areas for future research and investigation.

Funding This study was funded by the Department of Energy and Technology, Swedish University of Agricultural Sciences and the Nordic Council of Ministers.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Amine E, Baba N, Belhadj M, Deurenberg-Yap M, Djazayery A, Forrestre T, Galuska D, Herman S, James W, M'Buyamba Kabangu J (2003) Diet, nutrition and the prevention of chronic diseases. World Health Organ Tech Rep Ser 916

Andrén O, Kätterer T, Karlsson T (2004) ICBM regional model for estimations of dynamics of agricultural soil carbon pools. Nutr Cycl Agroecosyst 70:231–239. https://doi.org/10.1023/B:FRES.0000048471.59164.ff

Antman A, Brubæk S, Andersen BH, Lindqvist K, Markus-Johansson M, Sørensen J, Teerikangas J (2015) Nordic agriculture air and climate : baseline and system analysis report. Nordisk Ministerråd, Copenhagen. https://doi.org/10.6027/TN2015-570

Bajželj B, Richards KS, Allwood JM, Smith P, Dennis JS, Curmi E, Gilligan CA (2014) Importance of food-demand management for climate mitigation. Nat Clim Chang 4:924–929. https://doi.org/10.1038/nclimate2353

Burney JA, Davis SJ, Lobell DB (2010) Greenhouse gas mitigation by agricultural intensification. Proc Natl Acad Sci 107:12052–12057. https://doi.org/10.1073/pnas.0914216107

Connor DJ (2008) Organic agriculture cannot feed the world. Field Crop Res 106:187–190. https://doi.org/10.1016/j.fcr.2007.11.010

de Ponti T, Rijk B, van Ittersum MK (2012) The crop yield gap between organic and conventional agriculture. Agric Syst 108:1–9. https://doi.org/10.1016/j.agsy.2011.12.004

Enghardt-Barbieri H, Lindvall C (2003) De svenska näringsrekomendationerna översatta till livsmedel [The Swedish nutrition recommendations translated into food items] Livsmedelsverkets rapport. 1/2003

Eurostat (2016) Eurostat regional yearbook. Agricultural census 2010. https://ec.europa.eu/eurostat/statisticsexplained/index.php/Agricultural_census_2010 Accessed 02 Oct 2017

FAO (2017) FAOSTAT database. http://www.fao.org/faostat/en/#data

Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC, Balzer C, Bennett EM, Carpenter SR, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Siebert S, Tilman D, Zaks DPM (2011) Solutions for a cultivated planet. Nature 478:337–342. https://doi.org/10.1038/nature10452

Garnett T (2014) Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for life cycle assessment? J Clean Prod 73:10–18. https://doi.org/10.1016/j.jclepro.2013.07.045

Gattinger A, Muller A, Haeni M, Skinner C, Fliessbach A, Buchmann N, Mäder P, Stolze M, Smith P, Scialabba NE-H, Niggli U (2012) Enhanced top soil carbon stocks under organic farming. Proc Natl Acad Sci 109:18226–18231. https://doi.org/10.1073/pnas.1209429109

Hallström E, Carlsson-Kanyama A, Börjesson P (2015) Environmental impact of dietary change: a systematic review. J Clean Prod 91:1–11. https://doi.org/10.1016/j.jclepro.2014.12.008

IPCC (2013) Climate change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781107415324

Karlsson J, Röös E, Sjunnestrand T, Pira K, Larsson M, Andersen BH, Sørensen J, Veistola T, Rantakokko J, Manninen S, Brubæk S (2017) Future Nordic diets : exploring ways for sustainably feeding the Nordics. Nordisk Ministerråd, Copenhagen. https://doi.org/10.6027/TN2017-566

Mauser W, Klepper G, Rice M, Schmalzbauer BS, Hackmann H, Leemans R, Moore H (2013) Transdisciplinary global change research: the co-creation of knowledge for sustainability. Curr Opin Environ Sustain 5:420–431. https://doi.org/10.1016/j.cosust.2013.07.001

McMichael AJ, Powles JW, Butler CD, Uauy R (2007) Food, livestock production, energy, climate change, and health. Lancet 370:1253–1263. https://doi.org/10.1016/S0140-6736(07)61256-2

Mottet A, de Haan C, Falcucci A, Tempio G, Opio C, Gerber P (2017) Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. Glob Food Sec 14:1–8. https://doi.org/10.1016/j.gfs.2017.01.001

Muller A, Ferré M, Engel S, Gattinger A, Holzkämper A, Huber R, Müller M, Six J (2017) Can soil-less crop production be a sustainable option for soil conservation and future agriculture? Land Use Policy 69:102–105. https://doi.org/10.1016/j.landusepol.2017.09.014

Nordic Council of Ministers (2014) Nordic nutrition recommendations 2012 : integrating nutrition and physical activity, 5th edn. Nordisk Ministerråd, Copenhagen. https://doi.org/10.6027/Nord2014-002

Pradhan P, Ludeke MK, Reusser DE, Kropp JP (2014) Food self-sufficiency across scales: how local can we go? Environ Sci Technol 48:9463–9470. https://doi.org/10.1021/es5005939

Reganold JP, Wachter JM (2016) Organic agriculture in the twenty-first century. Nat Plants 2:15221. https://doi.org/10.1038/nplants.2015.221

Röös E, Karlsson H, Witthöft C, Sundberg C (2015) Evaluating the sustainability of diets–combining environmental and nutritional aspects. Environ Sci Pol 47:157–166. https://doi.org/10.1016/j.envsci.2014.12.001

Röös E, Patel M, Spångberg J, Carlsson G, Rydhmer L (2016) Limiting livestock production to pasture and by-products in a search for sustainable diets. Food Policy 58:1–13. https://doi.org/10.1016/j.foodpol.2015.10.008

Sanderson BM, O'Neill BC, Tebaldi C (2016) What would it take to achieve the Paris temperature targets? Geophys Res Lett 43:7133–7142. https://doi.org/10.1002/2016GL069563

Smith P (2013) Delivering food security without increasing pressure on land. Glob Food Sec 2:18–23. https://doi.org/10.1016/j.gfs.2012.11.008

United Nations, Department of Economic and Social Affairs, Population Division (2017) World Population Prospects: The 2017 https://esa.un.org/unpd/wpp/Download/Standard/Population/ Accessed 21 Nov 2017

Van Zanten HHE, Herrero M, Van Hal O, Röös E, Muller A, Garnett T, Gerber PJ, Schader C, De Boer IJM (2018) Defining a land boundary for sustainable livestock consumption. Glob Chang Biol 24:4185–4194. https://doi.org/10.1111/gcb.14321

Vermeulen SJ, Campbell BM, Ingram JSI (2012) Climate change and food systems. Annu Rev Environ Resour 37:195–222. https://doi.org/10.1146/annurev-environ-020411-130608

Virtanen Y, Kurppa S, Saarinen M, Katajajuuri J-M, Usva K, Mäenpää I, Mäkelä J, Grönroos J, Nissinen A (2011) Carbon footprint of food—approaches from national input–output statistics and a LCA of a food portion. J Clean Prod 19:1849–1856. https://doi.org/10.1016/j.jclepro.2011.07.001

Volkery A, Ribeiro T, Henrichs T, Hoogeveen Y (2008) Your vision or my model? Lessons from participatory land use scenario development on a European scale. Syst Pract Action Res 21:459–477. https://doi.org/10.1007/s11213-008-9104-x

Wezel A, Bellon S, Doré T, Francis C, Vallod D, David C (2009) Agroecology as a science, a movement and a practice. A review. Agron Sustain Dev 29:503–515. https://doi.org/10.1051/agro/2009004

World Cancer Research Fund / American Institute for Cancer Research (2007) Food, nutrition, physical activity, and the prevention of cancer: a global perspective. AICR, Washington, DC