MISTRA FOOD FUTURES

Introducing environmental considerations to the Nordic Nutrition Recommendations 2023

– Impacts on production and the environment

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Introducing environmental considerations to the Nordic Nutrition Recommendations 2023 – Impacts on production and the environment
Införandet av miljöhänsyn i de nordiska näringsrekommendationerna 2023 – Påverkan på produktion och miljö

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The overarching vision of the programme Mistra Food Futures is to create a science-based platform to enable transformation of the Swedish food system into one that is sustainable (in all three dimensions: environmental, economic and social), resilient and delivers healthy diets. By taking a holistic perspective and addressing issues related to agriculture and food production, as well as processing, consumption and retail, Mistra Food Futures aims to play a key role in initiating an evidence based sustainability (including environmental, economic and social dimensions) and resilience transformation of the Swedish food system.

Mistra Food Futures is a transdisciplinary consortium where key scientific perspectives are combined and integrated, and where the scientific process is developed in close collaboration with non-academic partners from all parts of the food system. Core consortium partners are Swedish University of Agricultural Sciences (SLU), Stockholm Resilience Centre at Stockholm University and RISE Research Institutes of Sweden.

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1. Introduction

Global food systems cause serious environmental impacts, including deforestation, biodiversity loss, greenhouse gas emissions, air pollution, and water pollution while not delivering adequate nutrition (Willett et al., 2019). In Sweden, nutritionally unbalanced diets are one of the main factors contributing to negative health outcomes (GBD Risk Factors Collaborators, 2020). Swedish food consumption has also been shown to be environmentally unsustainable, trespassing five of six food-related planetary boundaries (Moberg et al., 2020). Negative environmental impacts are caused in Sweden from domestic food production and abroad from the imports of foods and inputs (e.g. feed) (SEPA, 2022). Swedish agriculture causes 14% of Swedish territorial greenhouse gas emissions (SEPA, 2023), 90% territorial ammonia emissions, mainly from animal husbandry and manure handling, and is one of the main contributors to the nutrient input to the Baltic Sea and other waterways (McCrackin et al., 2018). Agricultural land use is a driver for biodiversity loss on a global scale (Benton et al., 2021). However, some biodiversity is dependent on certain types of agricultural landscapes, and conservation of this biodiversity requires the continued use of land for agricultural production, most importantly the use of semi-natural pastures. These pastures have been managed for thousands of years by low intensity mowing and grazing, which has shaped the unique biodiversity. However, these pastures have declined following agricultural intensification and specialisation. Since the mid 20th century 17% of open land uses (corresponding mainly to semi-natural grasslands) have been lost due mainly to agricultural land use abandonment and afforestation, with negative implications for grassland specialist flora (Auffret et al., 2018). Preserving these pastures is crucial for biodiversity conservation in Sweden (Eriksson, 2022).

Promoting sustainable agricultural practices, reducing food waste, and encouraging a shift towards more plant-based diets are integral components of addressing the environmental impacts of food systems in both Sweden and globally (Clark et al., 2020; Röös et al., 2017; Willett et al., 2019). Such changes are essential for building a more resilient and environmentally sustainable food system to meet the needs of a growing global population (Ingram, 2011). While production side improvements (e.g. increased efficiency in the use of inputs and technological advancements) and consumption side changes (e.g. changes to diets and reduction in food waste) are both needed, this report focuses on the potential influence of dietary guidelines on environmental targets (Clark et al., 2020).

Changing dietary patterns is a complex task influenced by various factors, such as established habits that are deeply ingrained over time becoming automatic behaviours that demand conscious effort to break (SAPEA, 2023). Cultural and social influences, emotional attachments to food, and the marketing of less healthy options contribute to the resistance to change. The availability and accessibility of certain foods, taste preferences, and a lack of education about nutrition and food preparation also play important roles (Lazaric et al., 2020). Additionally, stress, busy lifestyles, and societal pressure can impact food choices. Due to the urgency in combating negative health and environmental outcomes from food, there are many calls to implement policies to steering consumption in more healthy and environmentally sustainable direction (FAO, 2023; Martini et al., 2021; SAPEA, 2023).

More than 100 countries have established Food-Based Dietary Guidelines (FBDGs) that offer culturally adapted advice on composing healthy diets (FAO, 2023). These guidelines rely on estimated requirements or observed adequate nutrient intakes at population level. Sometimes, associations between food intakes and the risk of chronic diseases are considered. Each country translates these recommendations into specific food intake suggestions, based on local considerations. Common recommendations include the generous or increased consumption of wholegrain products, vegetables, and fruits, along with the reduction or limited intake of foods high in saturated fat, sugars, and/or salt (FAO, 2023; Martini et al., 2021). Historically, FBDG were limited to the intake of a healthy diet, but an increasing number of countries now include also environmental concerns when developing the FBDG (Wood et al., 2023). Sweden was a forerunner in this area by introducing environmental aspects in its FBDG in 2015 (Livsmedelsverkets, 2015). Since then, many countries have followed, including Brazil, the Netherlands, and Spain.

Despite the intention of helping consumers make informed choices, there is limited research on the effectiveness of FBDGs in achieving this goal. Existing studies often focus on consumer awareness rather than assessing whether individuals incorporate these guidelines into their actual food choices (Meijer et al., 2023). It is, however, clear from historic developments that issuing FBDG in isolation will not impact consumption patterns substantially (SAPEA, 2023). This is why a range of other policy instruments for steering consumption is being discussed and studied, including different types of informative policies, changes to food environment and financial policies such as taxes and subsidies (SAPEA, 2023). Nonetheless, FBDG remain crucial as they serve as educational tools and enhance awareness and understanding of healthy and sustainable dietary patterns. These guidelines also play a vital role in public health messaging, policy development, and fostering cultural shifts towards healthier eating.

In June 2023, the Nordic Council of Ministers launched the sixth edition of the Nordic Nutrient Recommendations (NNR2023). The NNR2023 are dietary guidelines developed in a collaborative effort by Nordic and Baltic countries. Developing the NNR2023 involved a scientific review of evidence in nutrition, with expert committees synthesizing this information into practical recommendations (Christensen et al., 2020). Public consultation ensures that the guidelines reflect societal values. For the first time, the NNR2023 included environmental considerations alongside nutrition and health. The NNR2023 are then intended to be used by the Nordic and Baltic countries to formulate national FBDG. The Swedish Food Agency is currently in this process with the aim to issue updated FBDG early 2025.

In the public consultation process, considerable feedback was received including concerns about how the implementations of the NNR2023—especially the recommendation to limit red meat consumption—in the national guidelines could negatively impact food producers and the preservation of semi-natural pastures. Although much of this critique builds on misunderstandings on the role of FBDG and their potential to affect production (see Wood et al., 2024 for a detailed analysis of the main critiques), there are also valid concerns about how a shift in consumption patterns reflected in the NNR2023 would impact Swedish food production and semi-natural pastures. To be acceptable, a transition to more sustainable food systems must be designed in a way that it is perceived as fair. Vulnerable actors that might be negatively affected must be identified, acknowledged, and handled.

The aim of this report is to investigate how potential, and reasonably probable, consumption changes following the implementation of the NNR2023 in the national Swedish FBDG could influence domestic food production and environmental outcomes. The environmental outcomes that we study include greenhouse gas emissions, ammonia emissions, and the area of semi-natural pastures grazed (which is used as a biodiversity indicator). Additionally, we discuss implications for animal welfare. We do this by comparing the NNR2023 without environmental considerations (only health-based) to the NNR2023 that additionally considers environmental factors.

2. Overview of the analysis performed

The NNR2023 made a shift from solely focusing on healthy diets to integrating healthy diets with environmental sustainability. In this report, we analyse how including the environmental considerations of the NNR2023 could influence agricultural production in Sweden and environmental outcomes in Sweden and abroad. We do this by exploring how the NNR2023 influences consumption and how such consumption changes could affect Swedish agricultural production, which will have impact on environmental outcomes. We compare how the NNR2023 with and without environmental considerations could influence production and environmental outcomes. This allows us to study the incremental effects of including environmental considerations in the NNR2023 compared to the NNR2023 that does not include environmental considerations.

We address the following research questions (RQ):

1. How could including environmental considerations in the NNR2023 potentially influence consumption of different food groups in Sweden?
2. What are the effects of these changes in consumption on Swedish agricultural production?
3. What are the effects of these changes in production and consumption on the environmental outcomes in Sweden and abroad?

2.1. Research question 1

RQ1 investigates how including the environmental considerations in the NNR2023 in the coming national dietary advice could influence consumption. In section 3, we present an overview of how the NNR2023 including environmental considerations differs from the recommendations relying solely on health considerations (NNR without environmental considerations). Based on scientific literature, we summarise what is known on the effectiveness of FBDG and other informative policy instruments in changing consumption. We use this information to reason around how including environmental considerations in FBDG might influence consumption and production, and show historical developments in consumption and production. The literature on the effectiveness of FBDG in changing consumption underlines that solely relying on informative policy instruments is unlikely to result in substantial changes in consumption but may change consumer preferences (see e.g. SAPEA, 2023).

In section 4, we analyse consumer preferences. These consumer preferences are analysed in an economic model (i.e. a demand system) that presents various elasticities. Especially cross-price elasticities are relevant for this report. Cross-price elasticities show whether consumers consider products as substitutes (i.e. positive cross-price elasticities) or not (i.e. negative cross-price elasticities), i.e. they indicate what products a consumer is likely to exchange for another. The demand system is based on the Almost Ideal Demand System (AIDS; Deaton & Muellbauer (1980)). This model analyses consumer behaviour in a hierarchical system covering four levels. The highest level is the most generic and considers major food groups (e.g. fruits and vegetables or protein rich products) while the lowest level is the most detailed level and considers products groups within a commodity (e.g. beef can be specified as Swedish, or organic beef). The demand model is tailored to the Swedish food system and uses data from a major Swedish retailer to investigate how price changes affect consumption. The model shows how likely or unlikely consumers substitute products within food groups (e.g. substitute imported beef by domestically produced beef) and across food groups (e.g. substitute red meat by poultry) and can be used as a basis for a discussion on how changes in consumer choices may be influenced by FBDG.

2.2. Research question 2

RQ2 investigates how consumption changes may affect Swedish production. Predicting how a change in consumption (i.e. demand) would influence producer behaviour is complex. General equilibrium models (GEMs)—e.g. the Common Agricultural Policy Regional Impact Analysis (CAPRI) model—can be used to analyse such questions. However, it was not possible to run such models within the scope of this project given time limitations. Instead, we analyse twenty-four scenarios with varying impacts of the NNR2023 on consumption to show a range of possible consequences on the domestic production and the environment. We run these scenarios with and without the environmental considerations in the NNR2023. These scenarios address “what-if” questions and do not necessarily represent what will happen in practice as a consequence of introducing environmental considerations in the NNR2023.

The scenarios are introduced in section 5 and focus on substituting red meat consumption by either poultry or plant-based alternatives. We consider small or large impacts of the NNR2023, where a small or large impact is defined as that 5% or 20%, respectively, of the population following the recommendations. We use a biophysical mass flow model of the Swedish agricultural system—CIBUSmod (Karlsson et al., forthcoming)—to analyse these scenarios. This model quantifies how changes in the demanded amount of food influence agricultural production conditional on given degrees of imports and exports. The model optimises outcomes conditional on an inputted demand but does not predict changes in demand from different policies or price changes. It also estimates environmental outcomes following such changes (see section 6). CIBUSmod analyses the Swedish food system at local spatial scale as it considers impacts on production and environmental outcomes at 106 harvest areas (*skördeområden*).

2.3. Research question 3

RQ3 investigates how changes in Swedish consumption and agricultural production affect environmental outcomes within Sweden and abroad. CIBUSmod considers the following environmental outcomes: (i) greenhouse gas emissions, (ii) ammonia emissions, and (iii) the area of grazed semi-natural pastures. Other environmental indicators not linked to the aim of this report, such as, water usage or pesticide usage are not considered. A limitation of CIBUSmod is that it does not consider changes in environmental impacts happening outside Sweden due to changes in feed or food imports. To overcome this limitation, we complement our analysis with a second modelling approach that uses static life cycle assessment (LCA) data on carbon footprints (Moberg et al., 2020). This modelling approach investigates how changes in red meat consumption affect climate impacts and has system boundaries beyond the Swedish agricultural system. It considers the whole (international) supply chain from cradle to Swedish retail, capturing climate impacts of both imported and domestically produced food.

3. Background

This section provides a background to the report. It introduces the NNR2023 in section 3.1 and discusses how informative policy instruments, such as FBDG, shape consumer behaviour in section 3.2. Finally, section 3.3 provides a background on how Swedish consumption, production, and market shares have developed over time

3.1. Nordic Nutrition Recommendations 2023

Table 1 describes some of the food groups that are considered in the NNR2023 and compares the NNR2023 only considering health aspects to the NNR2023 including environmental considerations. The environmental recommendations outlined in the NNR2023 are qualitative, providing desired changes, such as reduced dairy consumption for environmental considerations or specifying preferred products within a category, like recommending whole grain cereals other than rice. An implication of integrating the environmental aspects into the NNR2023 is recommendations towards less animal-based and more plant-based diets, as these diets generally have lower environmental impacts. For instance, the health based rationale of the NNR2023 recommends that weekly red meat consumption should not exceed 350 grams/week while when environmental considerations are also taken into account, the recommendation is to consume significantly lower amounts than 350 grams/week.

Table 1 Overview of the recommended amounts for selected food groups according to the NNR2023 and the NNR2023 including environmental considerations. Source: Blomhoff et al. (2023).

Food group	NNR2023 health rationale	NNR2023 including environmental considerations
Dairy and milk products	350-500 ml/day of low-fat milk and dairy products.	Dairy has a high environmental impact. No changes in the recommended amount. However, if consumption is lower than 350 grams/day, dairy can be replaced by plant-based or other foods.
Eggs	A moderate amount of eggs may be part of a healthy diet.	A moderate amount of eggs may be part of a healthy and sustainable diet.
Fats and oils	25 g/day of vegetable oils. Vegetable oils rich in unsaturated fatty acids and margarines produced from these products are preferred over butter and butter-mixes, hard margarines, and tropical oils (palm and coconut oil).	Limit animal-based fats (e.g. butter) and palm oil. No adjustment to amount of oil.
Fish	300-450 grams/week of which at least 200 grams/week fatty fish.	The environmental impact of fish differs across species. Consume fish with low environmental impact and from sustainable stocks.
Legumes and pulses	Legumes and pulses should be a significant part of the diet.	Legumes and pulses have low environmental impacts.
Nuts and seeds	20-30 grams/day.	Nuts and seeds have low environmental impact. Water use and biodiversity loss may be environmental issues related to some nuts. No adjustment to recommended amount.
Potatoes	Potatoes should be a significant part of the diet.	Potatoes have low environmental impacts. Consider replacing some cereals (e.g. rice) by potatoes.
Red meat	Low and not exceeding 350 grams/week.	Red meat has a high environmental impact. Consumption should be significantly lower than 350 grams/week and should not be compensated by increasing poultry consumption.
Vegetables, fruits and berries	A variety of vegetables, fruits, and berries of 500-800 grams/day.	Consume vegetables, fruits, and berries with low environmental impact, preferably locally grown and easy to store. No adjustment to recommended amount.
White meat (poultry)	Neutral for health. Processed white meat should be minimised.	To minimise environmental impact, do not increase white meat consumption. May be lower than current levels.
Whole grains	At least 90 grams/day of whole grains.	Consume low environmental impact grains. No adjustment to recommended amount. Limit rice consumption.

3.2. Changing consumer behaviour towards more sustainable and healthy diets

The importance of incorporating environmental sustainability aspects into FBDG has gained attention on a global scale (FAO, 2023; Martini et al., 2021). Although the NNR2023 points out a direction of change, the guidelines themselves are unlikely to result in major changes in consumption patterns. For this to happen, a set of consumption-based policy interventions (e.g. taxes/subsidies, information and changes to food environments) are needed (Röös et al., 2018; SAPEA, 2023). These policies must be matched with other policies, including those on the production side to handle potential trade-offs that might come from the needed consumption changes. A coherent and comprehensive food strategy is needed to design such a policy package. The NNR and following national FBDG are only a piece of the puzzle of such a food strategy.

There is limited research on the effectiveness of FBDG in influencing actual consumption. For instance, a recent literature review by Ran et al. (forthcoming) on policy interventions for Swedish healthy and sustainable diets found no studies on FBDG, leaving the influence of FBDG on consumption largely unexplored. Instead of studying impacts on consumption, FBDG have been studied in the context of consumer awareness, understanding, and decision-making. Brown et al. (2011) concluded that FBDG mostly influence consumer awareness and understanding. Additionally, Meijer et al. (2023) discussed how consumers' exposure to information (e.g. FBDG) may influence their decision-making processes by shaping their preferences. Other studies highlighted the importance of habits (Scholderer & Trondsen, 2008), norms and traditions (Vermeir & Verbeke, 2008) in shaping consumer behaviour towards more sustainable diets and showed how FBDG may shape these.

One of the few studies investigating the effectiveness of FBDG in changing consumer behaviour has been conducted by Mancino et al. (2008). The authors demonstrated how the USA's whole grains FBDGs, combined with policy instruments targeting producers and consumers, ultimately increased consumption of whole grains. Processors and retailers anticipated the FBDG and met them by launching new products or rebranded products with labels that these products contain whole grains. The increased availability of whole grain products resulted in more media attention. Increasing consumer awareness of whole grain products and ultimately changing consumer preferences resulted in increased whole grain consumption. This example illustrates how FBDG can play a role in shaping consumer preferences by leveraging joint efforts with industry and media as a result of combined policy instruments.

3.3. Developments in Swedish consumption, production, and market shares

This section discusses Swedish market shares for various product groups and relates these market shares to changes in production and consumption. Market shares are the share of Swedish production (in tonnes) relative to total consumption—which is defined by Jordbruksverket (2023d) as the Swedish production (including what is slaughtered and home consumption) + import – export. A market share of 100% or higher implies self-sufficiency, meaning that everything that is being consumed in Sweden can be produced domestically. The market share exceeds 100% if exports are larger than imports. This implies that domestic production exceeds consumption. Market shares lower than 100% reflect a lower level of self-sufficiency and imply that some of the recommended consumption reduction in the NNR2023 could theoretically be obtained by reducing imports without affecting Swedish production. Fluctuating market shares do not provide any information about level changes in production, consumption, import or exports, as they are expressed as a percentage. For red meat and poultry, we present how the market shares, consumption, and production have developed over time. We focus on red meat and poultry, as these products will be analysed more detailed in section 5. These trends help to create a better understanding of how Swedish consumption, production, and market shares have developed over time, providing a context for potential changes in consumption and the likelihood of significant changes occurring

Red meat and poultry

Figure 1 shows how the Swedish market share of red meat and poultry has developed since 1995. The presented market share for red meat is a weighted average of beef, pork, sheep, game, and horse meat in tonnes. The market shares of sheep, game, and horse meat are omitted from Figure 1 due to their limited consumption. Swedish market shares of red meat and poultry have decreased since 1995 until 2013. Since 2013, market shares generally slightly increased. Swedish market shares for red meat and poultry have decreased to 56% for beef, 82% for pork, and 73% for poultry in 2022. The weighted market share of red meat was 70% 2022.

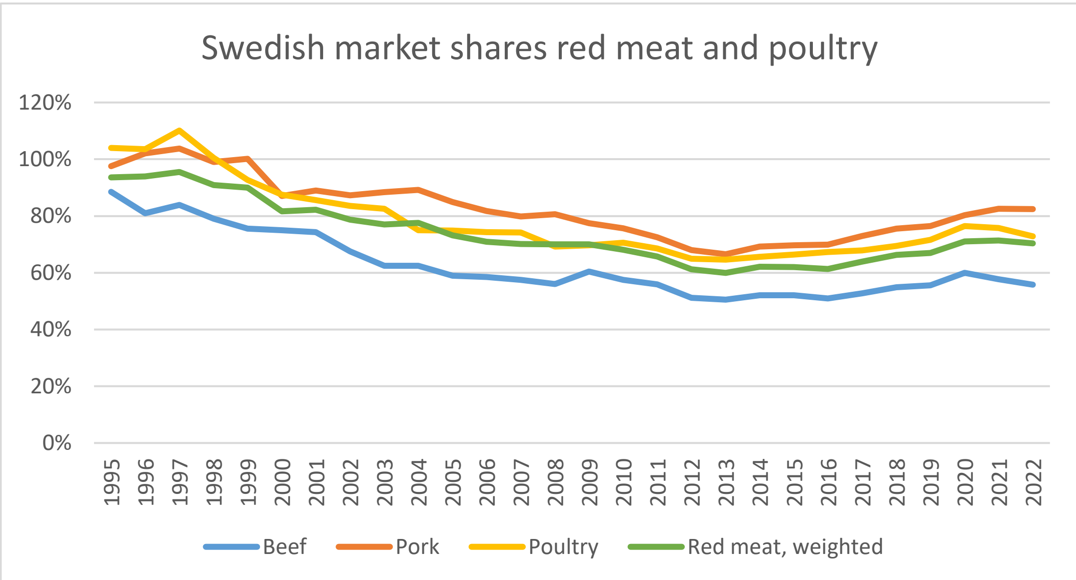

Figure 1 Developments in Swedish market shares of red meat and poultry over the period 1995-2022. Source: Jordbruksverket (2023d).

The decrease in market shares can be explained by the availability of cheaper EU meat, leading to an increase in meat consumption almost fully covered by imported meat. Decreasing market shares do not necessarily imply that Swedish production of red meat and poultry has decreased (Figure 2 and 3). From 1995-2022, pork production has decreased while beef production has remained relatively stable. Poultry production more than doubled (Jordbruksverket, 2023e). After a long period of increased consumption of red meat in Sweden, peaking between 2010 and 2016, consumption of red meat in Sweden has decreased with almost 9% until 2022 (Jordbruksverket, 2024). Poultry consumption has increased since 1995. The Swedish Board of Agriculture points to increased awareness of the environmental impacts of meat, heath aspects, trends, animal ethics, availability and economic factors as possible reasons to why red meat consumption decreased (Jordbruksverket, 2023e). During the same period, imports have decreased and the meat that Swedes eat today is to a larger extent produced domestically compared to 2016.

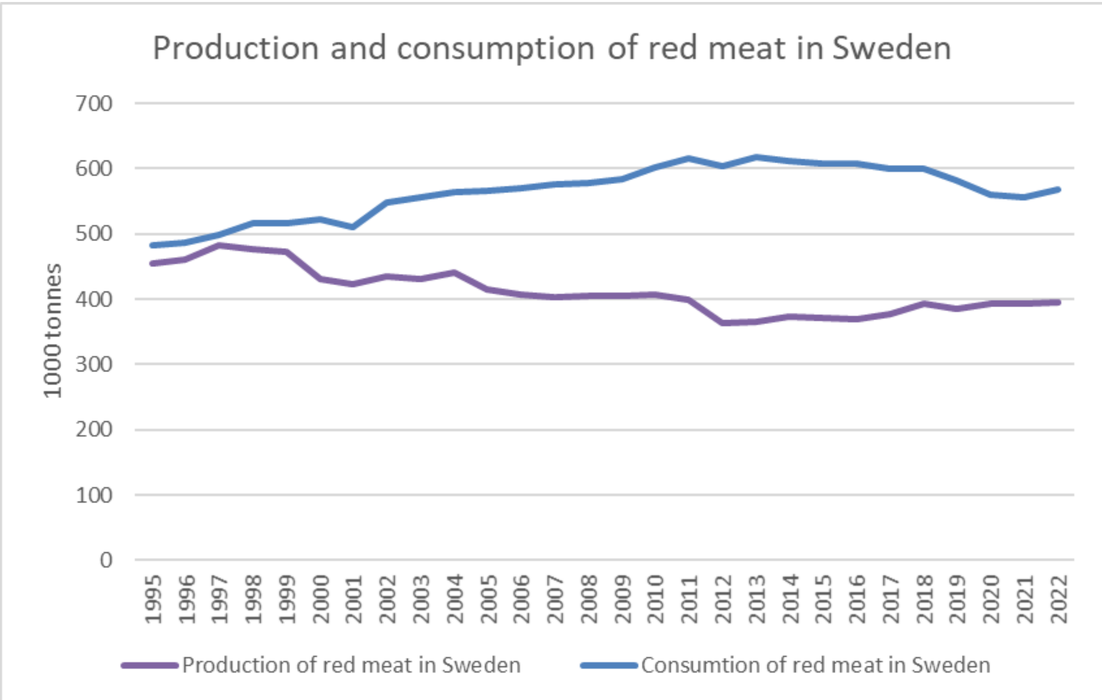

Figure 2 Production and consumption of red meat in 1000 tonnes in Sweden from 1995-2022. Source (Jordbruksverket, 2023b).

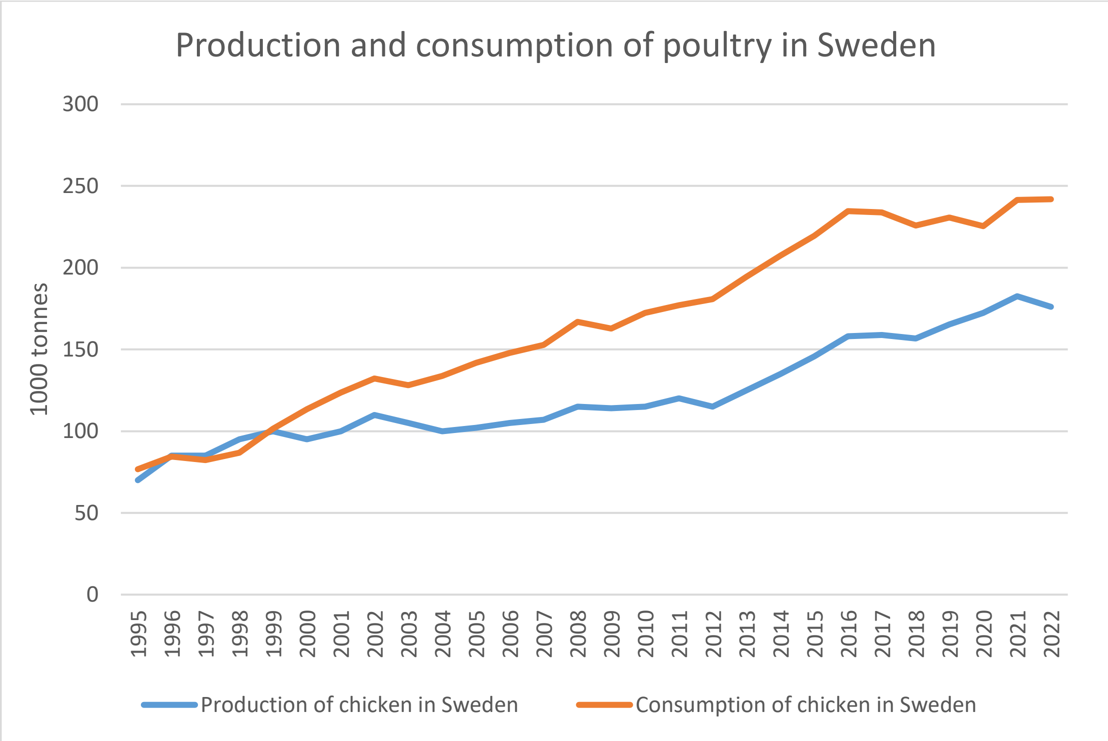

Figure 3 Production and consumption of poultry in 1000 tonnes in Sweden from 1995-2022 (Jordbruketisiffror, 2019; Jordbruksverket, 2023b).

Other food groups

Table 2 presents the Swedish market shares for several products. The Swedish market share of root vegetables (e.g. potatoes, carrots, onions) are relatively high, while tomatoes and cucumbers are more often imported. There are heterogeneous market shares in fat and oils, ranging from 62% for butter, 50% for rapeseed oil over to 0% for olive oil. The Swedish market share for fruits is relatively low, implying that there is a high percentage of imported fruits. Relatively high market shares occur for apples (28%) and strawberries (65%).

Table 2 Swedish market shares for selected products. Source: Jordbruksverket (2023d).

Product	Sub-product	Market share Swedish production	Product	Market share Swedish production
Grains [1]		136%	*Fruits*	
	Wheat	145%	Apple	28%
	Rye	120%	Banana	0%
	Barley	124%	Pear	5%[3]
	Oats	150%	Lemon	0%
			Strawberry	65%
Rice		0%		
			Dairy and eggs	
Potato		91%	Milk	102%
Sugar beet		100%	Eggs	101%
			Cheese	39%
Vegetables			Cream	84%
Tomato		17%		
Cucumber		45%	*Legumes*	
Iceberg lettuce		39%[3]	Peas (dry)	95% [3]
Carrot		96%	Broad beans	99% [3,4]
Onion		91%	Common bean	0%[3,5]
Cabbage		37%[3]		
			Meat	
Oils and fat			Beef	56%
Olive oil		0%	Pork	82%
Rapeseed and rapeseed oil[2]		50%	Poultry	73%
Butter		62%	Lamb	28%

[1] Sweden is a net-exporter of cereals, however cereals are also imported, such as durum wheat for pasta production. [2] Including imports for biofuels. [3] Schwarzmueller and Kastner (2022). [4] Mainly for feed. [5] There is a growing production of common beans in Sweden (Från Sverige, 2022), however this did not show in the 2013 data in Schwarzmueller and Kastner (2022).

4. Economic model on consumer behaviour

4.1. Understanding consumer substitution choices

The NNR2023 including environmental considerations states that the consumption of red meat should be reduced at a high degree, and that the reduction should favour plant-based alternatives rather than poultry. Whether or not it is likely that consumers make such a shift, can be discussed using the results of a demand system. Demand systems build on the assumption that the choices consumers make are utility maximizing, combining both relative prices and consumer preferences in a final purchasing situation. The NNR2023 may affect consumer preferences, which can be analysed using a demand system. As such, the demand system can be used to analyse informative policy instruments like the NNR2023.

The results from the demand system are presented as elasticities. The cross-price elasticities are of main relevance to this study. Although the magnitude of cross-price elasticities quantifies changes in consumption of one good when prices of other goods change, the sign of the elasticity tells us how the consumer view goods in relation to each other. This implies that these elasticities show the direction of consumption regardless of what type of policy is introduced, although it might be reasonable that the shifts are smaller from introducing information-based policy than from price-based policies (Faccioli et al., 2022). If new information becomes available, and the consumer decides to reduce consumption of red meat, the sign of the cross-price elasticities tells us what the consumer is likely to buy instead of red meat. We thus use the demand system results to discuss what consumption substitutions are likely to happen if the NNR2023 influences consumers. The model cannot predict the magnitude of change due to recommendations, but as information about the climate and environmental impacts of red meat is not new, and due to the general effects of information, it seems likely to assume that the effect on consumption is limited (see section 3.2).

We analyse the results from a newly constructed demand system estimated by the use of the Almost Ideal Demand System model (AIDS model by Deaton & Muellbauer, 1980). Originally, the demand system was constructed for the project Economic policy instruments to reduce greenhouse gas emissions from the Swedish food sector, funded by Formas. The system is based on sales data from a major Swedish retailer during 2020 and 2021.

Cross-price elasticities are the main indicator in our analysis, and can take positive or negative values. Positive values indicate that consumers consider goods to be substitutes. Negative values indicate that consumers do not consider products as possible substitutes (Varian, 2014) but rather that consumers i) keep both goods, or groups of foods in their diet, or ii) reallocate money from one group to keep more of the other good if e.g. prices increase. The demand system consists of four hierarchical levels (see Figure 4). It assesses how consumers consider changing (i) between major food groups (e.g. protein rich products and grain products), (ii) within food groups (e.g. meat and seafood), (iii) within one group, (e.g. from beef to poultry), and (iv) between different types of one product (e.g. between Swedish and imported beef).

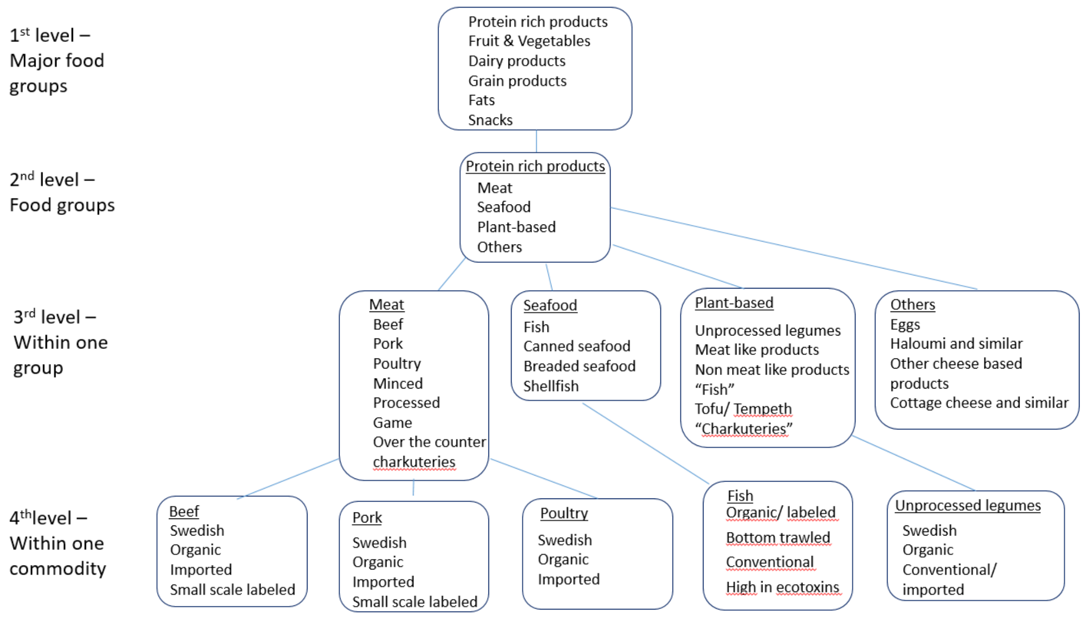

Figure 4 One branch of the whole demand system, presenting how the relationship between protein rich products is modelled. On the 1st level, the relationship between major food groups is assessed. On the 2nd level in the figure, we model the relationship between different groups of protein rich foods. On the 3rd level, we model relationships within a food group go into the groups included in the 2nd level and separate between (e.g. different types of meat). On the 4th level, we model different characteristics of individual commodities (as e.g. organic/ sustainability labelled or Swedish produced). Similar branches are available for all six major food groups on the 1st level, but are not presented here for the sake of simplicity.

Each box in Figure 4 is its own unit of analysis. Groups are on the 1st level initially defined based on similar usage for consumers and follows the NNR. We include protein products, fruit and vegetables, grain products, dairy products and fats. We have also included discretionary foods (e.g. candy, ice cream, or crisps) in our model, as this is a food group consumers spend a lot of money. On the 2nd level we are categorizing products on a more detailed level. It answer the following question: Will the consumers choose meat, seafood, plant based or some other types of protein for their meals? This type of division follows the literature on demand systems, where one focus has been on making detailed analyses on meat and meat consumption (Edgerton, 1997; Säll & Gren, 2015). One of the main novelties in our demand system is the inclusion of detailed analyses of plant-based protein products and seafood. This has not been conducted in Sweden before. As we have access to more detailed data on sales of plant-based foods and seafood compared to previous analyses, we are able to conduct separate analyses for these food groups on a more detailed level. This is an important addition as food consumption trends has changed towards e.g. more plant-based products.

On the 3^{rd} level we differentiate within the groups on the 2^{nd} level. It answers the following question: if consumers choose meat, what types of meat do they choose between? This division also follows the literature on demand systems, especially since analyses connected to climate impact has become more popular (Moberg et al., 2021; Säll & Gren, 2015). Lastly, after the choice of what type of meat should be bought, consumers decide on whether the meat should be organic, produced in Sweden or imported. This is captured on the 4^{th} level in Figure 4, which allows us to analyse consumer views on characteristics of products. These types of analyses are often done via choice experiments, where consumers choose between e.g. domestic or organic products at different price levels in a hypothetical setting (Lagerkvist et al., 2014; Yeh & Hirsch, 2023). Given the richness of our dataset we could do similar analyses on actual sales data, enabling us to analyse revealed preferences instead of stated preferences.

Each box in Figure 4 is connected from the lower levels (4^{th}) to the top level (1^{st}) via the lines in the figure. The connections are then analysed as follows. When e.g. price changes are introduced, the main changes happen within the box where prices change. These changes will then spill over to boxes at higher levels (e.g. from the 4^{th} level to the 3^{rd} level), all the way up to the first level. Finally, the model considers how remaining parts of the budget will trickle down to boxes from other branches (e.g. from protein rich products to fruits and vegetables at the 1^{st} level).

For example, if the price of imported beef increased relative to Swedish, organic or small-scaled produced beef, the major consumption shifts take place within the beef box at the 4^{th} level. The model outcomes show to what extent consumers would substitute imported beef with other beef, such as Swedish beef. The second largest effect of such a price increase would then take place within the meat group on the 3^{rd} level. Consumers could choose to buy less beef due to price increases and instead buy other types of meat, such as poultry. On the second level, consumers might decide to reduce meat consumption a bit, and instead spend money on other types of protein foods. A small part of the price increase effect on imported beef would thus show as an consumption increase in other protein rich foods, such as seafood. Lastly, consumers might choose to spend less money on protein rich foods altogether due to the price increase on imported beef and instead buy food from other major food groups on the 1^{st} level.

When potential consumption changes have made their way up from the 4th level to the 1st level on the protein branch, the allocation of the consumers food budget has changed. Money is re-allocated away from protein rich foods to other food groups, such as grain products or fruit and vegetables. The re-allocated sum will trickle down through the other product branches (e.g. grain products) based on initial consumption shares. If consumers initially spend more money on bread than on pasta, most of the newly allocated grain product budget will be spent on bread, and then trickle down to the 3rd level showing on what type of bread.

A limitation of the model is that it assumes a constant budget on the 1st level. This means that households allocate the same budget to food regardless of price levels and other non-food consumption goods. However, the allocation of the budget between groups within the demand system can change. The results may also depend on how groups are chosen. We decided to categorise food groups aligned with the NNR2023 to tailor our analysis to the NNR2023. The choice on how to group commodities is not always straightforward and may be subject to arbitrary selection. For instance, should drinking milk be sorted with dairy products or with drinks?

A negative relationship (cross-price elasticity) between two commodities implies that even if one of the prices goes down to close to zero, there is only a small chance that the consumer would choose that product in favour of the other. The elasticity shows that consumer preferences are not favouring a shift between the products, regardless of how policy makers might try to change consumption patterns. In our results, there is a strong negative relationship between meat and plant-based protein rich products (level 2 in Figure 4), showing that most of the included consumers in the dataset do not consider the two groups interchangeable.

4.2. Model results

Protein foods

Elasticities between major protein rich food groups (2nd level in Figure 4) show negative relationships between meat and plant-based foods, and positive relationships between meat and seafood and between meat and dairy based protein products. We also find positive relationships between plant-based products and both seafood and dairy-based protein foods. This implies that the average consumer would most likely change from meat to seafood and dairy-based products, and if further stimulated, there may be possibilities to shift from seafood and dairy-based product to more plant-based alternatives.

It is unlikely that a majority of consumers would change directly from meat to plant-based products following the advice to reduce red meat consumption. Previous studies have shown that a large share of the consumers would not consider plant-based protein rich products, even if price levels are low. These findings hold especially when plant-based products do not look or taste like meat (see e.g. Carlsson et al., 2022). Our demand system confirms their result on the relationship between meat and plant-based protein rich products. It is likely that recommendations to decrease consumption of animal food products mainly affect those who are already consuming some lacto-ovo-vegetarian foods (e.g. haloumi), or seafood.

NNR2023 states that if consumption of seafood is to increase, consumption should be from sustainable stocks or from production methods that are not unnecessary harmful to marine environments (e.g. bottom trawled). In the demand system, we have divided seafood into fish, shellfish, canned fish and breaded fish. These are then further subdivided into sustainability labelled fish (such as organic, Marine Stewardship Council (MSC) or Aquaculture Stewardship Council (ASC)), fish from unsustainable practices (e.g. bottom trawled), conventional production practices, and fish not recommended to eat large quantities of due to high exotoxin levels (Figure 4). Consumption of fish with a sustainability label is highly price sensitive, meaning that price changes will have a large effect on consumption levels. Sustainability labelled fish also shows a positive cross-price elasticity to fish from harmful or conventional practices, indicating that the NNR2023 recommendations of increasing fish consumption mainly from sustainable stocks could be possible.

Within the meat group (3rd level, Figure 4), it is mainly poultry and mixed minced meats (pork and beef mixes) that are considered substitutes to all other types of meat. This implies that if consumers are encouraged to reduce consumption of beef, they are most likely to replace it with poultry or with mixed minced meat.

Going deeper into the different types of meat, the high inflation levels in 2022 continued to decrease the Swedish market shares (see Figure 1). This is somewhat confirmed in our demand system. When we include the most expensive and exclusive imported beef, Swedish and imported beef products are not considered substitutes. However, after removing the most expensive imported products from the dataset, we find substitutability between both Swedish beef and Swedish small-scale beef (beef that has a local or small farm name clearly visible on the package) and imported beef. This would mean that when buying e.g. Wagyu beef from Japan, consumers want the exclusive product, which cannot be replaced by a Swedish product, but more regular imported beef can be replaced by Swedish products. Looking at the income elasticities in the demand system (i.e. how we spend our money when our income or budget change), we find a higher value for imported beef. This indicates that if consumers reduce the amount spent on beef, due to new recommendations, they might choose to reduce the imported beef more in percent than Swedish produced beef.

Regarding plant-based protein rich products, the highest consumption levels are for unprocessed legumes (e.g. beans, lentils, chickpeas) and meat-like substitutes (e.g. minced soy or soy sausages). This implies that these two groups will likely increase the most if consumers spend more money on plant-based protein rich products. Only unprocessed legumes were analysed on the 4th level, where we include organic and origin in the analysis. Due to the lack of organic or Swedish soy products in the dataset we could not conduct a similar analysis for other plant-based protein rich products. Within the unprocessed legume group, all products are found to be substitutes. This implies that consumers do not consider Swedish beans different from organic or imported beans.

Summarising the analysis of protein rich products, the demand model shows that consumers are most likely to move from meat towards seafood and dairy-based products. Consumers who are already consuming more seafood and dairy-based would likely be the ones most inclined to shift to more plant-based in their diets. It is unlikely that consumers would substitute red meat for plant-based protein rich products on a large scale because of dietary guidelines. If households reduce red meat consumption, they are likely to increase poultry consumption as a first step. Regarding Swedish products, there are possibilities to reduce red meat imports in favour of Swedish red meat products. As consumers are already buying mostly Swedish product in retail stores, and most of the imported meat is consumed in restaurants, such a shift would likely need price incentives where the relative prices of Swedish products in relation to imported products are reduced, or additional information campaigns.

Fruits and vegetables

To increase fruit and vegetables consumption, understanding what consumers consider substitutes is key. Recent inflation levels have shown that when overall prices increase, consumers reduce fruit and vegetable purchases but keep or even increase consumption of candy and sugary products (SCB, 2023). This is confirmed in our demand system, which is based on data from before the recent large inflation levels. We find fruit and vegetables to be strong substitutes to snacks on the 1st level in our demand system (Figure 4).

In the demand analysis, we were able to estimate elasticities on the 4th level for three different fruit and vegetables: onions, potatoes and apples. These three products were the only products where data was available for Swedish, imported and organic during most of the studied time period. This analysis could give some insights in how policy could affect production in Sweden. Mainly within the apple group, we found substitutability favouring Swedish production. This means that consumers are willing to change from imported to Swedish apples if relative prices are favouring Swedish apples or by the introduction of information campaigns. Within the groups of onions and potatoes, consumers rather substitute imported or conventionally produced for organic products instead of Swedish produced. It should be noted that if a product was both Swedish and organic, we have classified the product as organic. Analyses of Swedish organic products were not possible due to a lack of data.

Grain products

We did not include whole grain in the demand system, so we cannot discuss opportunities for increased whole grain consumption. One of the environmental recommendations in the NNR2023 regards reducing rice consumption. We find that substitution possibilities for reduced rice consumption are slim, with low positive effects only towards pasta.

Dairy

We investigated the possibilities of substituting cow-based dairy for plant-based substitutes for both cheese and drinks. Although the results indicate a possibility to convince some consumers to switch from hard cheese made from cow milk to plant-based cheese, we are doubtful about the number of households that are actually willing to do this. Consumption of plant-based cheese is at a very low level and even if a change is possible with some type of policy, the percentage changes our result indicate is very small in actual volume. In the category for drinks, we find a higher possibility of switching from cow milk towards plant-based drink products. Within the plant-based drinking group, most consumers choose oat drinks, and a shift from cow milk to plant-based drinks would thus mainly increase consumption of oat drinks. There is however a risk of increasing consumption of almond and coconut drinks which might not be beneficial for biodiversity and water usage (Karlsson Potter et al., 2020).

Fats and oils

For different types of fat, the possibility of substituting is large. The highest degree of substitution is found between butter and mixes of butter & rapeseed oil. Given the high climate impact of butter and the amount of saturated fats, a shift from butter to butter and rape mixes could substantially reduce negative environmental impacts from fats. On the 4^{th} level in the demand system, we analysed butter and rapeseed oil on a more detailed level. We find mostly substitutes, highlighting possible increases in Swedish market shares if policy favour of such a shift.

5. Environmental models

This section introduces the environmental models used to assess the impact of including environmental considerations in the NNR2023 compared to the NNR2023 without environmental impacts on Swedish production and environmental outcomes (both in Sweden and globally). Section 5.1 introduces the scenarios that are analysed and sections 5.2 and 5.3 introduce the models.

5.1. Scenarios

Twenty-four scenarios that span a space of potential outcomes of the NNR2023 recommendations on red meat consumption were analysed (Figure 5). The scenarios were constructed based on different combinations of four dimensions:

1. The level of impact of NNR2023 recommendations on red meat consumption (small or large; in the yellow boxes of Figure 5)
2. Whether recommendations include environmental considerations or only health aspects (no or yes; in the green boxes of Figure 5)
3. Assumed substitute for red meat in the diet (poultry or plant-based; in the orange boxes of Figure 5)
4. If the changes in consumption (reduction in red meat and increase in substitutes) affects Swedish production only, both Swedish production and imports (by today’s import shares) or imports only (blue boxes at the top of Figure 5)

Figure 5 provides an overview of the scenarios and shows reduction in red meat consumption (grey boxes) as well as reduction in demand for Swedish red meat production (blue boxes) given the different scenarios. A large impact of the NNR2023 was defined as a change corresponding to if 20% of the population follows the recommendations and a small impact was defined as corresponding to if 5% follows the recommendations. For the environmental considerations in the NNR2023, it is stated that red meat consumption should be “significantly” lower than the 350 grams/week recommended for health reasons. We interpret a “significant” reduction as 20% lower than the health recommendations (i.e. 280 grams/week). These different degrees of reduction result in a reduced red meat consumption ranging from 2% to 11% (grey boxes in Figure 5). For the substitutes for red meat in the diet, these were made based on mass, i.e. if consumption of red meat is decreased by 10 grams/week consumption of poultry or plant-based alternatives is increased by 10 grams/week, respectively. Plant-based was assumed to be 1/3 peas, 1/3 broad beans and 1/3 rapeseed oil.

Section 3 showed that informative policy instruments, such as the NNR2023, are unlikely to substantially change consumption without considering other production and consumption side measures. Hence, it is important to note that these scenarios answer “what-if” questions and do not necessarily reflect how consumption will be affected by the NNR2023. In other words, these scenarios should be viewed as examples of potential outcomes, where some scenarios (e.g. consumption changes only affecting Swedish production) are at the extreme end of potential outcomes and are unlikely to happen.

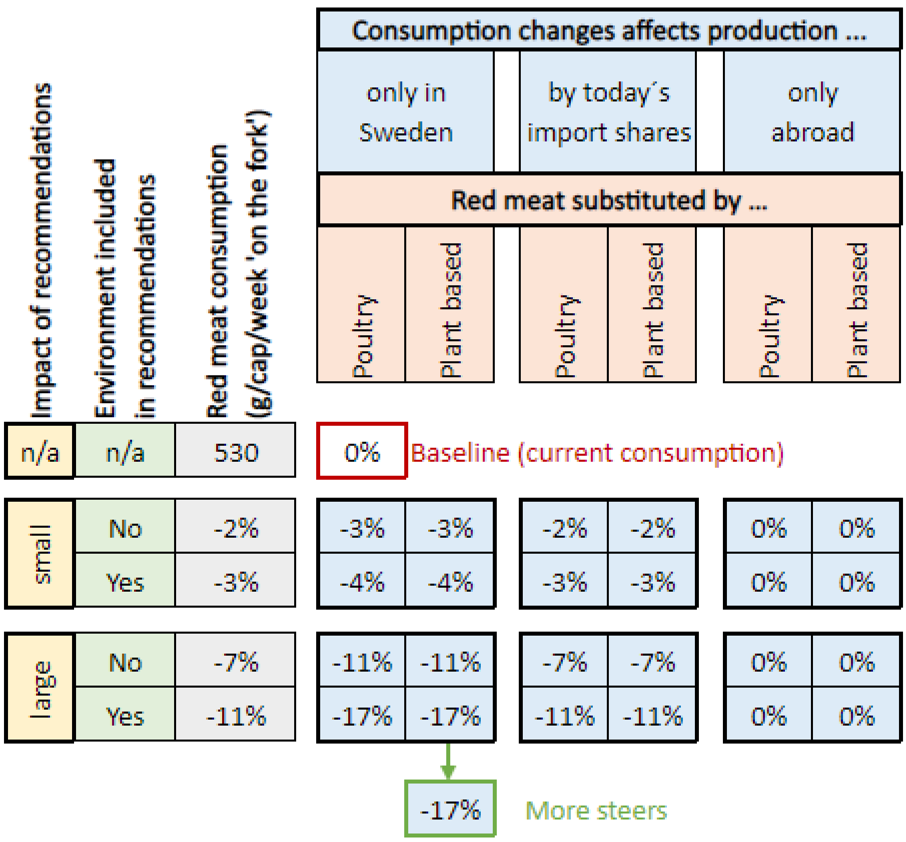

Figure 5 Scenarios included in the present study. The figures in grey boxes gives overall reduction of red meat consumption given a certain impact of the recommendations and figures in blue boxes gives reduction in red meat from Swedish production given which production the consumption changes affect (only in Sweden, by todays import shares or only imported).

On top of the twenty-four demand-side scenarios, we also studied one alternative scenario (“More steers”; lower box in Figure 5) that assumes production side measures supporting grazing-based beef production to limit the risk of reduced grazing in semi-natural grasslands following from reduced beef production. This was implemented in the model by assuming that 25% of conventional male calves are castrated and raised as steers with increased opportunities for grazing post weaning as compared to raising intact bulls. For organic farms, the share of steers already exceeds 25% (Swedish Board of Agriculture, 2023a) and no change was made there. Raising steers has previously been found to be a profitable production alternative in many circumstances (Hessle & Kumm, 2011) but today as much as 84% of male calves are raised as intact bulls (Swedish Board of Agriculture, 2023b). This scenario builds on one of the demand-side scenarios with the strongest impact on Swedish red meat production (i.e. large impact of the NNR2023 including environmental considerations, consumption changes, only affecting Swedish production and plant-based as substitute; see arrow in Figure 5). We present the results of this scenario separately in section 6.1.

Two modelling approaches were used to study how the different scenarios affected production and environmental outcomes. The first approach used CIBUSmod (version 1.0), which is a biophysical mass-flow model of the Swedish agro-food system developed at SLU within the Mistra Food Futures research programme. This model quantifies the effects on agricultural production in Sweden in terms of land use and animal numbers as well as greenhouse gas and ammonia emissions associated to Swedish agriculture. However, it does not account for impacts due to changed feed or food imports or impacts occurring post farm-gate. Therefore, we introduce a second modelling approach that uses static LCA-data on the carbon footprint taken from Moberg et al. (2020) to study the climate impact of consumption changes. This modelling approach includes the entire supply chain of both imported and domestically produced foods from cradle to Swedish retail.

In modelling approach 1, effects of the different scenarios were assessed in terms of agricultural land use, animal numbers, greenhouse gas and ammonia (NH_3) emissions, and the area of grazed semi-natural grassland.

Ammonia is the primary form of air pollution associated with Swedish agriculture. Currently agriculture stands for 90% of Sweden's territorial NH_3 emissions (Swedish EPA, 2023) and NH_3 is the only air pollutant under the National Emission reduction Commitments Directive (NEC Directive, 2016/2284), where Sweden failed to meet its emissions reduction commitment by 2020 (EEA, 2023). In the atmosphere, ammonia contributes to formation of fine particulate matter (PM2.5), which is detrimental to human health. When NH_3 is deposited in terrestrial and aquatic ecosystems, it can also contribute to eutrophication and acidification.

The preservation of semi-natural grasslands is crucial to biodiversity conservation in the agricultural landscape. Semi-natural grasslands have formed through long-term management for haymaking and grazing and are today one of the most species diverse habitats in Sweden (Eriksson & Cousins, 2014). The conservation status for most Swedish grassland habitats under the Habitats Directive (92/43/EEC) currently does not meet criteria for 'good conservation status' and both quantity and quality need to increase to improve the status (Swedish EPA, 2020). Preservation of semi-natural grasslands is one of the indicators of the Swedish environmental goal "ett rikt odlingsladskap" (Sveriges miljömål, 2024). While we limit our analysis here to semi-natural grasslands, it is important to note that agricultural production also affects biodiversity directly through land use and indirectly through nutrient and pollutant emissions and by contributing to climate change. Agricultural land use and expansion is one of the main drivers of terrestrial biodiversity loss (IPBES, 2019). Production of beef and pork requires large amounts of cropland (excluding grazing lands) and, when calculated per kilogram food, these products have use large amounts of croplands compared to other food products (Moberg et al., 2020; Poore & Nemecek, 2018). Several methods have been developed to assess terrestrial biodiversity loss due to land use and land transformation (e.g. Chaudhary & Brooks, 2018). However, these methods have coarse geographic resolution and cannot assess the positive impact from grazing semi-natural grasslands. The indicator that we use in this report (i.e. area of grazed semi-natural grassland) quantifies an important biodiversity conservation service from Swedish agriculture but does not quantify the negative impacts of production, which is needed for a complete assessment of the effects on biodiversity.

The following sections describe the two modelling approaches. First, the CIBUSmod modelling framework is described in section 5.2 and then the carbon footprint data used for the second modelling approach is described in section 5.3.

5.2. Modelling approach 1: CIBUSmod agro-food system model

CIBUSmod balances an exogenous demand for crop and animal products with agricultural production in Sweden. This means that demand is set outside the model and that the model does not predict changes in demand from different policies or price changes. The demand for crop and animal products is calculated by supplying an average per capita diet along with parameters on waste and conversion rates, import shares, and additional demand for non-food uses and exports. The production side is modelled from a large number of parameters describing the productivity in crop and animal production in terms of area and number of animals needed to supply a given demand for crop and animal products, respectively. Demand for feed is internally handled in the model to ensure feed crop areas that meet animal feed requirements. Key parameters are described in more detail below

The model analyses on a spatial scale of Swedish harvest regions (“skördeområden”), which subdivide Sweden into 106 agronomically uniform areas and represent the smallest spatial scale at which agricultural statistics on e.g. yields are presented (see Figure A1). Model parameters are supplied either on that level or on more aggregated level.

To distribute crop areas and animal numbers across regions, the model solves a convex optimisation problem that minimises deviation from current crop areas and animal number across regions. The justification for this is that the current distribution of crops and animals reflect the available infrastructure, logistic chains, and economic incentives for agricultural production. This makes it reasonable to assume that future changes in production do not deviate from this distribution more than necessary. Mathematically the optimisation goal is to

$$min \sum (f_{i,j} \cdot x_{i,j} - f_{i,j} \cdot x0_{i,j})^2$$

where $x_{i,j}$ and $x0_{i,j}$ is the area or number of crop or animal i in region j in the solution and current situation, respectively. $f_{i,j}$ is a scaling factor calculated as

$$f_{i,j} = \left(\frac{\overline{x0}}{x0_{i,j}}\right)^{sp}$$

where sp is a parameter that controls the "power" of scaling; $sp = 0$ means that the model tries to minimise the deviation from the current state in absolute terms while a larger sp means that relative deviations are also considered in the optimisation. A larger sp will yield larger absolute changes in crop areas and animal numbers in regions where the areas or numbers are currently large. Here $sp = 0.4$ is used, which has been found to produce plausible results in terms of avoiding large increases of "rare" crops in a region while still distributing changes across regions.

This problem is solved while ensuring that total agricultural production in Sweden meets demand for Swedish produced crop and animal products. Furthermore, a number of additional constraints are included to ensure agronomically feasible solutions:

1. Total land use is limited to currently available arable land and semi-natural grasslands in each region.
2. Crops are limited to regions with a suitable climate in terms of the number of growing degree-days. The minimum number of growing degree-days for each crop is estimated from the "coldest" region where the crop is currently grown.
3. Certain crops are limited to use a maximum share of cropland in each region to avoid crop rotations prone to disease build-up. Here grain legumes were limited to 16.7% (once every 6th year) and 10% (once every 10th year) for conventional and organic areas, respectively, and crops in the *Brassicaceae* family (i.e. rapeseed) were limited to 14.3% (once every 7th year) and 12.5% (once every 8th year) for conventional and organic areas, respectively.
4. The area of certain feed crops in each region must meet a minimum share of regional feed demand. Here the minimum share was set to 95% for all forage crops and grazing.
5. The maximum share of grazed biomass from semi-natural grasslands is limited per animal category. These values were set to 20% for dairy cows (Hessle & Danielsson, 2023), 85% for other cattle (Ahlgren et al., 2022), 69% for autumn lambs, 100% for other sheep (Ahlgren et al., 2022) and 14.5% for horses (Cederberg & Henriksson, 2020).

5.2.1. Implementation of scenarios

Scenarios are implemented in CIBUSmod by changing a set of parameters on the demand and/or production side. Parameters describing red meat consumption, consumption of the different substitutes, and import shares were changed in the scenarios. For the "more steers" scenario, parameters describing the fraction of male calves raised as steers were also changed. As scenarios assuming that consumption changes only affects imports have no effect on Swedish agricultural production (see right hand side in Figure 5), these were not modelled in CIBUSmod.

As demand for different crop products change in the scenarios, the model will adapt by adjusting areas of different crops trying to stay as close as possible to current land use. In the model, demand for grazing land can be met by semi-natural grasslands or grazing on arable land (i.e. permanent ley pastures or grazing on ley regrowth). As grazing demand is reduced, we assume that the incentive for keeping currently used semi-natural grassland areas in production is higher than continuing to graze on arable land as the former is eligible for higher support payments and the latter has more alternative uses for e.g. silage or other crops. This was implemented in the scenarios by reducing the goal area for grazing on arable land in proportion to the reduction in grazing demand. The share of grazing in semi-natural grasslands is, however, also limited by constraint (5), which was not changed in the scenarios.

5.2.2. Environmental impact assessment

CIBUSmod calculates greenhouse gas (carbon dioxide, methane and nitrous oxide) and ammonia emissions associated with nitrogen application to agricultural soils, enteric fermentation, manure management and energy use in crop production, stables, greenhouses and grain dryers as well as the supply chain emissions for fertilisers and energy. The current version of the model does not include any emissions associated with food or feed imports or food and feed processing post farm-gate. The methods and emission factors used are mainly based on the IPCC Guidelines (IPCC, 2019) and will be described in more detail in Karlsson et al. (forthcoming).

5.2.3. Input parameters

The model relies on a large number of parameters. The most important parameters for the analysis presented in this report are described. The baseline input parameters have been validated to ensure reasonable agreement with available national statistics and authoritative reports on e.g. crop areas and animal numbers, crop and animal production, energy use and nitrogen and phosphorous application as well as agricultural greenhouse gas emissions according to National Inventory Reports (NIR). These steps will be described in Karlsson et al. (forthcoming), and all model code will be made available at https://github.com/SLU-foodsystems/CIBUSmod-public/tree/v1.0. Until then, data supporting the findings in this report are available from the authors upon request.

Current consumption

The model includes a large number of food items that together describe an average per capita diet. Data on current consumption has been curated from different sources depending on food item in the diet. Meat consumption was based on consumption data (i.e. “Direktkonsumtion”) for the year 2020 according to the Swedish Board of Agriculture’s statistical database

Crop yields

The model includes 56 crop types including all major cereals such as winter wheat and spring barley, forage crops such as ley for silage or grazing, semi-natural grasslands, grain legumes, rapeseed and a number of horticultural crops, greenhouse crops and fruit trees.

Yields for different crops were estimated from the Swedish Board of Agriculture’s statistics database on harvest region level where available. For many crops and regions, yield data is not available at that level. In those cases, data on a larger spatial scale was used (i.e. county, PO8 or national level) along with a “help crop” with good data coverage (generally spring barley) to extrapolate yields to regions with missing data. This generates yield data for all crops in all regions but cultivation of many crops are constrained by constraint (2). For crops with poor data availability, the extrapolated yields are highly uncertain but as the model distributes crops based on how they are currently distributed, resulting areas are typically much larger in regions where yield data are available.

For semi-natural grasslands, yield statistics are not collected. Only a handful of studies have assessed grassland productivity with field measurements (E. Spörndly & Glimskär, 2018). We used the biomass productivity of dry, mesic, moist and shaded semi-natural pastures presented by Spörndly & Glimskär (2018) together with national datasets on tree cover and soil moisture from METRIA. These datasets were overlain with semi-natural grassland parcels from the Swedish Land Parcel Identification System (“Blockdatabasen”). For pastures with sparse vegetation (i.e. grassland parcels classified as ‘Alvar’, ‘Mosaic pastures’ or ‘Pastures with limited grass cover’), gross productivity was set to 1,000 kg DM/ha (Hessle & Danielsson, 2023). Gross productivity was also adjusted for climatic variability based on relative ley yields in different regions with Uppsala set to 1. This resulted in an average national gross productivity in semi-natural pastures of 3,000 kg DM/ha which, adjusted for pasture utilisation rates based on Hessle & Danielsson (2023), gave a net productivity of 1,300 kg DM/ha. This is higher than estimated by Hessle & Danielsson (2023) but slightly lower than values used by Cederberg & Henriksson (2020).

Plant nutrient requirements

In CIBUSmod, nitrogen (N) and phosphorus (P) requirements are calculated as a function of yield. The equations are based on fertiliser recommendations from the Swedish Board of Agriculture (2014). Exceptions are nitrogen fertilisation rates for grain legumes, vegetables, fruits and berries. These nitrogen fertilisation rates are based on Tidåker et al.

(2021), Yara (2023) and Nilsson (2011) while phosphorus fertilisation rates for vegetables and fruits (apple and pear) that are based on Yara (2023).

For the major crops (cereals, ley including ley for grazing, oil crops potatoes and sugar beets) where regional (production area (PO8)) yield and fertilisation statistics are available, the calculated nitrogen fertilisation requirements generally exceed the fertilisation rate in national statistics. Therefore, nitrogen fertilisation rates were adjusted for these crops using the proportion of arable land under ley cultivation in the respective areas.

The use of mineral N and P fertilisers is calculated by subtracting plant-available N and P in manure in each region from the calculated requirements.

Animal productivity

CIBUSmod calculates animal productivity and herd structures from a number of parameters on fertility, slaughter ages, slaughter weights, and mortality. These parameters were sourced from national statistics and published papers and reports. For cattle, data were mainly sourced from Växa cattle statistics (www.vxa.se/statistik), Swedish Board of Agriculture (2023b) and Ahlgren et al. (2022). For sheep, data were mainly sourced from Ahlgren et al. (2022). For pigs, data from Gård & Djurhälsan's WinPig statistics (https://www.gardochdjurhalsan.se/winpig/), Landquist et al. (2020) and Zira et al. (2021) was used. For broiler chicken, data were mainly sourced from Edman et al. (2022).

Feed requirements and rations

Different methods are used to calculate feed requirements for different animals depending on data availability and importance of animal category for total feed demand. For cattle, feed requirements are calculated based on equations of metabolizable energy requirements for maintenance, growth, lactation and gestation in Spörndly (2003). For pigs, equations for net energy requirements Simonsson (2006) and Göransson & Lindberg (2011) are used. For sheep, a yearly dry matter intake of 554-748 kg DM was assumed for ewes, and for lambs, a total intake of 114-255 kg DM from birth to slaughter was assumed based on Ahlgren et al. (2022). The ranges represent differences across rearing systems (i.e. spring, winter or autumn lambs). For broilers, a dry matter feed requirement of 1.52 kg DM per kg live weight gain was assumed (Edman et al., 2022) and for breeding hens 48 kg DM per inserted animal was assumed, which also includes feed for roosters.

Feed requirements are then combined with specified feed rations in terms of the share of feed intake from different feedstuffs. Feed rations were based on previously published reports for cattle and sheep (Ahlgren et al., 2022; Einarsson et al., 2022), pigs (Landquist et al., 2020), and broilers (Edman et al., 2022). To translate energy requirements into dry matter feed requirements, feed tables from the Swedish University of Agricultural Sciences or from *feedipedia.org* if feedstuff ware used. The resulting feed rations for cattle, sheep, pigs and broiler production are shown in Table A1.

5.3. Modelling approach 2: Climate footprint data

Additionally, the overall impact from dietary changes (i.e. including imported products) for all scenarios was calculated using climate footprint data of Swedish production, using a weighted average for imported products (representing Swedish import) with data from Moberg et al. (2020). These data are adjusted for waste up until consumed product (food intake) in accordance with FAO (2011). Reductions in climate impact compared to the total diets were calculated using the total impact of the Swedish diet from Moberg et al. (2020).

6. Results and discussion

This section presents and discusses the results. In section 6.1, we present the results of CIBUSmod and present the impact of including environmental considerations of the NNR2023 on Swedish production and environmental outcomes compared to the NNR2023 without environmental considerations. Section 6.2 discusses the climate impacts of these scenarios. The scenarios primarily focused on reduced red meat consumption and substituting it by either plant-based alternatives or poultry. However, the NNR2023 also includes other food groups that are not considered in these scenarios. The potential impacts on production and the environment of introducing the environmental considerations of the NNR2023 compared to the NNR2023 without environmental considerations are discussed in section 6.3. Section 6.4 discusses implications for animal welfare. Finally, section 6.5 provides a general discussion.

6.1. Modelling approach 1: CIBUSmod agro-food system model

6.1.1. Cropland use and animal numbers

The different demand-side scenarios led to a 0-6.9% reduced demand for cropland in Sweden (Figure 6). The different substitution options (plant-based or poultry) had similar effect on Swedish cropland use because of the fact that poultry production is efficient in terms of feed conversion and therefore requires relatively low amounts of land for feed production. Poultry production also uses a relatively high share of imported feeds compared to cattle and pig production (e.g. 19% soybean meal in the broiler rations, Table A1). So, in scenarios with poultry as a substitute for red meat, feed imports and cropland use outside Swedish borders increase. The difference in demand for Swedish cropland between including the environmental considerations in the NNR2023 recommendations or not was 0.3-0.7 percentage units under a small impact of recommendations and 1.3-2.3 percentage units under a large impact of recommendations.

Impact of recommendations	Environment included in recommendations	Red meat consumption (g/cap/week 'on the fork')	Consumption changes affects production ... only in Sweden — Red meat substituted by ... Poultry	Plant based	by today´s import shares — Poultry	Plant based	only abroad — Poultry	Plant based
n/a	n/a	530	0%	Baseline (current consumption)				
small	No	521	-1,1%	-1,2%	-0,6%	-0,7%	0%	0%
small	Yes	516	-1,8%	-1,9%	-1,0%	-1,0%	0%	0%
large	No	494	-4,5%	-4,6%	-2,5%	-2,6%	0%	0%
large	Yes	474	-6,8%	-6,9%	-3,9%	-3,9%	0%	0%

Figure 6 Change in demand for Swedish cropland in the different scenarios relative to current (~2020) cropland use.

In the baseline, 42%, 38%, 1.8% and 3.7% of Swedish cropland was used for ley, cereals, grain legumes and rapeseed cultivation, respectively (Figure 7a). In the scenarios considering current import shares and large impact of recommendations, ley cultivation decreased by up to 85,000 ha to around 40% of cropland (Figure 7b-c). In scenarios where plant-based food replaced red meat, cereal cultivation decreased by up to 17,000 ha and up to 6,000 ha in scenarios where poultry substituted red meat (Figure 7b-c). As ley cultivation decreased, the share of cropland devoted to cereals increased to from 38% today to 39-40% in the scenarios, despite the overall reduction in area. The total share of cropland devoted to grain legumes and rapeseed increased to up to 2.2% and 4.1%, respectively. The observed increases in grain legume cultivation are well within previously assessed Swedish potentials across all scenarios (Röös et al., 2018). Figure 7 shows the patterns of land use changes for two of the scenarios with the current market shares.

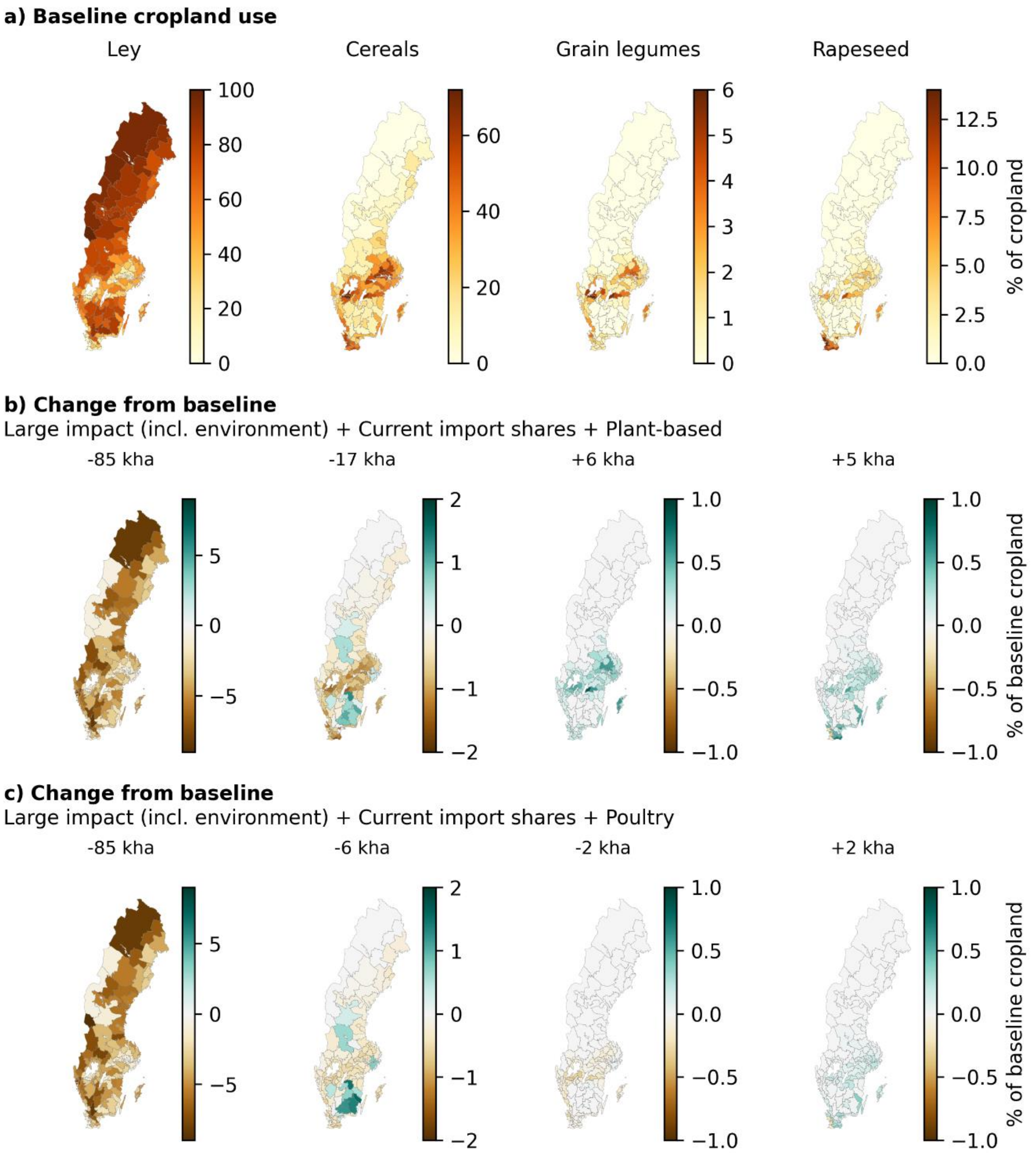

Figure 7 a) Share of cropland used for ley, cereals, grain legumes and rapeseed in the baseline. b-c) Change in cropland use for scenarios with the current import shares. Changes are shown as percentage of total cropland in each region in the baseline for the cases when plant-based food is assumed to substitute red meat in the diet (b) and for poultry as a substitute for red meat (c). The numbers on top of each map show the absolute change in Swedish cropland use for that crop in thousands of hectares (kha).

The total number of cattle in Sweden decreased between 0 and 16% in the different scenarios, but as dairy consumption and production was assumed constant across all scenarios, this reduction only affected animals in dedicated beef production systems (i.e. suckler herds), which were reduced by 0-42% in the scenarios. Thus, the share of beef originating from dairy cows and their offspring increased in scenarios affecting Swedish production. The number of pigs and sheep decreased by 0-17% and 0-21%, respectively. In scenarios with poultry as a substitute for red meat, the number of Swedish broilers and their parents increased by up to 35%. The number of broiler chickens slaughtered annually increased from 107 million heads in the baseline to up to 144 million heads.

6.1.2. Greenhouse gas emissions

Greenhouse gas emissions from Swedish agriculture (including emissions associated with the production of fertilisers and fuels) were reduced by 0-8.8% in the different scenarios (Figure 8). The impact of the different greenhouse gases are aggregated to carbon dioxide equivalents using GWP100 factors according to IPCC's Fourth Assessment Report. Across the scenarios, methane accounted for 52-53% of reductions in greenhouse gas emissions while nitrous oxide and carbon dioxide accounted for 42-43% and 3.2-5.8% of reductions, respectively. Figures B1-B4 show the changes per greenhouse gas. Including the environmental considerations in the NNR2023 recommendations reduced greenhouse gas emissions by 0.4-0.8 and 1.6-3.1 percentage units under a small and large impact of recommendations, respectively. Greenhouse gas emissions reductions were slightly larger when assuming plant-based substitutes for red meat compared to poultry, but differences were small in comparisons to emissions reductions from reduced red meat production.

			Consumption changes affects production ...					
			only in Sweden		by today´s import shares		only abroad	
			Red meat substituted by ...					
Impact of recommendations	Environment included in recommendations	Red meat consumption (g/cap/week 'on the fork')	Poultry	Plant based	Poultry	Plant based	Poultry	Plant based
n/a	n/a	530	0%	Baseline (current consumption)				
small	No	521	-1,2%	-1,4%	-0,7%	-0,8%	0%	0%
small	Yes	516	-2,0%	-2,2%	-1,1%	-1,3%	0%	0%
large	No	494	-5,2%	-5,7%	-2,8%	-3,2%	0%	0%
large	Yes	474	-8,0%	-8,8%	-4,4%	-4,9%	0%	0%

Figure 8 Change in greenhouse gas emissions from Swedish agricultural production (modelling approach 1) in the different scenarios relative to current (~2020) emissions. Emissions are evaluated with GWP_{100} using a factor of 1 for carbon dioxide, 25 for (biogenic) methane and 298 for nitrous oxide.

6.1.3. Ammonia emissions

Ammonia emissions from Swedish agriculture were reduced by 0-11% across the different scenarios (Figure 9). The strongest decreases were observed in scenarios with a large impact on Swedish red meat production. The difference between including environmental considerations in the recommendations or not was 0.5-1.1 percentage units under a small impact of recommendations and 2.0-3.8 percentage units under a large impact of recommendations, with higher reductions in emissions when the environmental considerations were included.

According to Sweden's binding commitments under the NEC Directive, NH3 emissions need to reduce to below 48 thousand metric tonnes (kt) per year from the current annual emissions of 51 kt in 2022 (Swedish EPA, 2023). In the scenarios with a large impact of NNR2023 recommendations including environmental considerations and consumption affecting only Swedish production, the level of national NH3 emissions reductions in agriculture would bring Sweden below its 2030 commitment (assuming constant emissions in other sectors). It should however be noted that there are also production side measures that can be taken to reduce NH3 emissions from agriculture, which were not included in the present analysis. These are mainly centred on the use of low emissions technologies in livestock housing, manure management and fertiliser application (Bittman et al., 2014; Sutton et al., 2022).

			Consumption changes affects production ...					
			only in Sweden		by today´s import shares		only abroad	
			Red meat substituted by ...					
Impact of recommendations	Environment included in recommendations	Red meat consumption (g/cap/week 'on the fork')	Poultry	Plant based	Poultry	Plant based	Poultry	Plant based
n/a	n/a	530	0%	Baseline (current consumption)				
small	No	521	-1,6%	-1,8%	-0,9%	-1,0%	0%	0%
small	Yes	516	-2,5%	-2,8%	-1,4%	-1,6%	0%	0%
large	No	494	-6,4%	-7,0%	-3,7%	-4,1%	0%	0%
large	Yes	474	-10%	-11%	-5,7%	-6,3%	0%	0%

Figure 9. Changes in ammonia emissions from Swedish agriculture) in the different scenarios relative to current (~2020) emissions.

6.1.4. Semi-natural grasslands

Due to the lower number of ruminants in the demand-side scenarios where reduced red meat consumption was assumed to affect Swedish production, a 0.7-6.6% reduction in the area of grazed semi-natural grassland was observed (Figure 10). The scenarios with a small impact of the NNR2023 show a marginal effect on semi-natural grassland area (below 1% reduction). The difference between including the environmental considerations in the NNR2023 or not was 0.1-0.3 percentage units under a small impact of the recommendations and 1.2-3.5 percentage units under a large impact of the recommendations, with a reduced area of grazed semi-natural grassland when including environmental considerations. The share of total grazed biomass from semi-natural grasslands increased from 42% in the baseline to 43-48% in the different demand-side scenarios, reflecting the assumption that reduced demand from grazing would affect grazing on arable land relatively more than grazing in semi-natural grasslands. Semi-natural grasslands have a higher biodiversity than grazing lands on arable land.

			Consumption changes affects production ...					
			only in Sweden		by today´s import shares		only abroad	
			Red meat substituted by ...					
Impact of recommendations	Environment included in recommendations	Red meat consumption (g/cap/week 'on the fork')	Poultry	Plant based	Poultry	Plant based	Poultry	Plant based
n/a	n/a	530	0%	Baseline (current consumption)				
small	No	521	-0,4%	-0,4%	-0,2%	-0,2%	0%	0%
small	Yes	516	-0,8%	-0,8%	-0,3%	-0,3%	0%	0%
large	No	494	-3,1%	-3,1%	-1,2%	-1,2%	0%	0%
large	Yes	474	-6,6%	-6,6%	-2,4%	-2,4%	0%	0%

Figure 10 Change in the area of semi-natural grasslands in the different scenarios relative to current (~2020) areas.

We used the area of grazed semi-natural grassland as an indicator for biodiversity conservation services provided by grazing livestock systems. It is, however, important to acknowledge that this is not the only way that animal farming affects biodiversity. Emissions of greenhouse gases and ammonia indirectly impacts biodiversity through climate change and eutrophication and livestock feed production uses land resources in Sweden and abroad that could otherwise potentially be available for nature conservation. For example, our results here show that the scenarios substituting red meat by plant-based alternatives would reduce demand for soybean meal imported to Sweden by up to 4%, while in scenarios where poultry substitutes red meat, demand for soybean meal imports increases by up to 11%. Soybean meal is a globally traded commodity that has been associated with e.g. deforestation in South America (Fehlenberg et al., 2017). In all scenarios affecting Swedish production, we also observed a reduced demand for cropland (Figure 6). This extra "room" in the production system could potentially be used to extensify production by e.g. scaling up organic farming, which has been shown to support greater biodiversity in the agricultural landscape compared to conventional farming (Tuck et al., 2014).

Example of production-side change to increase grazing of semi-natural grasslands

It is important to note that previous studies have found that the lack of profitability in grazing-based production systems rather than a lack of animal numbers is the major limiting factor for grazing in semi-natural grasslands today (Larsson et al., 2020). Therefore, there are a number of policy measures that could be taken to facilitate the grazing of semi-natural grasslands for biodiversity preservation. The results for the "more steers" scenario (see Figure 5), that assume production side policies favouring grazing-based production systems, show that a grazed area of semi-natural grassland equivalent to the current area is achievable (semi-natural grasslands decreased 0.3%) despite a reduced total ruminant herd. In this scenario, the share of grazed biomass from semi-natural grasslands increased to 53%. As steers are slaughtered at an older age, emissions of greenhouse gases and ammonia are higher in such systems. This trade-off was, however, found to be small in comparison to reduced emissions from an overall reduced red meat production (0.5 and 0.1 lower percentage unit decrease in greenhouse gas and ammonia emission, respectively compared to the scenario with the highest reduction in red meat which was replaced with plant-based alternatives). The "more steers" scenario would rely on production side policies that favour grazing by promoting profitability in grazing based production (see Jamieson & Hessle (2021) for a review of challenges and opportunities for grazing in semi-natural grasslands).

6.2. Climate impact including imports (modelling approach 2)

Climate impact reductions for the total diet from decreased consumption of red meat and increased consumption of substitutes is shown in Figure 11. For scenarios only affecting Swedish production relative reductions here are lower compared to results from the first modelling approach. This is because the results are presented as reductions from total climate impact based on the whole diet, where imported foods make up a large share. The difference between including the environmental considerations in the NNR2023 or not was 0.3-0.4 percentage units under a small impact of recommendations and 1.3-1.5 percentage units for the large impact of the NNR2023. In general, reductions were higher when plant-based foods replaces red meat in the diet, although the differences were small. The current Swedish diet exceeds the planetary boundary (expressed per capita) for greenhouse gas emissions (as defined in Willet et al. (2019)) by more than threefold (Moberg et al., 2020), meaning that the greenhouse gas emissions from the total diet would have to be reduced by around 70% to meet this target.

			Consumption changes affects production ...					
			only in Sweden		by today´s import shares		only abroad	
			Red meat substituted by ...					
Impact of recommendations	Environment included in recommendations	Red meat consumption (g/cap/week 'on the fork')	Poultry	Plant based	Poultry	Plant based	Poultry	Plant based
n/a	n/a	530	0% Baseline (current consumption)					
small	No	521	-0.6%	-0.7%	-0.6%	-0.7%	-0.6%	-0.7%
small	Yes	516	-0.9%	-1.1%	-0.9%	-1.1%	-1.0%	-1.1%
large	No	494	-2.4%	-2.7%	-2.4%	-2.7%	-2.4%	-2.8%
large	Yes	474	-3.6%	-4.2%	-3.7%	-4.2%	-3.7%	-4.3%

Figure 11 Change in climate impact from substituting part of the red meat consumption with poultry and plant-based alternatives, climate reduction is presented as decrease from total climate impact of the total diet.

6.3. The influence on production and environment for other food groups

The scenarios analysed in sections 6.1 and 6.2 consider substituting red meat by poultry or plant-based alternatives. This section explores how including the environmental considerations in the NNR2023 may potentially influence consumption, production, and environmental sustainability for other food groups not considered in these scenarios (see Table 1 for an overview). We discuss the potential additional influence of including the environmental considerations in the NNR2023 compared to the recommendations with a health rationale only. Therefore, we only consider these changes attributed to including environmental considerations. Note that these descriptions are not a result of quantitative modelling. Hence, these descriptions should be interpreted cautiously.

The environmental considerations of the NNR2023 are qualitative (i.e. descriptive, sometimes with a suggested direction of change). Making claims about total impact on production or environment is not possible, as this requires quantitative recommendations for the environmental considerations of the NNR2023.

Cereals

The NNR2023 recommends an intake of at least 90 grams of whole grains per day. When including environmental considerations, NNR2023 states that whole grains other than rice should be preferred due to high methane emission from rice paddies (IPCC, 2019). We consider the influence on production and environmental outcomes of substituting some rice by either pasta or potatoes. Potatoes are not included in the cereal group and are not nutritionally comparable to whole grains. However, they are included as potatoes are potential substitutes for some cereals because the way they are eaten in a meal, as a staple food, is similar.

The average rice consumption per capita is 6.3 kg per year (Jordbruksverket, 2023a). All rice is imported (19% from Thailand, 14% from Italy, 67% rest of the world (Moberg et al., 2019). Sweden has good conditions for producing cereals and potatoes and market shares for these products are currently high suggesting that large parts of the production already happen domestically (Table 2). Hence, replacing rice by other whole grain products or potatoes could offer room for increasing self-sufficiency, increasing production, and reducing dependency on imports, in line with the National Food Strategy for Sweden (Ministry of Enterprise and Innovation, 2017). The environmental impacts of whole grains or potatoes are lower than the environmental impacts of rice.

Vegetables, fruits, and berries

The NNR2023 recommends consuming 500-800 grams of vegetables, fruits, and berries per day. The environmental considerations of the NNR2023 recommend consuming fruits and vegetables that store well in order to reduce waste and lower environmental impacts (Blomhoff et al., 2023). Examples of fruits and vegetables that can be easily stored are apples, pears, root vegetables (e.g. carrots), onions, and some brassicas (e.g. cabbage). Additionally, the environmental considerations of the NNR2023 state that locally produced fruits and vegetables generally have lower climate impact due to less waste during transport and storage.

In general, those fruits and vegetables that can be easily stored already have high Swedish market shares compared to other fruits and vegetables (see Table 2). For instance, the Swedish market shares of apples, carrots, and onions is, respectively, 28%, 96%, and 91%, and due to established domestic production there may be room to further increase these market shares and production. The economic model discussed in section 3 showed that for some fruits and vegetables, substitutability towards Swedish produce happens. This implies that Swedish produce tend to be favoured by consumers, which is confirmed by Ekelund et al. (2007). This means that considering the environmental dimension of the NNR2023 may contribute to increasing domestic production of easily stored fruits and vegetables while increasing Swedish market shares and self-sufficiency, which are goals of the National Food Strategy for Sweden (Ministry of Enterprise and Innovation, 2017).

Increasing Swedish self-sufficiency and production of fruits and vegetables could reduce carbon footprints due to lower emission during transport. This holds for most easily storable fruits and vegetables discussed above (Moberg et al., 2019). However, fruits and vegetables, also imported, are generally associated with low climate impact per kilogram product compared to most of our common food products (Moberg et al., 2019), implying that the environmental benefits may be limited.

Potatoes

The NNR2023 states that the intake of boiled or baked potatoes can be part of a healthy diet without specifying an amount based on neither health nor environmental considerations. It is thus not possible to discuss the influence on production and environmental outcomes of introducing environmental considerations in the NNR2023 compared to the NNR2023 without environmental considerations.

Pulses and legumes

The NNR2023 recommends that pulses and legumes are included in a regular diet without specifying a recommended intake neither health nor environmental considerations. It is thus not possible to discuss potential influences of the recommendation based on environmental considerations. However, the environmental considerations state that pulses have low climate impacts and can therefore substitute some food groups with higher climate impacts. In section 5.1 and 5.2, we described how substituting red meat by pulses (i.e. peas and broad beans) has an impact on production and the environment. Other environmental benefits of producing legumes include nitrogen fixation in soil (Blomhoff et al., 2023) and that cultivating cereals after legumes can obtain similar yields while reducing the N fertiliser rate with 20 to 35 kg N per hectare compared to a system where cereals follow cereals (Preissel et al., 2015; Röös et al., 2018). Currently, the main pulses produced in Sweden are peas and broad beans and the market shares for these crops are high (Table 2). Most peas and broad beans grown in Sweden are used for feed and only partly for direct human consumption. There is, however, ongoing product development where these crops are used to produce plant-based protein rich food products. One example is the planned pea protein facility in Lidköping that is expected to start producing pea protein from domestically produced peas for human consumption in 2026 (Lantmännen, 2022). There is also some production, mainly in the southeast of Sweden, of common bean (such as kidney beans and white beans) for direct human consumption.

Nuts and seeds

The NNR2023 recommends consuming 20 to 30 grams of nuts and seeds per day based on health considerations. The environmental considerations of the NNR2023 state that nuts and seeds have low climate impacts but presents no quantitative deviation from this range. Earlier studies have shown that the climate impact and land use per kilogram products of nuts and seeds can be higher than many other plant-based foods categories (Karlsson Potter & Röös, 2021), while substantially lower than animal-based foods (Poore & Nemecek, 2018). Compared to other-plant based foods, nuts and seeds are nutrient and energy dense and therefore a comparison of environmental impact per kilogram product is not feasible for describing impacts of changes on a dietary-level. The use of fresh water for producing particularly tree-nuts (e.g. almonds, hazelnuts and pistachio nuts) has been highlighted by several studies. For instance, the comparison of different nuts on the Swedish market (Karlsson Potter et al., 2020) and increasing consumption of tree-nuts could increase the use of fresh water for irrigation in countries where those nuts are produced.

The vast majority of the consumed nuts and seeds in Sweden is imported, implying that the impacts of including the environmental considerations in the NNR2023 are unlikely to influence Swedish production. However, field trials show that some seeds could be grown in Sweden with good yield, such as sunflower seeds and hemp seed (Husållningssällskapet, 2013), revealing some potential to increase Swedish production if incentives are right.

Fish and seafood

The NNR2023 recommends consuming 300-450 grams of fish per week, of which at least 200 grams of fatty fish. The NNR2023 including environmental considerations recommends consuming fish from sustainably managed stocks and prioritising fish with lower environmental impacts (Blomhoff et al., 2023). Depending on how much fish can be sourced from sustainable stocks or farmed with low environmental impact, the environmental recommendation could lead to lower consumption. There are, however, possibilities to increase Swedish production. In a recent analysis of current and future fish production and consumption in Sweden, the potential to increase Swedish self-sufficiency and production in seafood is highlighted, although this would require substantial changes within fisheries and along the whole production chain as well as increase in aquaculture (Ziegler et al., 2023). Climate impacts of capture fisheries are mostly attributed to diesel use on vessels, while considerable climate impact comes from feed production for farmed fish and seafood (Avadí & Fréon, 2013; Gephart et al., 2021). The most consumed fish species in Sweden are salmon, herring, cod, and shrimp. All of these fish species are mostly imported from Norway. Climate footprints vary depending how fish is produced (farmed or caught) (Philis et al., 2022), the country of origin, and whether fish is imported or not (Ziegler et al., 2023).

Milk and dairy products

The NNR2023 recommends consuming between 350 and 500 ml of low fat milk per day. However, dairy is an important contributor to greenhouse gas emissions due to high methane emissions (IPCC, 2019). Furthermore, feed for dairy cows contributes to land, fertiliser and pesticide use (Wood et al., 2023). Therefore, the environmental considerations of the NNR2023 state that milk consumption may be lower than 350 ml per day if replaced by plant-based alternatives or other foods. This tentative way of presenting the environmental consideration of the NNR2023 implies that there may be little differences compared to the NNR2023 without environmental considerations. This could imply that there is limited to no impact on production and/or the environment.

We explore how substituting part of the milk by plant-based alternatives could influence Swedish production and the environment. Substituting small amounts of dairy by plant-based drink (e.g. oat or soy drink) could slightly reduce the demand for Swedish milk. The environmental impacts of substituting milk by plant-based alternatives have been investigated by Grant and Hicks (2018). They concluded that milk is generally associated with higher greenhouse gas emissions than plant-based alternatives per kg of product. Additionally, land use and water use is generally lower for plant-based dairy substitutes (Karlsson Potter et al., 2020). Biodiversity impacts of plant-based dairy products can in some cases be higher than dairy products, depending on where the ingredients are grown. For instance, coconut milk (can be used as a as cream in cooking) has been shown to have a higher biodiversity impact than Swedish dairy cream (Karlsson Potter et al 2020). Some ingredients for producing plant-based drinks, such as almond, have been associated with high water use. However, the water use for the actual drink depends on the amount used for producing the drink (Karlsson Potter et al., 2020). For instance, for oat drink, studies have shown that climate impact, land use, and water use to be substantially lower than dairy milk (Karlsson Potter et al 2020). Sweden has good conditions for producing oats and rapeseed oil that are the main ingredients in oat drink, potentially opening up an opportunity to increase production.

Eggs

The NNR2023 recommends that the intake of up to one egg per day may be part of a healthy diet. Including the environmental considerations of the NNR2023 does not change this recommendation. This means that it is unlikely that the NNR2023 with and without environmental considerations influence production and the environment differently.

Fats and oils

The NNR2023 recommends consuming at least 25 grams of vegetable oils per day. The recommendations with health considerations and environmental considerations are very similar but for different (health and environmental) reasons. This means that it is unlikely that the NNR2023 with and without environmental considerations influence production and the environment differently.

6.4. Animal welfare

This section discusses how including the environmental considerations in the NNR2023 may change animal welfare of red meat and poultry compared to the NNR2023 not considering environmental aspects.

Red meat

The scenarios analysed in section 6.1 and 6.2 have shown how different levels of adhering to the NNR2023 recommendations could affect Swedish agricultural production, and the environment by reducing red meat consumption and substituting it by either poultry or plant-based alternatives. We discuss how animal welfare might be affected by going from red meat recommendations in NNR2023 to the red meat recommendations in NNR 2023 including environmental considerations. The NNR2023 including environmental considerations recommends a lower intake of red meat (produced in Sweden, abroad or derived from a combination of domestic and imported produce) compared to the NNR2023. Overall, this implies fewer animals in the production of red meat.

The welfare of farm animals is by large affected by the practices used to manage, feed and house the animals. Farm animal welfare is often understood in terms of the Five Freedoms, described by the Farm Animal Welfare Council (2009), covering freedom from hunger and thirst, discomfort, pain, injury and disease, fear and distress and freedom to practice natural behaviour. Animal welfare is regulated by national animal welfare legislations, which in the European Union (EU) cannot be lower than the EU minimum standards. As the animal welfare regulations are not impacted by the nutritional recommendations for humans, there are no apparent reasons to assume that welfare of animals used for food production will be impacted by the NNR2023. It can also be noted that strictly following the NNR2023 implies that in total fewer animals will be used in food production. This means that fewer animals risk poor welfare due to not having their five freedoms respected, which in turn can lead to reduced animal welfare problems in food production simply because fewer individual animals are part of the production.

Poultry

The NNR2023 recommends minimising processed poultry consumption. From an environmental perspective, the NNR2023 recommends that total poultry consumption (including non-processed poultry) should not increase. Instead, it states that reducing red meat consumption should not lead to increased poultry consumption. Since the NNR recommends against increasing in total poultry consumption, the nutritional recommendations in themselves are not likely to impact animal welfare.

However, the scenarios analysed in section 6.1 and 6.2 considered substituting red meat by poultry, ultimately increasing the amount of broilers. If the reduction of red meat is achieved by increased poultry consumption, overall negative effects on animal welfare can occur if broiler production has poorer animal welfare compared with red meat production.

It is not straightforward to compare the welfare of one animal species to another, as production systems differ substantially (L. Göransson, personal communication, 2024). A comparison of animal welfare consequences between two different animal species and production systems would need to consider factors such as the number of animals involved, the extent of negative animal welfare impacts, and the duration of the impacts to mention some. Still, it can be concluded that if a reduction in the consumption of red meat is achieved by an increased consumption of poultry, more individual animals will be raised in a production system that has well-known animal welfare problems (Dawson et al., 2021; L. Göransson, personal communication, 2024). The situation in the organic broiler production might be better (Göransson et al., 2020), so the consequences might be less severe for individual animals if consumers choose organic over conventional poultry when substituting red meat.

Fish

The NNR2023 including environmental considerations recommends consuming fish from sustainable managed fish stocks. It seems unlikely that including these environmental considerations in the NNR2023 will have a major influence on animal welfare levels of fish, as it recommends what fish should be consumed without mentioning under what circumstances (i.e. animal welfare) fish should be caught.

6.5. General discussion

In this section we discuss the results described in sections 6.1-6.4. First, we describe potential trade-offs between impacts on production and environmental outcomes and explore potential opportunities for increasing Swedish production. Second, we discuss limitations of this report. Finally, we present some tentative policy implications.

Trade-offs between production and environmental outcomes and opportunities for Swedish production

The scenarios revealed trade-offs between agricultural production and some of the environmental outcomes in Sweden. On the one hand, reducing red meat consumption by only reducing red meat imports does not affect the number of Swedish animals, the area of grazed semi-natural pastures, or greenhouse gas and ammonia emissions within Sweden. This implies that Swedish red meat production and the area of cropland remain largely unaffected but also that there are no environmental gains in Sweden. On the other hand, only reducing Swedish production has the most significant environmental benefits in Sweden in terms of greenhouse gas and ammonia emission (in territorial terms), but will adversely impact biodiversity impacts from grazing of semi-natural pastures. These scenarios reduce total cropland demand and the numbers of animals produced in Sweden. How reducing the number of animals may influence rural economies is not investigated in our environmental models. Previous research has indicated that a possible implication of reducing the number of animals could be that regions specialising in livestock production will have a lower income in the short run (Rieger et al., 2023). However, in the long run, damage to the overall agricultural sector may be limited, as there is enough time to change towards more production of crops and other vegetables with opportunities to increase production to compensate income losses in livestock production (Geibel & Freund, 2023). Having said that, it should be noted that this opportunity is likely more limited in some parts of Sweden, depending on agronomic conditions in different parts of the country.

We discuss some opportunities for Swedish production. The scenarios revealed that there is a degree of reduced cropland demand, depending on the scenario being analysed. This frees up some land that may become available for other production opportunities that are in line with the NNR2023 including environmental considerations. Some opportunities to increase Swedish production include: fruits and vegetables that can be easily stored, rapeseed, pulses and legumes, and sunflower and hemp seeds (see section 6.3). However, these opportunities to increase Swedish production should also consider whether it is practically feasible to implement them, as it remains uncertain how the production system for different crops responds to increase demands and how it can be feasibly integrated in a crop rotation. The reduced cropland demand may also open up for more extensive production by e.g. increasing the share of cropland farmed organically in line with the Swedish food strategy.

Limitations

Informative policy instruments, such as the NNR2023, are unlikely to affect consumer behaviour on its own (SAPEA, 2023). Hence, the scenarios that were analysed should be interpreted as "what-if" scenarios, meaning that they do not necessarily reflect likely future pathways. Another limitation of this report is that the environmental models provide useful insights into how Swedish agricultural production in terms of land use and animal numbers at an aggregated level may change but that these models cannot provide insights into farm-level and supply chain level changes.

Understanding the implications of these changes for farms and supply chain actors (e.g. slaughterhouses, cooperatives, processors) requires analysing different units of analysis beyond the national level due to the complexity, dynamic nature, and long-term character of structural change processes (Neuenfeldt et al., 2019). For example, the observed decrease in animal numbers may influence farms differently, either by influencing the number of farms or average farm sizes. It could be that smaller livestock farms are affected more by a decrease in animal numbers than larger farms. However, the environmental models do not give us any insights into potential direction of these structural changes. Determining these outcomes goes beyond the report's scope, as it requires a nuanced understanding of farm structural change trends and is contingent on agricultural policies. These factors are not considered in CIBUSmod. To accurately assess how these long-term trends in agricultural production affect farms, agent-based models aimed at understanding structural agricultural change like AgriPoliS (Happe et al., 2009; Pitson et al., 2020) or general equilibrium models, such as CAPRI (Rieger et al., 2023), could be used.

Policy implications

Our findings have the following implications for policymakers. First, Sweden has binding commitments under the NEC Directive to reduce ammonia emission to 48 kt (Swedish EPA 2023), with agriculture significantly contributing to these emissions. There are several ways to reduce agricultural ammonia emissions, including improved nutrient management and low emission technologies in animal housing, manure management and fertiliser application (Sutton et al. 2022). These technology-driven solutions however likely need to be combined with reduced animal numbers to move into the direction of meeting the NEC directives. We analysed how several scenarios considering different ranges of reduced red meat consumption substituted by either poultry or plant-based protein rich foods would reduce the number of animals, which would result in lower ammonia emission. In the most extreme scenario where ammonia is reduced most—which is seemingly unlikely to happen—the level of national agricultural ammonia emissions are decreased to such an extent that it would meet Sweden's 2030 commitment. Furthermore, one of the Swedish Environmental Objectives relates to a varied agricultural landscape, which includes biodiversity. The environmental models considered the area of grazed semi-natural grasslands as an indicator for biodiversity conservation services. Under different scenarios, the area of semi-natural grassland decreased, which may be associated with lower biodiversity preservation. However, previous studies have shown that the area of grazed semi-natural grassland is mostly driven by the lack of profitability.

Second, our findings may have implications for the National Food Strategy of Sweden (Ministry of Enterprise and Innovation, 2017), which aimed at increasing food production and self-sufficiency in Sweden. In particular, introducing environmental considerations in the NNR2023 offer opportunities for increased production and self-sufficiency for fruits and vegetables that can be easily stored, rapeseed, pulses and legumes, and potatoes and cereals to replace rice.

Third, the NNR2023 points out a direction of change when it comes to how food consumption must change for improved public health and decreased environmental impact. However, the guidelines themselves are unlikely to change consumption patterns. Achieving sustainable consumption, following the NNR2023 including environmental considerations, and especially encouraging consumers to switch from red meat to more plant-based foods, thus requires a combination of different policies. Röös et al. (2021) highlight three entry points for action: i) intensify work in the public sector (e.g. plant-based training for chefs), ii) develop national targets for sustainable food consumption (e.g. formulating concrete consumption-based greenhouse gas emission targets linked to the NNR2023), and iii) develop and implement effective and attractive policy instrument packages, which can include price-based policies on several food groups combined with informative policy instruments.

7. Conclusions

The aim of this report is to investigate how potential consumption changes following the environmental considerations of the NNR2023 compared to the NNR2023 without environmental considerations could influence domestic food production and environmental outcomes. These environmental outcomes include greenhouse gas emissions, ammonia emissions, and the area of semi-natural pastures grazed. Additionally, impacts on animal welfare were investigated. We answered three research questions.

RQ1: How could including environmental considerations in the NNR2023 potentially influence consumption of different food groups in Sweden?

Changing consumer behaviour is a complex task. Introducing FBDG, such as the NNR2023, on its own will not heavily affect consumer behaviour. However, the NNR2023 can play a role in shaping consumer preferences. We analyse these consumer preferences using a demand system to understand how consumer substitute goods or do not consider goods as substitutes, mostly focussing on substitutions for red meat consumption. The following conclusions can be drawn:

- The demand system showed that consumers tend to substitute red meat by other meat (e.g. poultry) or seafood. It is unlikely that consumers will switch from red meat to plant-based protein rich foods. This implies that a recommendation to reduce red meat consumption may lead to increased poultry or seafood consumption.
- For those consumers who are willing to reduce red meat consumption, there is a possibility to slightly reduce imported red meat with a greater proportion than Swedish red meat. This means that some consumers would consider a shift towards a higher proportion of Swedish red meat if the prices and information provision are right.

RQ2: What are the effects of these changes in consumption on Swedish agricultural production?

We analysed twenty-four scenarios with different substitutions of red meat by poultry or plant-based protein rich foods and varying changes in imports and Swedish production. The following conclusions can be drawn:

- Given the current market shares of Swedish red meat, there is space to decrease Swedish red meat consumption without affecting Swedish production. This can happen when reduced red meat consumption only results in reductions of imported red meat. In these scenarios, there are no impacts on domestic land use, the number of animals, greenhouse gas emissions, ammonia emissions and use of semi-natural grasslands. However, a scenario where only imported red meat is reduced seems unlikely to happen.

- If reductions in red meat consumption were assumed to affect Swedish red meat production, substituting red meat for poultry or plant-based protein rich foods reduces the demand for Swedish cropland. Compared to the NNR2023 with only health considerations, cropland demand was reduced more when environmental considerations are included in the NNR2023. The difference between including the environmental considerations in the NNR2023 recommendations or not was 0.3-0.7 percentage units under a small impact of recommendations and 1.3-2.3 percentage units under a large impact of recommendations. There are some opportunities to increase cropland for grain legumes or rapeseed and increase Swedish production of these foods.
- For food groups other than red meat or poultry, we discuss potential changes introduced by including the environmental considerations in the NNR2023 compared to the health-based rationale of the NNR2023. The NNR2023 including environmental considerations recommends to increase consumption of fruits and vegetables that can be easily stored and reduce rice consumption in favour of other cereals. If consumption follows these recommendations, this may open up opportunities to increase Swedish production of fruits and vegetables that can be easily stored and cereals.

RQ3: What are the effects of these changes in production and consumption on the environmental outcomes in Sweden and abroad?

The environmental impacts of substituting red meat with poultry or plant-based protein rich foods are assessed in terms of Swedish greenhouse gas emissions, ammonia emissions, the area of grazed semi-natural grasslands, and global climate footprints. The NNR2023 including environmental considerations leads to a higher reduction of these environmental impacts than the NNR2023 only based on health considerations. Additionally, changes in animal welfare are considered. The following conclusions can be drawn:

- Compared to the NNR2023 with only health considerations, greenhouse gas emissions were reduced more when environmental considerations are included in the NNR2023. The difference in greenhouse gas emission reductions in the NNR2023 including the environmental considerations or not is 0.4-0.8 and 1.6-3.1 percentage units under a small and large impact of the recommendations, respectively.
- Compared to the NNR2023 with only health considerations, ammonia emissions were reduced more when environmental considerations are included in the NNR2023. The difference in ammonia reductions between including environmental considerations in the NNR2023 or not was 0.5-1.1 percentage units under a small impact of the recommendations and 2.0-3.8 percentage units under a large impact of the recommendations.

- The area of grazed semi-natural grassland reduced for all scenarios where Swedish production of red meat decreased. Earlier studies indicate that a lack of profitability in grazing-based systems rather than the animal numbers is the main factor limiting the utilization of the semi-natural grasslands. Therefore, production-side policy measures are of high importance to maintain the semi-natural grasslands.
- Compared to the NNR2023 with only health considerations, the climate footprint of the whole Swedish diet reduced more when environmental considerations are included in the NNR2023. The difference in climate footprint reduction between including environmental considerations in the NNR2023 or not is between 0.3-0.4 percentage units under a small impact of the recommendations and between 1.3-1.5 percentage units under large impact of the recommendations.
- Overall, animal welfare levels are unlikely to change due to the inclusion of environmental considerations in the NNR2023. However, in the analysed scenarios that consider substituting red meat by poultry, more individual animals will be raised and thus more individuals will be at risk of experiencing poor animal welfare.

References

Ahlgren, S., Behaderovic, D., Wirsenius, S., Carlsson, A., Hessle, A., Toräng, P., Seeman, A., Braver, T., & Kvarnbäck, O. (2022). *Miljöpåverkan av svensk nöt- och lammköttsproduktion*. RISE. https://www.diva-portal.org/smash/record.jsf?dswid=-2324&pid=diva2%3A1718732

Auffret, A. G., Kimberley, A., Plue, J., & Waldén, E. (2018). Super-regional land-use change and effects on the grassland specialist flora. *Nature Communications*, *9*(1), Article 1. https://doi.org/10.1038/s41467-018-05991-y

Avadí, A., & Fréon, P. (2013). Life cycle assessment of fisheries: A review for fisheries scientists and managers. *Fisheries Research*, *143*, 21–38. https://doi.org/10.1016/j.fishres.2013.01.006

Benton, T. G., Bieg, C., Harwatt, H., Pudasaini, R., & Wellesley, L. (2021). *Food system impacts on biodiversity loss* (pp. 1–75).

Bittman, S., Dedina, M., Howard, C. M., Oenema, O., & Sutton, M. (2014). *Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen. Centre for Ecology & Hydrology*.

Blomhoff, R., Andersen, R., Arnesen, E. K., Christensen, J. J., Eneroth, H., Erkkola, M., Gudanviciene, I., Halldorsson, T. I., Hoyer-Lund, A., Lemming, E. W., Meltzer, H. M., Pitsi, T., Schwab, U., Siskna, I., Thorsdottir, I., & Trolle, E. (2023). *Nordic Nutrition Recommendations 2023*. Nordic Council of Ministers.

Brown, K. A., Timotijevic, L., Barnett, J., Shepherd, R., Lähteenmäki, L., & Raats, M. M. (2011). A review of consumer awareness, understanding and use of food-based dietary guidelines. *British Journal of Nutrition*, *106*(1), 15–26. https://doi.org/10.1017/S0007114511000250

Carlsson, F., Kataria, M., & Lampi, E. (2022). How much does it take? Willingness to switch to meat substitutes. *Ecological Economics*, *193*, 107329. https://doi.org/10.1016/j.ecolecon.2021.107329

Cederberg, C., & Henriksson, M. (2020). *Gräsmarkernas användning i Sverige*. Chalmers Tekniska Hogskola. https://research.chalmers.se/publication/517805

Chaudhary, A., & Brooks, T. M. (2018). Land use intensity-specific characterization factors to assess product biodiversity footprints. *Environmental Science and Technology*, *52*(9), 5094–5104.

Christensen, J. J., Arnesen, E. K., Andersen, R., Eneroth, H., Erkkola, M., Høyer, A., Lemming, E. W., Meltzer, H. M., Halldórsson, Þ. I., Þórsdóttir, I., Schwab, U., Trolle, E., & Blomhoff, R. (2020). The Nordic Nutrition Recommendations 2022 – principles and methodologies. *Food & Nutrition Research*, *64*. https://doi.org/10.29219/fnr.v64.4402

Clark, M. A., Domingo, N. G. G., Colgan, K., Thakrar, S. K., Tilman, D., Lynch, J., Azevedo, I. L., & Hill, J. D. (2020). Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science*, *370*(6517), 705–708. https://doi.org/10.1126/science.aba7357

Dawson, L. C., Widowski, T. M., Liu, Z., Edwards, A. M., & Torrey, S. (2021). In pursuit of a better broiler: A comparison of the inactivity, behavior, and enrichment use of fast- and slower growing broiler chickens. *Poultry Science*, *100*(12), 101451. https://doi.org/10.1016/j.psj.2021.101451

Deaton, A., & Muellbauer, J. (1980). An Almost Ideal Demand System. *The American Economic Review*, *70*(3).

Edgerton, D. L. (1997). Weak Separability and the Estimation of Elasticities in Multistage Demand Systems. *American Journal of Agricultural Economics*, *79*(1), 62–79. https://doi.org/10.2307/1243943
Edman, F., Wallman, M., & Nilsson, K. (2022). *Klimatavtryck av Svensk Fågels kycklingproduktion 2021, version 3*. RISE. https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1687585&dswid=-9521
EEA. (2023). *National Emission reduction Commitments Directive reporting status*. https://www.eea.europa.eu/publications/national-emission-reduction-commitments-directive-2022/national-emission-reduction-commitments-directive
Einarsson, R., Henriksson, M., Hoffmann, M., & Cederberg, C. (2022). The nitrogen footprint of Swedish food consumption. *Environmental Research Letters*, *17*(10), 104030. https://doi.org/10.1088/1748-9326/ac9246
Ekelund, L., Fernqvist, F., & Tjärnemo, H. (2007). Consumer preferences for domestic and organically labelled vegetables in Sweden. *Acta Agriculturae Scandinavica, Section C — Food Economics*, *4*(4), 229–236. https://doi.org/10.1080/16507540701800665
Eriksson, O. (2022). Coproduction of Food, Cultural Heritage and Biodiversity by Livestock Grazing in Swedish Semi-natural Grasslands. *Frontiers in Sustainable Food Systems*, *6*. https://www.frontiersin.org/articles/10.3389/fsufs.2022.801327
Eriksson, O., & Cousins, S. A. O. (2014). Historical Landscape Perspectives on Grasslands in Sweden and the Baltic Region. *Land*, *3*(1), 300–321. https://doi.org/10.3390/land3010300
Faccioli, M., Law, C., Caine, C. A., Berger, N., Yan, X., Weninger, F., Guell, C., Day, B., Smith, R. D., & Bateman, I. J. (2022). Combined carbon and health taxes outperform single-purpose information or fiscal measures in designing sustainable food policies. *Nature Food*, *3*(5), Article 5. https://doi.org/10.1038/s43016-022-00482-2
FAO. (2011). *Global food losses and food waste: Extent, causes and prevention; study conducted for the International Congress Save Food! at Interpack 2011, [16 - 17 May], Düsseldorf, Germany* (J. Gustavsson, Ed.). Food and Agriculture Organization of the United Nations.
FAO. (2023). *SDG Progress report 2023: Tracking progress on food and agriculture-related SDG indicators 2023*. https://doi.org/10.4060/cc7088en
Farm Animal Welfare Council. (2009). *Farm Animal Welfare in Great Britain: Past, Present and Future*. Farm Animal Welfare Council.
Fehlenberg, V., Baumann, M., Gasparri, N. I., Piquer-Rodriguez, M., Gavier-Pizarro, G., & Kuemmerle, T. (2017). The role of soybean production as an underlying driver of deforestation in the South American Chaco. *Global Environmental Change*, *45*, 24–34. https://doi.org/10.1016/j.gloenvcha.2017.05.001
Från Sverige. (2022, February 10). *Svenskodlade baljväxter från GoGreen*. https://fransverige.se/aktuellt/svenskodlade-baljvaxter-fran-gogreen/
GBD Risk Factors Collaborators. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *Lancet*, *396*, 1223–1249. https://doi.org/10.1016/S0140-6736(20)30752-2
Geibel, I., & Freund, F. (2023). The effects of dietary changes in Europe on greenhouse gas emissions and agricultural incomes in Ireland and Denmark. *Environmental Research Letters*, *18*(12), 124026. https://doi.org/10.1088/1748-9326/ad0681
Gephart, J. A., Henriksson, P. J. G., Parker, R. W. R., Shepon, A., Gorospe, K. D., Bergman, K., Eshel, G., Golden, C. D., Halpern, B. S., Hornborg, S., Jonell, M.,

Metian, M., Mifflin, K., Newton, R., Tyedmers, P., Zhang, W., Ziegler, F., & Troell, M. (2021). Environmental performance of blue foods. *Nature, 597*(7876), Article 7876. https://doi.org/10.1038/s41586-021-03889-2

Ghazani, S. M., & Marangoni, A. G. (2022). Microbial lipids for foods. *Trends in Food Science & Technology*, *119*, 593–607. https://doi.org/10.1016/j.tifs.2021.10.014

Göransson, L. (2024). *Personal communication, expert in animal welfare, e-mail 2024 01 26.* [Personal communication].

Göransson, L., Yngvesson, J., & Gunnarsson, S. (2020). Bird Health, Housing and Management Routines on Swedish Organic Broiler Chicken Farms. *Animals*, *10*(11), 2098. https://doi.org/10.3390/ani10112098

Grant, C. A., & Hicks, A. L. (2018). Comparative Life Cycle Assessment of Milk and Plant-Based Alternatives. *Environmental Engineering Science*, *35*(11), 1235–1247. https://doi.org/10.1089/ees.2018.0233

Happe, K., Schnicke, H., Sahrbacher, C., & Kellermann, K. (2009). Will They Stay or Will They Go? Simulating the Dynamics of Single-Holder Farms in a Dualistic Farm Structure in Slovakia. *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie, 57*(4), 497–511. https://doi.org/10.1111/j.1744-7976.2009.01167.x

Hessle, A., & Danielsson, R. (2023). *Antal nötkreatur som krävs för att nå gynnsam bevarandestatus i svenska naturbetesmarker och djurens metanutsläpp*. Department of Animal Environment and Health, Swedish University of Agricultural Sciences. https://res.slu.se/id/publ/123395

Hessle, A., & Kumm, K.-I. (2011). Use of beef steers for profitable management of biologically valuable semi-natural pastures in Sweden. *Journal for Nature Conservation*, *19*(3), 131–136. https://doi.org/10.1016/j.jnc.2010.10.002

Ingram, J. (2011). A food systems approach to researching food security and its interactions with global environmental change. *Food Security, 3*(4), 417–431. https://doi.org/10.1007/s12571-011-0149-9

IPBES. (2019). Summary for policy makers of the global assessment report on biodiversity and ecosystems services. In *The International Science-Policy Platform on Biodiversity and Ecosystem Services*.

IPCC. (2019). *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme* (IGES).

Jamieson, A., & Hessle, A. (2021). *Hinder och möjligheter för ökad naturbetesdrift ur ett lantbrukarperspektiv: En kunskapsöversikt. Institutionen för husdjurens utfodring och vård, Sveriges lantbruksuniversitet*. https://res.slu.se/id/publ/115251

Jordbruketisiffror. (2019). Andelen svenskproducerat kött i vår konsumtion har ökat de senaste åren. *Jordbruket i siffror*. https://jordbruketisiffror.wordpress.com/2019/03/13/andel-svenskproducerat-kott-i-var-konsumtion-okar/

Jordbruksverket. (2023a). *Direktkonsumtion efter Vara, Variabel och År*. Direktkonsumtion Efter Vara, Variabel Och År. http://statistik.sjv.se/PXWebPXWeb/pxweb/sv/Jordbruksverkets statistikdatabas/Jordbruksverkets statistikdatabas__Konsumtion av livsmedel/JO1301K1.px/

Jordbruksverket. (2023b). *Köttkonsumtion av kött* [Text]. https://jordbruksverket.se/mat-och-drycker/hallbar-produktion-och-konsumtion-av-mat/konsumtion-av-kott

Jordbruksverket. (2023c). *Marknadsrapport animalieprodukter 2022*.

Jordbruksverket. (2023d). *Priser och marknadsinformation för livsmedel*. https://jordbruksverket.se/mat-och-drycker/handel-och-marknad/priser-och-marknadsinformation-for-livsmedel
Jordbruksverket. (2023e). *Totalkonsumtion efter Vara, Variabel och År*. Totalkonsumtion Efter Vara, Variabel Och År. http://statistik.sjv.se/PXWebPXWeb/pxweb/sv/Jordbruksverkets statistikdatabas/Jordbruksverkets statistikdatabas__Konsumtion av livsmedel/JO1301K2.px/
Karlsson, J. O., Karlsson-Potter, H., Lagnelöv, O., Ericsson, N., Einarsson, R., & Hansson, P.-A. (forthcoming). *CIBUSmod: A spatially disaggregated biophysical agri-food systems model for studying national-level demand- and production-side intervention scenarios*.
Karlsson Potter, H., Lundmark, L., & Röös, E. (2020). *Environmental impact of plant-based foods*.
Karlsson Potter, H., & Röös, E. (2021). Multi-criteria evaluation of plant-based foods – use of environmental footprint and LCA data for consumer guidance. *Journal of Cleaner Production*, *280*, 124721. https://doi.org/10.1016/j.jclepro.2020.124721
Lagerkvist, C. J., Berthelsen, T., Sundström, K., & Johansson, H. (2014). Country of origin or EU/non-EU labelling of beef? Comparing structural reliability and validity of discrete choice experiments for measurement of consumer preferences for origin and extrinsic quality cues. *Food Quality and Preference*, *34*, 50–61. https://doi.org/10.1016/j.foodqual.2013.12.009
Landquist, B., Woodhouse, A., Axel-Nilsson, M., Sonesson, U., Elmquist, H., Velander, K., Wallgren, P., Karlsson, O., Eriksson, I., & Åberg, M. (2020). *Uppdaterad och utökad livscykelanalys av svensk grisproduktion*. RISE. https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1516404&dswid=-2324
Lantmännen. (2022). *Miljardinvestering gör Lantmännen unikt i norra Europa*. Lantmännen. https://www.lantmannen.se/om-lantmannen/press-och-nyheter/pressmeddelanden/2022/miljardinvestering-gor-lantmannen-unikt-i-norra-europa2/
Larsson, C., Boke Olén, N., & Brady, M. (2020). *Naturbetesmarkens framtid—En fråga om lönsamhet*. Rapport/AgriFood Economics Centre. https://res.slu.se/id/publ/115477
Lazaric, N., Le Guel, F., Belin, J., Oltra, V., Lavaud, S., & Douai, A. (2020). Determinants of sustainable consumption in France: The importance of social influence and environmental values. *Journal of Evolutionary Economics*, *30*(5), 1337–1366. https://doi.org/10.1007/s00191-019-00654-7
Livsmedelsverkets. (2015). *Swedish dietary guidelines—Risk and benefit management report* (Livsmedelsverkets Rapportserie).
Mancino, L., Kuchler, F., & Leibtag, E. (2008). Getting consumers to eat more whole-grains: The role of policy, information, and food manufacturers. *Food Policy*, *33*(6), 489–496. https://doi.org/10.1016/j.foodpol.2008.05.005
Martini, D., Tucci, M., Bradfield, J., Di Giorgio, A., Marino, M., Del Bo', C., Porrini, M., & Riso, P. (2021). Principles of Sustainable Healthy Diets in Worldwide Dietary Guidelines: Efforts So Far and Future Perspectives. *Nutrients*, *13*(6), Article 6. https://doi.org/10.3390/nu13061827
McCrackin, M. L., Gustafsson, B. G., Hong, B., Howarth, R. W., Humborg, C., Savchuk, O. P., Svanbäck, A., & Swaney, D. P. (2018). Opportunities to reduce nutrient inputs to the Baltic Sea by improving manure use efficiency in agriculture. *Regional Environmental Change*, *18*(6), 1843–1854. https://doi.org/10.1007/s10113-018-1308-8

Meijer, G. W., Grunert, K. G., & Lähteenmäki, L. (2023). Chapter Seven - Supporting consumers' informed food choices: Sources, channels, and use of information. In F. Toldrá (Ed.), *Advances in Food and Nutrition Research* (Vol. 104, pp. 229–257). Academic Press. https://doi.org/10.1016/bs.afnr.2022.10.005

Ministry of Enterprise and Innovation. (2017). *A National Food Strategy for Sweden – more jobs and sustainable growth throughout the country*.

Moberg, E., Karlsson Potter, H., Wood, A., Hansson, P.-A., & Röös, E. (2020). Benchmarking the Swedish Diet Relative to Global and National Environmental Targets—Identification of Indicator Limitations and Data Gaps. *Sustainability*, *12*(4), 1407. https://doi.org/10.3390/su12041407

Moberg, E., Säll, S., Hansson, P.-A., & Röös, E. (2021). Taxing food consumption to reduce environmental impacts – Identification of synergies and goal conflicts. *Food Policy*, *101*, 102090. https://doi.org/10.1016/j.foodpol.2021.102090

Moberg, E., Walker Andersson, M., Säll, S., Hansson, P.-A., & Röös, E. (2019). Determining the climate impact of food for use in a climate tax—Design of a consistent and transparent model. *The International Journal of Life Cycle Assessment*, *24*(9), 1715–1728. https://doi.org/10.1007/s11367-019-01597-8

Neuenfeldt, S., Gocht, A., Heckelei, T., & Ciaian, P. (2019). Explaining farm structural change in the European agriculture: A novel analytical framework. *European Review of Agricultural Economics*, *46*(5), 713–768. https://doi.org/10.1093/erae/jby037

Nilsson, T. (2011). *Gödsling av hallon. LTJ-fakultetens faktablad*.

Philis, G., Ziegler, F., Jansen, M. D., Gansel, L. C., Hornborg, S., Aas, G. H., & Stene, A. (2022). Quantifying environmental impacts of cleaner fish used as sea lice treatments in salmon aquaculture with life cycle assessment. *Journal of Industrial Ecology*, *26*(6), 1992–2005. https://doi.org/10.1111/jiec.13118

Pitson, C., Bijttebier, J., Appel, F., & Balmann, A. (2020). How Much Farm Succession is Needed to Ensure Resilience of Farming Systems? *EuroChoices*, *19*(2), 37–44. https://doi.org/10.1111/1746-692x.12283

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, *360*(6392), 987 992.

Preissel, S., Reckling, M., Schläfke, N., & Zander, P. (2015). Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: A review. *Field Crops Research*, *175*, 64–79. https://doi.org/10.1016/j.fcr.2015.01.012

Rieger, J., Freund, F., Offermann, F., Geibel, I., & Gocht, A. (2023). From fork to farm: Impacts of more sustainable diets in the EU-27 on the agricultural sector. *Journal of Agricultural Economics*, *74*(3), 764–784. https://doi.org/10.1111/1477-9552.12530

Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D., & Garnett, T. (2017). Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Global Environmental Change*, *47*, 1–12. https://doi.org/10.1016/j.gloenvcha.2017.09.001

Röös, E., Carlsson, G., Ferawati, F., Hefni, M., Stephan, A., Tidåker, P., & Witthöft, C. (2018). Less meat, more legumes: Prospects and challenges in the transition toward sustainable diets in Sweden. *Renewable Agriculture and Food Systems*, 1–14. https://doi.org/10.1017/S1742170518000443

Röös, E., Larsson, J., Sahlin, K. R., Jonell, M., Lindahl, T., André, E., Säll, S., Harring, N., & Persson, M. (2021). *Policy Options for Sustainable Food Consumption – Review and Recommendations for Sweden*.

Säll, S., & Gren, I.-M. (2015). Effects of an environmental tax on meat and dairy consumption in Sweden. *Food Policy*, *55*, 41–53. https://doi.org/10.1016/j.foodpol.2015.05.008

SAPEA. (2023). *Towards sustainable food consumption: Evidence review report* (1.0). Zenodo. https://doi.org/10.5281/ZENODO.8031939

SCB. (2023). *Livsmedelsförsäljningsstatistik 2022* [dataset].

Scholderer, J., & Trondsen, T. (2008). The dynamics of consumer behaviour: On habit, discontent, and other fish to fry. *Appetite*, *51*(3), 576–591. https://doi.org/10.1016/j.appet.2008.04.011

Schwarzmueller, F., & Kastner, T. (2022). Agricultural trade and its impacts on cropland use and the global loss of species habitat. *Sustainability Science*, *17*(6), 2363–2377. https://doi.org/10.1007/s11625-022-01138-7

SEPA. (2022). *New methods and environmental indicators supporting policies for sustainable consumption in Sweden: Final report – PRINCE phase 2*. Naturvårdsverket. https://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-10263

SEPA. (2023). *Jordbruk, utsläpp av växthusgaser*. https://www.naturvardsverket.se/data-och-statistik/klimat/vaxthusgaser-utslapp-fran-jordbruk/

Simonsson, A. (2006). *Fodermedel och näringsrekommendationer för gris* (Institutionen för husdjurens utfodring och vård, 266). Sveriges lantbruksuniv.

Spörndly, E., & Glimskär, A. (2018). *Betesdjur och betestryck i naturbetesmarker*. Sveriges Lantbruksuniversitet. https://pub.epsilon.slu.se/15649/

Spörndly, R. (2003). *Fodertabeller för idisslare* (Institutionen För Husdjurens Utfodring Och Vård 257). Sveriges lantbruksuniversitet.

Sutton, M. A., Howard, C. M., Mason, K. E., Brownlie, W., & Cordovil, C. (2022). Nitrogen Opportunities for Agriculture. *Food & Environment. UNECE Guidance Document on Integrated Sustainable Nitrogen Management. UK Centre for Ecology & Hydrology*.

Sveriges miljömål. (2024). *Sveriges miljömål*. https://www.sverigesmiljomal.se/

Swedish Board of Agriculture. (2014). *Riktlinjer för gödsling och kalkning 2015*.

Swedish Board of Agriculture. (2023a). *Slakt av djur uppfödda med ekologiska produktionsmetoder*.

Swedish Board of Agriculture. (2023b). *Slakt av större lantbruksdjur vid slakteri*.

Swedish EPA. (2020). *Sveriges arter och naturtyper i EU:s artoch habitatdirektiv – Resultat från rapportering 2019 till EU av bevarandestatus 2013-2018*. https://www.naturvardsverket.se/4ac60f/globalassets/media/publikationer-pdf/6900/978-91-620-6914-8.pdf

Swedish EPA. (2023). *Informative Inventory Report Sweden 2023 – Submitted under the Convention on Long-Range Transboundary Air Pollution*. https://www.naturvardsverket.se/494814/contentassets/a793266c97e54f95806a9793fad82217/informative-inventory-report-sweden-2023.pdf

Tidåker, P., Potter, H. K., Carlsson, G., & Röös, E. (2021). Towards sustainable consumption of legumes: How origin, processing and transport affect the environmental impact of pulses. *Sustainable Production and Consumption*, *27*, 496–508.

Tuck, S. L., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L. A., & Bengtsson, J. (2014). Land-use intensity and the effects of organic farming on biodiversity: A hierarchical meta-analysis. *J Appl Ecol*, *51*, 746–755. https://doi.org/10.1111/1365-2664.12219

Varian, R. H. (2014). *Intermediate Microeconomics with Calculus: A Modern Approach: International Student Edition*. W. W. Norton & Company.

Vermeir, I., & Verbeke, W. (2008). Sustainable food consumption among young adults in Belgium: Theory of planned behaviour and the role of confidence and values. *Ecological Economics*, *64*(3), 542–553. https://doi.org/10.1016/j.ecolecon.2007.03.007

Vijay, V., Pimm, S. L., Jenkins, C. N., & Smith, S. J. (2016). The Impacts of Oil Palm on Recent Deforestation and Biodiversity Loss. *PLOS ONE*, *11*(7), e0159668. https://doi.org/10.1371/journal.pone.0159668

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Majele Sibanda, L., … Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, *393*(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Wood, A., Moberg, E., Curi-Quinto, K., Van Rysselberge, P., & Röös, E. (2023). From "good for people" to "good for people and planet" – Placing health and environment on equal footing when developing food-based dietary guidelines. *Food Policy*, *117*, 102444. https://doi.org/10.1016/j.foodpol.2023.102444

Yara. (2023). *Växtnäring*. https://www.yara.se/vaxtnaring/

Yeh, C.-H., & Hirsch, S. (2023). A meta-regression analysis on the willingness-to-pay for country-of-origin labelling. *Journal of Agricultural Economics*, *74*(3), 719–743. https://doi.org/10.1111/1477-9552.12528

Ziegler, F., Axelsson, A., Sanders, C., & Hornborg, S. (2023). *Sverige och sjömaten– idag och i morgon. Kan vi samtidigt öka produktion, konsumtion och hållbarhet?* [Mistra Food Futures Report #17]. SLU Repro.

Zira, S., Rydhmer, L., Ivarsson, E., Hoffmann, R., & Röös, E. (2021). A life cycle sustainability assessment of organic and conventional pork supply chains in Sweden. *Sustainable Production and Consumption*, *28*, 21–38. https://doi.org/10.1016/j.spc.2021.03.028

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Appendix A – Additional model descriptions

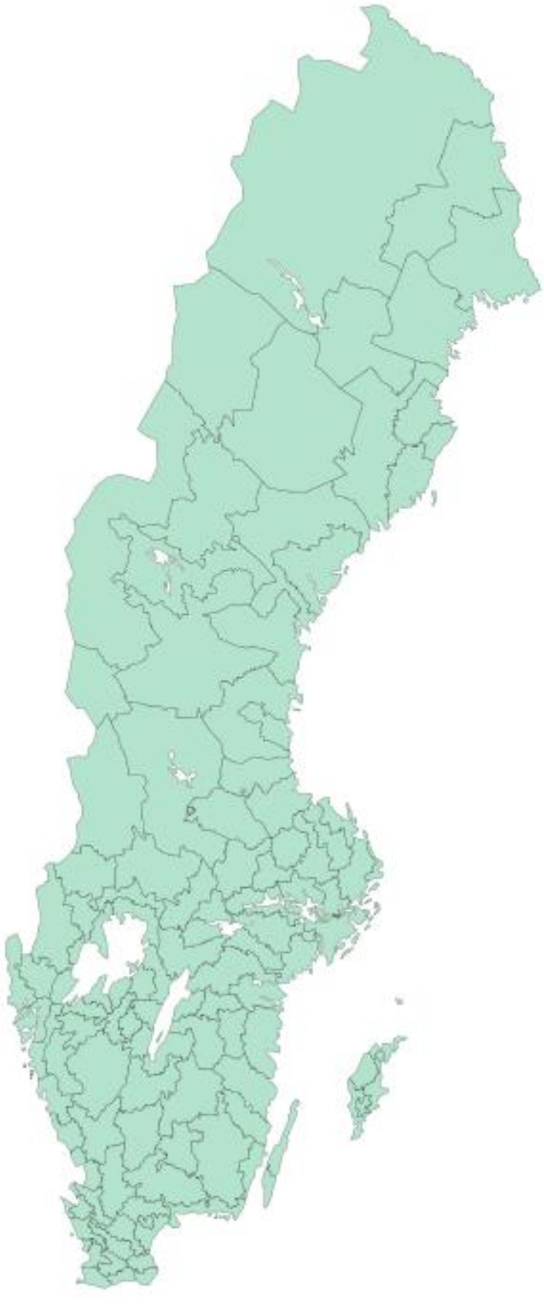

Figure A 1 Map of Sweden with the 106 harvest regions ("skördeområden").

Table A 1 Animal feed rations in CIBUSmod [kg DM head^{-1} year^{-1}]. The figures represents rations if one hypothetically assumes that an animal of a specific category would be alive for one year. Animals such as broilers, slaughter pigs, lambs and bulls are however slaughtered earlier and therefore does not consume the entire ration. These values represent feed intake and do not include any ensilation, storage or feeding losses, which are accounted for to calculate the final demand for feed in the model. Rations are shown for aggregated feed categories while in the model 41 different feeds are used including e.g. different cereals, soybean meal, rapeseed meal, various cereal by-products, etc.

	Ley silage and hay	Other silage and straw	Grazing	Cereals	Peas and broad beans	Soybean meal	Other concentrates and minerals	Total
Beef cattle								
Suckler cows	757	827	2 238				33	**3 856**
Calves <1yr	541		207	205	3.7	0.6	20	**977**
Heifers >2yr	2 069		914				22	**3 005**
Steers >1yr	2 057		909				21	**2 987**
Bulls >1yr	2 139	147		1 179	97	2.1	69	**3 633**
Dairy cattle								
Dairy cows	3 128	511	442	1 536	21	45	1 054	**6 736**
Calves <1yr	879		171	161	21	0.7	24	**1 255**
Heifers >1yr	1 415		993	121	1.9	0.9	39	**2 571**
Steers >1yr	1 593		1 118	137	2.1	1.0	44	**2 894**
Bulls >1yr	1 845	110		837	65	2.8	83	**2 943**
Sheep								
Ewes and rams	311		368	17		4.0	10	**710**
Lambs	54		83	9.2		2.1	5.3	**154**
Pigs								
Sows				987	11	87	163	**1 249**
Gilts				616	6.9	54	102	**779**
Boars				181	2.0	16	30	**228**
Piglets				133	1.6	12	19	**166**
Slaughter pigs				502	65	23	204	**794**
Broilers								
Breeding hens				26		7.3	5.7	**39**
Broilers				19		5.1	4.0	**28**

Appendix B – Supplementary results

			Consumption changes affects production ...					
			only in Sweden		by today´s import shares		only abroad	
			Red meat substituted by ...					
Impact of recommendations	**Environment included in recommendations**	**Red meat consumption (g/cap/week 'on the fork')**	Poultry	Plant based	Poultry	Plant based	Poultry	Plant based
n/a	n/a	530	0%	Baseline (current consumption)				
small	No	521	-0.3%	-0.5%	-0.2%	-0.3%	0%	0%
small	Yes	516	-0.5%	-0.9%	-0.3%	-0.5%	0%	0%
large	No	494	-1.4%	-2.1%	-0.7%	-1.2%	0%	0%
large	Yes	474	-2.1%	-3.2%	-1.1%	-1.9%	0%	0%
				-3.2%	More steers			

Figure B 1 Change in carbon dioxide (CO_2) emissions from Swedish agricultural production (modelling approach 1) in the different scenarios relative to current (~2020) emissions.

			Consumption changes affects production ...					
			only in Sweden		by today´s import shares		only abroad	
			Red meat substituted by ...					
Impact of recommendations	**Environment included in recommendations**	**Red meat consumption (g/cap/week 'on the fork')**	Poultry	Plant based	Poultry	Plant based	Poultry	Plant based
n/a	n/a	530	0%	Baseline (current consumption)				
small	No	521	-1.1%	-1.2%	-0.6%	-0.7%	0%	0%
	Yes	516	-1.8%	-1.9%	-1.0%	-1.1%	0%	0%
large	No	494	-4.6%	-5.0%	-2.5%	-2.8%	0%	0%
	Yes	474	-7.3%	-7.8%	-4.0%	-4.3%	0%	0%
				-7.1%	More steers			

Figure B 2 Change in nitrous oxide (N_2O) emissions from Swedish agricultural production (modelling approach 1) in the different scenarios relative to current (~2020) emissions.

Impact of recommendations	Environment included in recommendations	Red meat consumption (g/cap/week 'on the fork')	Consumption changes affects production ... only in Sweden		by today´s import shares		only abroad	
			Red meat substituted by ... Poultry	Plant based	Poultry	Plant based	Poultry	Plant based
n/a	n/a	530	0%	Baseline (current consumption)				
small	No	521	-0.1%	-0.3%	-0.1%	-0.2%	0%	0%
small	Yes	516	-0.3%	-0.5%	-0.1%	-0.3%	0%	0%
large	No	494	-0.7%	-1.2%	-0.4%	-0.7%	0%	0%
large	Yes	474	-1.1%	-1.8%	-0.5%	-1.1%	0%	0%

-1.7% More steers

Figure B 3 Change in fossil methane (CH_4) emissions from Swedish agricultural production (modelling approach 1) in the different scenarios relative to current (~2020) emissions.

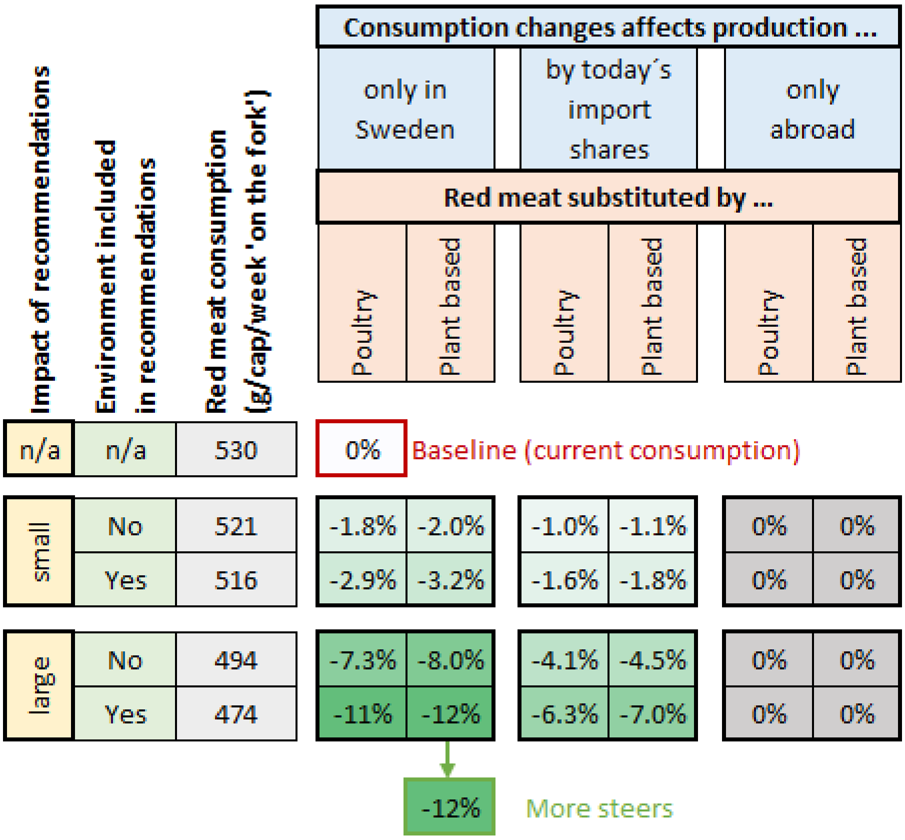

Figure B 4 Change in biogenic methane (CH_4) emissions from Swedish agricultural production (modelling approach 1) in the different scenarios relative to current (~2020) emissions.

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