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# Modeling the Impacts of Self-Sufficiency Scenarios on Norwegian National Nutrient Supply

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## ABSTRACT

As a part of the Norwegian strategy to meet the commitments they have made through international climate agreements with associated climate targets, the Norwegian Environmental Agency has proposed adjustments in Norwegian food production, creating implications for domestic food supply. More specifically, the proposed measures include reductions in domestic ruminant production systems. Mathematical modeling assessed four scenarios, which demonstrated the importance of modeling nutritional impacts, by providing the nutrient supply outcomes of reducing or eliminating ruminant meat, pork, and dairy production. The results show potential vulnerabilities in the system under these scenarios, particularly to meet domestic demand for these products and specific nutrient needs. While nutrient reliance on imported ruminant meat and pork is currently low, increasing self-sufficiency in plant-based foods, protein, energy, and fat is a concurrent goal from the Norwegian government. Further, our results demonstrate that meat contributes significantly in terms of self-sufficiency for several nutrients. These findings offer insights into the broader impacts of environmentally focused policy changes on the food system. By seeking a balance between environmental sustainability and nutrient adequacy, this study highlights the need to consider the effects of environmental goals on nutritional needs when reshaping national food systems.

## 1 | Introduction

### 1.1 | Norway Background

Self-sufficiency of food and nutrients is increasingly a key policy consideration for preparation and resilience for shocks and stresses to national food systems. A country's capacity to provide food to its population hinges on the balance between domestic food production, imports, exports, and the balance between the use of food commodities for human consumption versus other uses. Production is influenced by the country's natural resources, climate, and socio-political conditions. Sustainable Development Goals (SDGs) 2 (zero hunger) and 12 (responsible consumption and production) identified that changes to current global food

systems need to be made from human and environmental standpoints (World Health Organization 2015).

The Norwegian Environment Agency (NEA) has proposed national changes in dietary patterns, addressing food waste, increasing reliance on domestically produced plant-based foods, protein, energy, and fat while simultaneously changing current dietary patterns to reduce ruminant meat and dairy consumption, all of which are predominantly motivated by national targets related to climate gas emissions (The Norwegian Environment Agency 2023). Further, the Norwegian government has announced a target to increase self-sufficiency (including animal feed) to 50% (Norwegian Government 2021). The rate is currently approximately 39% and is restricted by limited amounts

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of agricultural land (3% of total land area), short growth season, hilly terrain and, in certain regions, high precipitation, as well as consumer food preferences (NIBIO 2023b). Consequently, Norwegian self-sufficiency primarily relies on the production of animal-derived foods such as meat, dairy and fish, in addition to barley, oats and potatoes (FAO 2020; NIBIO 2023b).

Given these constraints on arable land, natural resources and growth conditions, it is critical that dietary changes are considered not only in terms of environmental outcomes but also in relation to what can feasibly be produced within Norway. Dietary shifts that are poorly aligned with domestic production capacity may reduce the degree of national self-sufficiency and increase dependence on imports. Therefore, proposed changes to consumption patterns must be evaluated in light of the agricultural landscape, available resources, and production systems.

Within the proposed changes for the Norwegian agricultural sector, modifying dietary patterns has been identified as a primary target to hit reduction targets for greenhouse gas (GHG) emissions for 2030 (The Norwegian Environment Agency 2023). The NEA estimated that dietary changes could reduce national GHG emissions by 1.2 million tonnes of CO<sub>2-eq</sub> (Norwegian Environment Agency 2023), which is 13% of Norway's agricultural emissions and 2.3% of total national emissions.

Further, the Nordic Nutrition Recommendations have newly been revised (NNR2023), recommending a maximum intake of 350 g (ready-to-eat) red meat per week (Blomhoff et al. 2023). The Norwegian food based dietary guidelines (FBDGs) as of spring 2024 suggested the same maximum recommendation for red meat. This is a stricter recommendation for red meat compared to the previous recommendation of a maximum of 500 g weekly. A key recommendation from the NNR2023 suggests reducing meat and dairy intake while increasing consumption of legumes/pulses, whole grains, fruits, vegetables, vegetable oils, nuts, and seeds. This shift aims to make current dietary patterns more plant-based (Blomhoff et al. 2023). The NEA recently stated that if the recommendation for red meat intake is reduced to 350 g per week, is implemented, and public measures are taken to reduce the intake of red meat, an average intake of 233 g per week may be expected, compared to the current 515 g (NEA 2024; Arbeiderpartiet and Senterpartiet 2021). NEA (2024) has noted that this would reduce agricultural emissions by 2.2 million tonnes CO<sub>2-eq</sub> by 2035 (24% of agricultural emissions and 4.2% of total national emissions). However, it should be noted that these analyses did not add emissions from foods replacing the animal-derived products and that the analyses have been criticized for underestimating the economic consequences and the effects on agricultural activity and usage of agricultural resources (Oslo Economics 2021).

The majority of animal-derived products consumed in Norway are locally produced, thus any changes to consumers' dietary patterns are likely to result in changes to domestic production systems. The NEA has also noted that domestic food production should be maintained while decreasing reliance on importing food in an effort to reduce transport emissions of the Norwegian food system (The Norwegian Environment Agency 2023). Modeling the impacts of changes to Norwegian food production and supply is one method for understanding the extended effects of

changing production. Changes in food systems at a national level could result in numerous outcomes, spanning food and nutrition security, environmental, economic, and social impacts (Zurek et al. 2022).

## 1.2 | Changing Food Systems

Food systems are multifaceted and function as complex adaptive systems (Clancy 2022). Any alterations made to food systems require a comprehensive examination of their far-reaching impacts on natural resources, economic prosperity, social well-being, and dietary outcomes (Peters and Thilmany 2022).

A significant consequence of change is altered potential to ensure the provision of nutritionally adequate food. Investigating repercussions on nutrient adequacy based on establishing a new 'business as usual' state is imperative. It is essential to assess whether the proposed food system can sustain the population's nutritional needs adequately under shocks or stresses.

The proposed dietary changes lead to an opportunity to investigate the resilience of the changed food system by considering its self-sufficiency. Clapp (2017) defines self-sufficiency as "*the percentage of food consumed that is produced domestically after filling demand for exports and uses.*" Proposed changes, like the reduction of beef and dairy or the increase in plant-based food for the population, need careful consideration from a nutritional self-sufficiency standpoint.

Self-sufficiency is a key metric used to assess national food system resilience. Self-sufficiency is commonly calculated as the proportion of total food consumption that is supplied by domestic production, often measured in terms of energy (calories), mass, or economic value. Further, the potential dietary energy supply from domestic production, excluding exports, may also be used. In Norway, the official self-sufficiency rate is estimated based on the share of calorie intake originating from domestic production (NIBIO 2023b). This is relevant in the context of aligning domestic food production with actual dietary patterns. It provides insight into how well current production systems support the existing structure of food consumption and detects potential mismatches between production and consumption, thereby revealing areas of dependency and vulnerability within the national food system. This is valuable for assessing long-term strategies related to sustainability, dietary transitions, and agricultural production.

However, food is more than calories and protein. It is the primary source of essential vitamins, minerals, and bioactive compounds necessary for good health. As national policies increasingly promote changes to food production and dietary patterns for environmental reasons, it becomes crucial to assess not only food mass or energy content, but the nutritional quality of the resulting food supply.

While some changes could be environmentally beneficial on one or more parameters, such alterations may have trade-offs concerning the nutritional adequacy for the population. For example, the contribution of imported items to nutrient adequacy requires analysis in the context of the current food system and the proposed changes (The Norwegian Environment Agency 2023).

Greater reliance on imported foods to meet nutrient adequacy targets heightens the national food system's vulnerability to trade changes influenced by climatic, economic, and political dynamics (Warren et al. 2021). It may also affect agricultural activity and the availability of land resources due to altered production and changes in the ability to maintain cultivable soil resources. In a nutritional context, shocks to food imports may also result in an inability to meet population nutritional requirements. Shocks in this context include extreme weather, geopolitical shifts, or financial crises (Zurek et al. 2022). Analyzing the nutritional significance of imported items on the national food supply would add further context for any proposed changes for Norway. The changes suggested by the Norwegian authorities might be interpreted as food system stresses, where the long-term drivers of change are predictable, such as shifts in land use, dietary patterns, climate change, demographic shifts, commodity price trends, and biodiversity loss (Zurek et al. 2022). In this study, we focus on the national nutrient adequacy implications of the NEA's proposal for modifying Norwegian food production and trade.

It is essential to consider both the mass of food produced and the full nutritional content of this food in any changes in food systems, as these could potentially pose long-term risks to public health via poor diets. Healthy nutrition has been demonstrated as the most effective strategy for avoiding long-term health consequences (Cifelli 2021; Mozaffarian 2019), which further emphasises the need for food system changes to be carefully considered before implementation. Modeling dietary choice at a population level is subject to high uncertainty, and thus it is simpler to assess the nutrient supply to the national population against national or global need (Smith et al. 2024). By integrating a nutritional context into the mass balance, scenarios to meet authorities' proposals for food system change can be evaluated on their nutrient supply outcomes.

The aim of this study was to evaluate the impacts of five scenarios, designed to examine the effects of dietary changes in red meat and dairy, proposed by the NEA and NNR2023, on nutrient supply and address nutrient adequacy impacts of a complete self-sufficiency scenario. This research involves modeling changes in nutrient supply stemming from reducing animal production and assessing outcomes against Norwegian nutritional guidelines (Nordic Council of Ministers and Secretariat 2012; NIBIO 2023b).

Our study contributes to the existing literature by modeling food system scenarios with a detailed nutrient perspective, incorporating 35 macro- and micronutrients. By applying this broader lens, we identify not just total energy gaps but specific vulnerabilities in nutrient adequacy that may arise from the reduction or elimination of certain food groups.

In the Norwegian context, this is particularly relevant. Policy proposals aiming to reduce domestic ruminant production in favor of more plant-based diets must be evaluated against both environmental goals and nutritional sufficiency. Given the country's limited arable land and reliance on imports for many plant foods, our analysis provides an important decision-support tool for balancing sustainability with food security and public health. This study offers a more nuanced basis for policy development than existing self-sufficiency indicators.

## 2 | Methods

### 2.1 | Scenarios for Analysis

Five scenarios were designed, and one scenario was used as a control, to understand the impacts of changes in Norwegian food production and trade on nutrient supply, compared to national recommendations, based on the Norwegian nutritional guidelines (Table 1).

The scenarios model the change in Norwegian food and nutrient supply from different production volumes of livestock-derived foods. Scenarios reducing (at different amounts) land-based livestock production were used to demonstrate the impacts on Norwegian food security and nutrient availability. Reduction of red meat in the following scenarios was based on a reduction in red meat intake from the currently recommended amount, 500 g per week/average, to 350 g per week as proposed by NNR2023 (Blomhoff et al. 2023) and the newly proposed FBDGs, and a resulting average intake of 233–333 g per week as noted by the NEA (Animalia 2023; The Norwegian Environment Agency 2023). This is equivalent to a reduction of ~30% in the recommended intake and an actual reduction in meat intake of ~30%–55% based on the estimated for current red meat intake (515 g/week; Animalia 2023), dependent on the range within 233–333 g/week. Scenarios exploring reductions in red meat were formulated at levels both above and below this percentage and based on reductions estimated by the NEA.

### 2.2 | Nutrient Analysis

This analysis replicated the established methodology used by the Sustainable Nutrition Initiative's DELTA Model (Smith et al. 2021). Food balance sheet data were obtained from the United Nations Food and Agriculture Organization (FAO) from 2020 (FAO 2020), which captures the total quantity of food items intended for human consumption in a given country after consideration of trade, non-food uses, and supply chain losses. For each food item in each scenario, priority was given to maintaining export and other usage demands based on 2020 levels before allocating the remainder of each food item mass to food for human consumption. Masses are expressed as  $\text{kg}_{\text{food}} \text{capita}^{-1} \text{day}^{-1}$  and  $\text{kcal} \text{capita}^{-1} \text{day}^{-1}$ , where the Norwegian population was 5.5 million (Department of Economic and Social Affairs, Population Division, and United Nations 2022).

Feed allocation was maintained at current levels. This decision was made as there is uncertainty regarding the set quality threshold levels and suitability of reallocating animal feed to human food in scenarios of reduced feed demand and that the data required for linking feed ingredients to different livestock/aquaculture species was not available. This assumption is addressed in the discussion.

Inedible portions were deducted from each food item total, using values noted in the Norwegian composition data (Norwegian Food Safety Authority 2022). Where these were not available (for several fish and seafood items), values were assumed based on similar items.

**TABLE 1** | Scenarios used in this study.

Scenario	Description	Relevance
Current scenario (CS)	Based on production-, import- and export-data from 2020 (FAO)	Control/reference point, against which other scenarios can be compared.
No imports scenario (NI)	Imported items are removed from the system, domestically produced items fill 2020 demand for exports and other uses as in the CS scenario.	The intention of this scenario is to assess the current self-sufficiency status for Norway.
Plant-based scenario (PB-S)	Complete elimination of all land-based livestock production, including ruminants, pigs, poultry, and reindeer, within the Norwegian food system, while allowing seafood production to remain.	This was an extreme scenario, included to investigate the contribution of livestock production to the food system. By removing all land-based animal production, we explored the boundaries of possible change to understand the extent to which such measures might influence Norwegian nutrient supply.
Reduction of livestock production scenario I (RM30-D25)	Domestic production of ruminant meat was reduced by 30% and domestic dairy production by 25% (RM30-D25).	The primary aims of this strategy were to reduce meat availability to the Norwegian consumers. This scenario aligns with the goal outlined by the policy proposal to transition toward a reduced meat society.
Reduction of livestock production scenario II (R50-D30)	This scenario extended the above by decreasing the domestic ruminant meat production by 50% and domestic dairy production by 30% (R50-D30).	This scenario allowed for further investigation of how reduced ruminant production might affect nutrient availability in the domestic food system.
Reduction of livestock production scenario III (RM30)	This scenario considered a 30% reduction of both domestically produced pork and ruminant meat (RM30), with no other adjustments.	In the NNR2023 recommendations and the Norwegian dietary advice, “red meat” comprises both ruminant meat and pork. Hence, this scenario is in line with these recommendations and allows an additional perspective to the two previous scenarios.

To obtain the food supply nutrient composition, the items in the FBS were matched to composition data from the Norwegian Food Safety Authority (2022). The Norwegian food composition database does not contain information on amino acid composition, so the FBS items were also matched to the United States Department of Agriculture (USDA) composition database (USDA, FoodData Central 2020) to calculate the total quantity of these nutrients within the Norwegian food supply. Essential amino acid compositions were determined by normalizing amino acid content against each item’s protein content in the NNR2012 protein composition. Protein and amino acid composition values were adjusted for digestibility using true ileal digestibility coefficients from literature (see Smith et al. 2021, for details). Data were ultimately available for 35 nutrients.

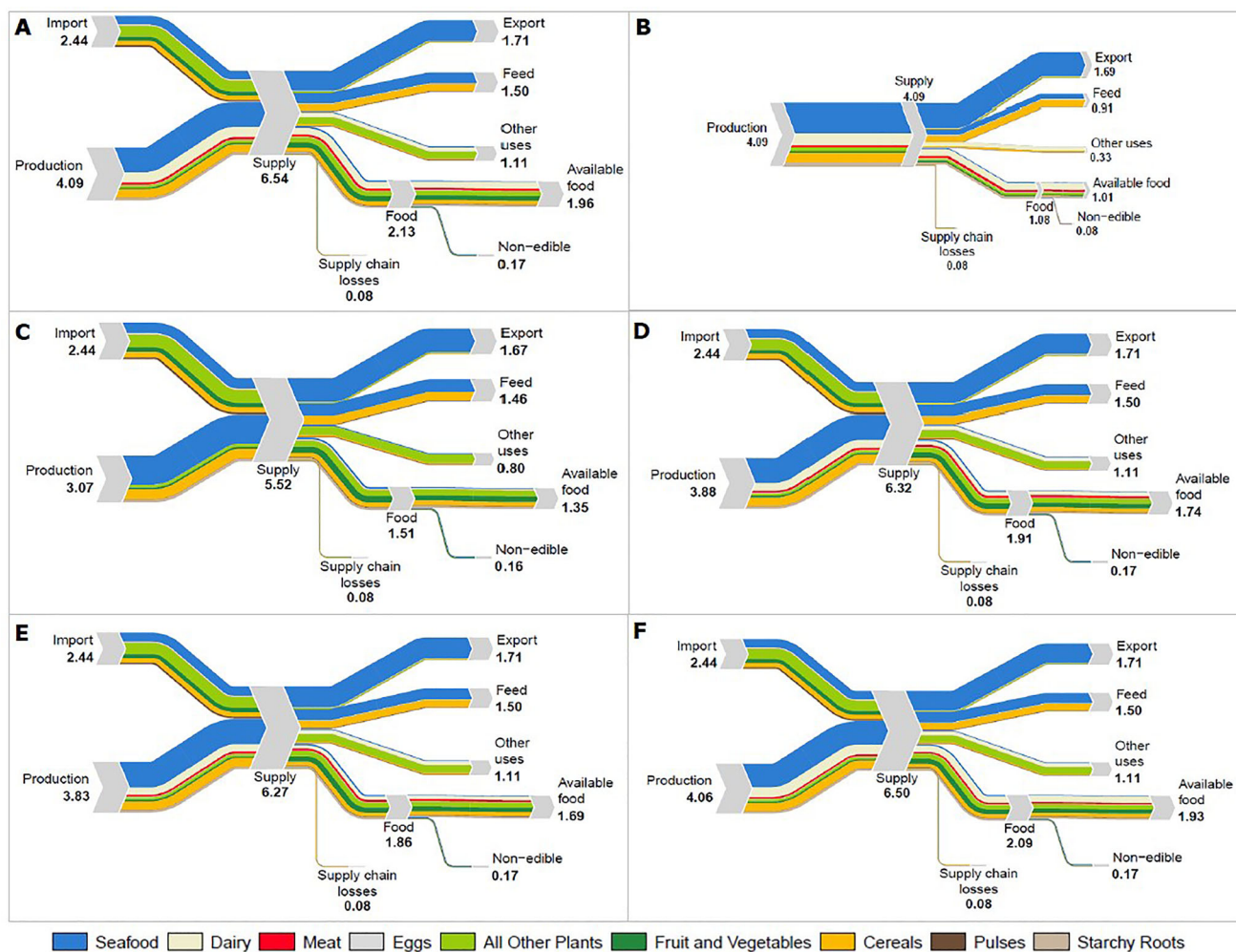
The Nordic Nutrition Recommendations 2012 (NNR2012; Nordic Council of Ministers and Secretariat 2012), in combination with national demographic data from the United Nations World Population Prospects (Department of Economic and Social Affairs, Population Division, and United Nations 2022), were used to calculate demographically weighted population nutrient requirements. A physical activity level of 1.8 was assumed for all nutrient reference values requiring this information. For amino acids, the NNR2012 do not include reference values, so these were sourced from a joint FAO/WHO/UNU report (Food and Agriculture

Organization, World Health Organization, and United Nations University 2007) and treated in the same manner. It should be noted that some of the nutrient reference values have been updated in NNR2023. However, since these were yet to be officially implemented in the Norwegian dietary recommendations, they were not included in the analyses in this study. This is addressed further in the discussion.

Self-sufficiency was also assessed, both at the food group and nutrient level. Self-sufficiency was calculated as the percentage of 2020 national food consumption (for the food group calculation) or 2020 national nutrient requirements (for the nutrient calculation) that could be met in each scenario in the absence of imports, with all exports and non-food uses held constant at the 2020 level.

### 3 | Results

Figure 1A–F shows the food supply dynamics of the Norwegian food system under various scenarios. Figure 1A shows the current food supply system, with 1.98 kg<sub>food</sub> capita<sup>-1</sup>day<sup>-1</sup> food available to the Norwegian consumer, of diverse food types sourced both domestically and internationally. Figure 1B–F represents the modifications to the system following the scenarios outlined in the methods.



**FIGURE 1** | Sankey diagrams showing Norwegian food mass flows. Line widths are proportional to the magnitude of the corresponding flow, and the line colors indicate the food group. Units of nodes are in  $\text{kg}_{\text{food}} \text{capita}^{-1} \text{day}^{-1}$ . (A) current scenario, (B) no imports, (C) elimination of domestic animal production, (D) reduction of ruminant meat by 30% and dairy by 25%, (E) reduction of ruminant meat by 50% and dairy by 30%, (F) Reduction of red meat and pork by 30%.

Seafood production dominated the Norwegian food production system, with most seafood exported. A small proportion of seafood was available as food domestically, with 55.7% of this domestically produced. Of the seafood produced, 82.1% is exported, with the remainder used as feed ingredients and food. The major imports for 2020 were in the “Other plants” group, which were beverages (alcoholic and non-alcoholic), followed by seafood.

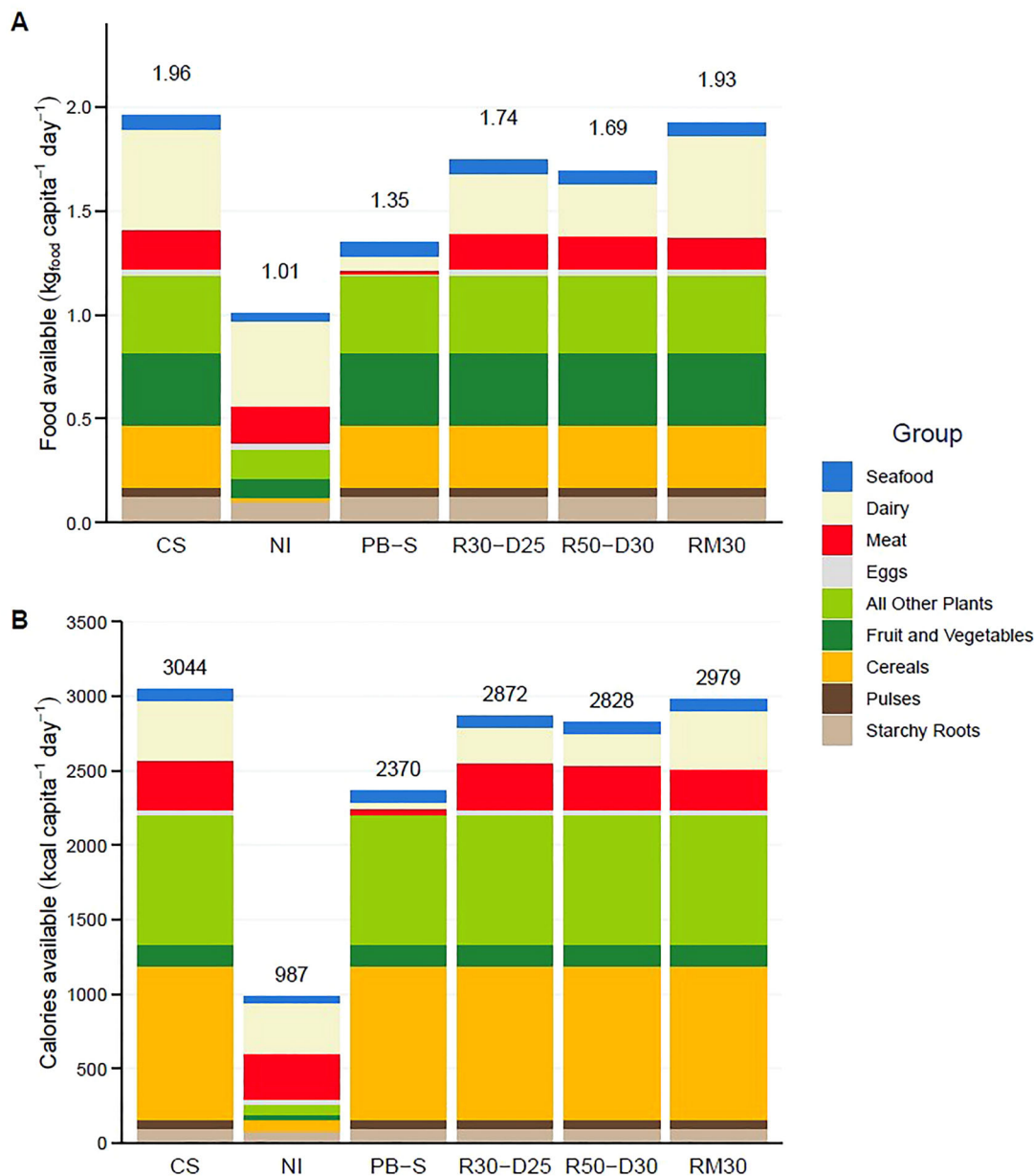
In all scenarios, export needs were maintained as domestic production of seafood items was sufficient to meet export needs, and a relatively small amount of other items is exported. Of the export mass, 92.3% were seafood items, 4.2% were oilcrops, 2% milk, and smaller quantities of various other items. The NI scenario (Figure 1B) showed that, as well as nearly  $1 \text{ kg}_{\text{food}} \text{capita}^{-1} \text{day}^{-1}$  reduced food availability for human consumption in the absence of imports, the current production system would not be able to meet demands for other uses. Items such as pelagic fish and fish oil, oil crops, sweeteners, and alcoholic beverages, which are normally sourced from imports, are not available for these uses. These items are used as feed, for industrial uses, or in

the production of other items. Substitution of items to meet the other use demands was not possible with the current dataset due to the lack of detail on exact end use for each item. The remaining scenarios (Figure 1D–F) contained sufficient feed to meet demand given the presence of imports.

Figure 2A displays the 2020 food mass available for consumption by the Norwegian population after removal of non-edible portions. All simulated scenarios had reduced food mass available to the Norwegian population.

The PB-S scenario had  $0.61 \text{ kg}$  lower food mass available compared to CS and the fewest distinct food items of any scenario. NI showed a nearly 50% reduction of available food mass, compared to CS. The R30-D25, R50-D30, and RM30 scenarios resulted in up to  $0.3 \text{ kg}_{\text{food}} \text{capita}^{-1} \text{day}^{-1}$  reductions in total food mass availability.

Figure 2B shows the effects of the scenarios on the amount of calories available to the Norwegian population. The CS scenario had  $3044 \text{ kcal capita}^{-1} \text{day}^{-1}$  available. The largest decline in



**FIGURE 2** | Food mass (A) and calories (B) available for five scenarios to the Norwegian population. CS: current scenario, NI: no imports, PB-S: elimination of domestic animal production, R30-D25: reduction of ruminant meat by 30% and dairy by 25%, R50-D30: reduction of ruminant meat by 50% and dairy by 30%, RM30: reduction of red meat and pork by 30%.

accessible calories occurred in the NI scenario, where the calories available amounted to only 32% of the CS. The remaining scenarios showed caloric decreases comparable to the mass decreases.

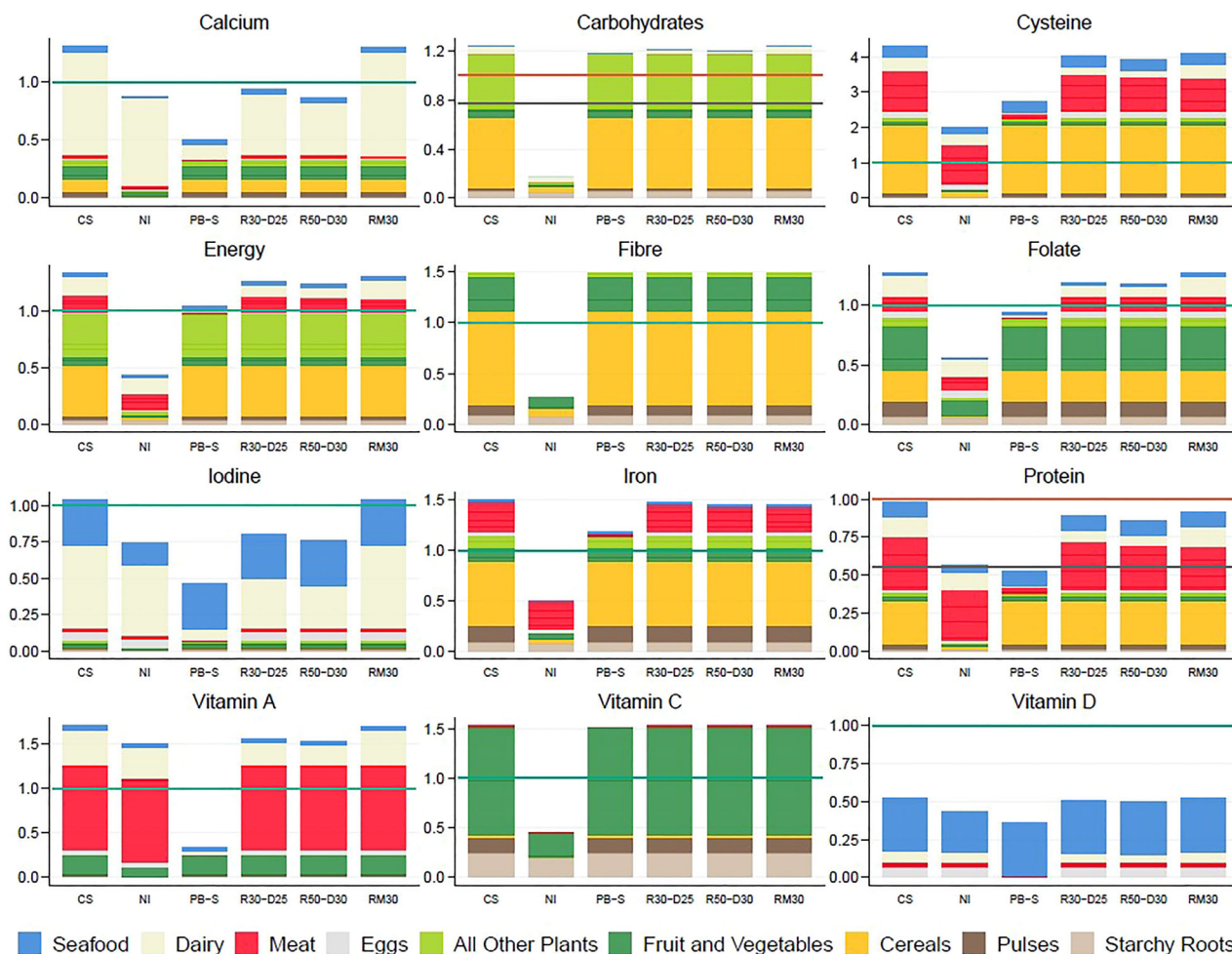
Figure 3 presents the outcomes for the supply of selected macro- and micronutrients against the recommended target or upper intake values, highlighting the most notable results. In general, the PB-S and NI scenarios consistently yielded the lowest supplies for all macro- and micronutrients examined in this study, although this did not necessarily mean insufficient supply.

The current supply of domestically produced meat and dairy is critical to meeting vitamin A requirements as shown by the

NI and PB-S scenarios. Dairy and seafood play a critical role in iodine supply, with this becoming inadequate in scenarios with decreased dairy availability. Internationally sourced cereals were essential for carbohydrate, energy, fiber, folate, iron, and protein supply.

The reduction or elimination of domestic dairy production resulted in the failure to meet targets for calcium and iodine, with calcium having the most varied results among the scenarios. The decreased supply of fruits, vegetables, and the other plants group in the NI scenario resulted in insufficiencies for energy, vitamin C, and folate.

The nutrient results presented here were a selection of the most noteworthy changes observed. The remainder of the nutrients



**FIGURE 3** | Selected examples for ratios of daily nutrient supply. Colored bars show supply by food group. Horizontal colored lines denote demographically weighted target intakes (green), safe upper intake levels (red), and safe lower intake levels (gray) based on the Nordic Nutrition Recommendations (Nordic Council of Ministers and Secretariat 2012). CS: current scenario, NI: no imports, PB-S: elimination of domestic animal production, R30-D25: reduction of ruminant meat by 30% and dairy by 25%, R50-D30: reduction of ruminant meat by 50% and dairy by 30%, RM30: reduction of red meat and pork by 30%.

considered in this analysis can be found in the Supporting Information.

In terms of self-sufficiency, the highest food group self-sufficiency values in 2020 were for land-based animal-sourced foods, ranging from 81% to 99% (Table S1). Naturally, these values decreased proportionally under the scenarios of reduced animal production. For many plant food groups, self-sufficiency was 0%, showing the high reliance of the Norwegian food system on imported plant foods. The highest plant value was 74%, for starchy roots.

For the nutrients (Table S2), amino acid self-sufficiency and protein self-sufficiency were achieved in 2020, largely due to the substantial protein oversupply present in the system. Results for other nutrients were mixed, but notably Norway was not self-sufficient for energy, total fat, or any of the essential fatty acids. Generally, nutrients that are largely sourced from animal-sourced foods (e.g., vitamin B12) had higher self-sufficiency values than those largely sourced from plants (e.g., vitamin C). Scenarios with reduced food production resulted in reduced nutrient self-sufficiency.

## 4 | Discussion

The results demonstrate the impacts on nutrient supply of several scenarios aimed to be reflective of the directions proposed by the NEA and NNR2023 (Blomhoff et al. 2023; The Norwegian Environment Agency 2023). The results demonstrated that the availability of many of the nutrients included in this analysis depends on imports. Further, for several nutrients, adequacy depends predominantly on animal-derived products produced in Norway (e.g., calcium, iodine, cysteine, iron, protein, vitamin A).

The analysis showed a significant reduction in food availability for the Norwegian consumer in the PB-S scenario, removing all land-based livestock production, compared to current production levels. Despite the decrease in food supply per capita, the nutrient supply analysis indicated that only a specific set of nutrients failed to meet the requirements in this scenario, with calcium and iodine showing the greatest shifts, largely due to changes in dairy production. However, self-sufficiency was drastically reduced in an expected manner for the scenarios where reliance on imported foods would be increased. This can be seen in the Supporting

Information. It should also be noted that the availability of energy, as well as several nutrients, in the PB-S scenario was just enough for meeting the population requirement. Hence, meeting nutritional needs for all individuals would depend on the intake of a certain amount of discretionary foods. This demonstrates a risk of increased vulnerability if reducing land-based livestock production without a plan for increased production or import of healthy foods to replace lost volumes of animal-derived foods.

Self-sufficiency is commonly assessed using metrics based on energy supply. However, a growing body of literature highlights the limitations of such approaches when assessing food security and public health (Beal and Ortenzi 2022; Beal et al. 2024). Energy adequacy does not guarantee sufficient intake of essential nutrients, and national food systems may deliver excess calories while failing to meet micronutrient needs (Wang et al. 2019). There is an increasing need to evaluate agricultural production through a nutritional lens, aligning it with human dietary requirements (Herrero et al. 2017). Our study contributes to this by applying a nutrient-based framework to assess self-sufficiency and resilience, thereby providing a more holistic and health-relevant understanding of national food system performance.

It is important to note that our scenario results apply to national average food and nutrient supplies, whereas in reality food and nutrients are not distributed evenly across populations. For example, while nutrients like calcium, iron, and protein were close to the requirement level in some scenarios, this would translate in reality to a distribution of intakes including individuals both above and below the requirement. Thus, a result that shows national average adequacy should not be seen as resolving all insufficiencies for all demographic groups. The NI scenario showed that without the contribution of imported cereals, fruits, vegetables, and other plant foods, reaching nutrient adequacy was not feasible. The important contribution of these food groups demonstrates the current system's reliance on imports to meet both non-food demands and population nutrient targets.

Historical Norwegian diets, shaped by limited access to imported foods, relied more heavily on locally available resources such as potatoes, dairy products, root vegetables, local cereals such as barley and oat, fish, meat, and offal. Although less varied, traditional diets offer valuable insights into dietary patterns that optimize local production and minimize food waste. Preserving and re-incorporating elements of these practices into future strategies could enhance the sustainability and robustness of Norway's food system in times of global uncertainty. Four of the scenarios explored here were focused on the reduction of animal-sourced foods. The results highlight the current dependence on domestically produced meat and dairy for meeting certain nutrient requirements in Norway, specifically calcium, iodine, and vitamin A. The imported streams of meat and dairy are minimal, as demonstrated by the PB-S scenario, and do not contribute significantly to overall nutrient supply. Instances where domestic dairy production was reduced by 25% or 30% did not meet nutrient targets for calcium and iodine, whereas reductions in pork or ruminant meat did not result in undersupplies. In cases where nutrient adequacy was not achieved, a trade-off analysis could be carried out to align agricultural GHG emissions with nutrient targets. This could involve concentrating solely on specific animal production systems, while also examining how

the additional land freed up could support increased production of alternative food items like vegetables and cereals. However, this is a challenging task since >50% of Norwegian agricultural land is only suitable for ruminant production (NIBIO 2023a) and predicting which land areas would transition comes with high uncertainty. Further, the limiting factor in terms of plant-based production is currently not agricultural land, but market preferences with regard to vegetables and cereals that are cultivable in Norway, and customs barriers (NIBIO 2023b). Meeting domestic demand for the variety of fruit and vegetables expected by the Norwegian population is simply not feasible from domestic production. Vegetable production occupies a small fraction of Norwegian agricultural land (2%–3%; NIBIO 2023a), so even a large relative increase is likely to have a minor impact on livestock production.

The results of this study might not fully capture the nutrient benefits as the extra animal feed that could be used for human food was not applied. Feed was found to be predominantly seafood and cereals, with cereals likely being in surplus as fish is the major ingredient in fish feed. Redirecting this surplus toward human consumption, especially in light of the observed reductions in meat and dairy consumption, could enhance nutrient availability for the population. However, in addressing nutrient deficiencies in Norway, particularly concerning vitamin D, cereals may offer limited assistance. Another limitation to this is the suitability of feed items as food, which is not noted in the FBS data, and would require further data.

The FBS assess food availability at a commodity level rather than a consumer food level. As such, additives and fortificants that may be added during food processing are not considered. A further limitation relates to the level of detail in the FBS, which does not distinguish between food items at the same level as the food composition data. As a result, nutrient contributions are calculated based on the closest possible match for each food item and averaged to match the level of detail in the FBS. Consequently, total nutrient supply should be considered indicative rather than precise.

Another critical aspect not addressed is consumer food waste, primarily due to the lack of detailed country-specific data. European data suggest that cereals are the most commonly wasted food group, with approximately a quarter of them being discarded (FAO 2011). The study demonstrated that even substantial reductions in food production do not necessarily lead to decreased nutrient availability unless specific foods are completely eliminated (e.g., PB-S). Accounting for consumer waste might slightly alter nutrient sufficiencies, but based on the scenarios results from this study, the overall impact could be expected to be minimal.

A newer version of the Nordic Nutrient Recommendations was released in 2023, which emphasizes the use of FBDGs that focus on having high intakes of vegetables and fruits (500–800 g per day), whole grains (90 g per day), fish (42–64 g cooked weight per day), low-fat dairy (350–500 g per day), and legumes (significant portion of diet; Blomhoff et al. 2023). The recommendations also note maintaining or decreasing white meat consumption and replacing the deficit with increased consumption of plant foods and fish from sustainably managed stocks. These guidelines are

based on considerations from both health and environmental considerations, which also include co-production from dairy and poultry. Compared to the 2023 dietary guidelines for the Norwegian population, all scenarios (including CS) were insufficient in potatoes, pulses, and nuts while oversupplying red meat and cereals. Red meat (not including poultry) was a food that exceeded dietary guidelines, even under scenarios where food supply was reduced. Based on the nutrient sufficiency results, reduction of this food group would result in difficulties in being able to meet requirements for several key nutrients, including vitamin A, and would require an increase of fruits and vegetables, legumes, and/or cereals. Balancing both nutrient requirements and food-based dietary guidelines could lend itself to optimization techniques where both nutrient targets and dietary guidelines are constrained, while domestic production GHG emissions are optimized.

The majority of Norwegian beef production is based on dual-purpose Norwegian Red dairy cows, which contribute to both beef and dairy production. This is beneficial in terms of GHG emissions as the emissions per unit are reduced, resulting in dairy and beef emissions below the global average (Bonesmo et al. 2013, Samsonstuen et al. 2023). Analysis of strategies to retain a proportion of dairy production within national systems has been explored in a Norwegian context by Schreiber et al. (2021), where the authors examined the environmental impact of increased milk yield per cow and the shift in beef production from dual-purpose dairy cattle to specialized beef breeds and also investigating the effects on emission quantifications and environmental aspects using different metrics and indicators. This analysis aimed to maintain the same domestic milk production to meet the needs of the Norwegian population in 2040 (Schreiber et al. 2021). Enhancements to the present study could involve employing an allocation methodology for more accurate farm-to-fork mass flows as well as nutrient-based allocation methodologies to link environmental outcomes with human dietary needs. This improvement would enable a better understanding of the feed allocation perspective and facilitate the integration of beef and dairy productivity into the nutrition-focused model. Examining the environmental repercussions of shifts in food systems provides a comprehensive context for decision-making, especially in policy development.

While integrating environmental considerations is feasible, McLaren et al. (2021) underscore the need for careful analysis due to the challenges associated with linking environmental impact to nutrition. McLaren et al. (2021) highlight issues such as environmental impact per mass or volume basis, the appropriateness of generic life cycle assessment (LCA) methodology, quantifying the nutritional value of food, and assessing specific impacts. Schreiber et al. (2021) further compare these challenges, shedding light on the complexities of both environmental and food production-related aspects. These results demonstrate that there could be a trade-off between the environmental impacts of food production, imports, and the resulting nutrition available to the population. Reduction of nutrient-dense foods such as organ meats, small-dried fish, dark green leafy vegetables, ruminant meat, and cow milk should be analyzed carefully to consider the implications on nutrient outcomes as noted by Beal and Ortenzi (2022). The environmental impacts of domestic food production or importation need to be balanced with the nutritional outcomes.

The results shown here demonstrate the importance of dairy in the current Norwegian nutrient supply, given its contribution to national nutrient adequacy. For calcium and iodine, the CS results showed that the targets were only marginally met currently. Given the chronic health implications of deficiencies in these nutrients, the reduction of dairy availability could lead to long-term health impacts on the Norwegian population (Cifelli 2021; Mozaffarian 2019). Other food sources, such as fish, eggs, dark leafy vegetables, and fortified foods, may be considered for inclusion in food supplies to meet these nutrient requirements (Beal and Ortenzi 2022; Blomhoff et al. 2023). Balancing both animal- and plant-sourced foods in a varied and diverse food supply will decrease the risk of micronutrient deficiencies.

The results also demonstrate the role of meat in self-sufficiency for several macronutrients, minerals, vitamins, and amino acids, as it comprises a significant fraction of zinc, selenium, vitamins B6 and B12, riboflavin, niacin, and thiamin. Hence, if not evaluated carefully, a reduction in meat production may introduce vulnerability into the domestic food system. If not compensated by increased national production and intake of other foods, it may increase import rates.

Potential alternatives to replace the nutrient gaps left by the removal of meat and dairy production may involve plant-based sources as suggested in the proposed changes (Blomhoff et al. 2023). It should be noted that foods from the category *Cereals* and *All other plants* comprise a larger fraction of the total food mass in terms of calories than in terms of weight, whereas the opposite is the case for foods from the category *Vegetables*. Hence, if changing diets to comprise less animal-based foods and more plant-based foods, care must be taken in order to ensure that the total intake of calories does not increase above recommended levels. It should also be noted that in the results from this study, foods from the category *All other plants* include alcoholic and non-alcoholic beverages, hence are not necessarily all optimal substitutes for other foods.

More thought is required to address the balance of using plant-sourced and animal-sourced products to meet nutrient targets. In one train of thought, these targets could be met by increasing the amount of imported animal-sourced foods, particularly dairy products, to meet calcium and iodine targets. However, reliance on imported animal-based foods to address these nutrient insufficiencies could expose the system to risks and increased vulnerability to external shocks while potentially increasing the environmental impacts associated with importing foods (Warren et al. 2021). The results suggest that there is a trade-off between domestically produced nutrient-dense food and imported options, which was also highlighted by Goold et al. (2020). Goold et al. (2020) revealed that the sustainability of the United Kingdom's pork system was at risk if domestic supplies cannot support the current consumption levels, which are closely tied to demand and prices. Even though the present research did not explicitly model economic factors, it is crucial to conduct future projects that predict the vulnerability of the domestic food supply.

There is a significant dependence on cereal products within the current Norwegian food supply. The results demonstrate that 64% of cereals within the Norwegian supply are produced domesti-

cally, a large proportion of which are for feed use (Figure 1), with the majority available to the Norwegian population as food being wheat. The need for food item diversification is twofold: one, diversity of food supply and consumption is beneficial beyond meeting nutrient targets (Verger et al. 2021; Beal and Ortenzi 2022), and two, if domestic or international cereal supplies for Norway become unavailable or reduced, this would have adverse effects on food and nutrient security, either directly or via feed availability. Given scarce arable land availability in Norway, measures to significantly change the overall diet of the population should take resource availability and production capacity into account.

Sourcing for key staples is globally becoming more reliant on key countries, which was not addressed in this research but has been investigated elsewhere (Silvestrini et al. 2024; Clapp 2017). Stress and shocks within food systems have the potential to magnify outcomes, leading to consequences more severe than anticipated (Zurek et al. 2022). Identifying specific areas of the food system and understanding the downstream effects on nutrient adequacy is crucial for proactive intervention. The findings indicate that under the NI scenario, the local food system becomes highly susceptible to local production shocks, leading to compromised nutrient adequacy outcomes. Achieving a balance among nutrient adequacy, food diversity, and other metrics, including cost, sourcing, and the associated environmental impacts, is essential for optimizing the resilience and sustainability of the Norwegian food system. Norway's current food system is representative of the current globalized food system, which can provide consumers with year-round access to diverse foods but comes with costs, which could be environmental (due to long distances needed for importing or sub-optimal production practices outside local regulations) or risk-based (Schreiber et al. 2021). A comprehensive national food system model is essential to navigate these complexities and generate results that encompass likely impacts from nutritional, social, environmental, and economic perspectives.

In this study, we have assessed different production and trade scenarios and their impact on nutrient availability in the Norwegian food system. Significant changes in some parts of agricultural production could be supplemented by changes in other parts of the production, import, and/or export. However, this analysis is useful in order to demonstrate the nutrient gaps that emerge and potential vulnerability in the food system. Further work should include model-based assessments of scenarios that also include replacement of food items, based on the frames set by resource availability, nutritional needs, consumer preferences, self-sufficiency requirements, and climate adaptation.

## 5 | Conclusion

Understanding the nutrient implications of policy-induced changes in food choices can bring attention to potential micronutrient deficiencies resulting from inappropriate system change. Norway has proposed alterations to its domestic livestock production as part of the agricultural sector's contribution to overall emissions reduction, which were used as a framework for scenario modeling here.

Our results highlighted the reliance of the Norwegian system on imports for meeting micro- and macronutrient targets, as well as the current role of domestically produced dairy and, to some extent, meat, in meeting targets for specific nutrients or in self-sufficiency. Some reduction of meat and dairy production and national consumption is feasible while meeting nutrient targets but has wider-reaching consequences than just nutrition.

The overall findings indicate that modifying food systems to align with broader sustainability targets will have effects on national nutrient adequacy. Any changes to the food system must carefully consider the associated nutritional implications.

The results underline the importance of integrated food system planning, where nutritional adequacy, production capacity, environmental targets, and trade vulnerability are considered together in policy development processes.

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### Author Contributions

**Raquel Lozano:** methodology, formal analysis, writing – original draft, visualization. **Nick William Smith:** conceptualization, methodology, formal analysis, writing – review and editing. **Katrine Lekang:** conceptualization, methodology, formal analysis, writing – review and editing. **Warren Charles McNabb:** writing – review and editing, supervision.

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### Conflicts of Interest

Katrine Lekang is employed by Matprat. Raquel Lozano, Nick William Smith, and Warren Charles McNabb have received research funding for this and other research from the food industry.

### Data Availability Statement

Data will be made available to any interested party on reasonable request to the corresponding author.

### Table of Contents

The Norwegian Environmental Agency has proposed adjustments in Norwegian food production, creating implications for domestic food production. Mathematical modeling assessed four scenarios that demonstrated the importance of modeling nutritional impacts. Scenarios examined the effect of reducing or eliminating ruminant meat, pork, and dairy production, and removing all imports. The results show potential vulnerabilities in the system under these scenarios, particularly to meet domestic demand for these products and specific nutrient needs.

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## Supporting Information

Additional supporting information can be found online in the Supporting Information section.

TABLE S1 Self-sufficiency rates by food group for each scenario as defined in the methodology. Where no value is shown, there has been no change from the CS scenario. TABLE S2 Self-sufficiency rates by nutrient for each scenario as defined in the methodology. Values shown are % of the target intake, lower intake, or upper safe intake level for each nutrient. Values are only shown where relevant nutrient reference values exist in recommendations. Values in the Target and Lower columns are color-coded if below 100. FIGURE S1 Dairy nutrient ratios for macronutrients. Colored bars show supply by food group. Horizontal colored lines denote demographically weighted target intakes (green), safe upper intake levels (red), and safe lower intake levels (gray) based on the Nordic Nutrition Recommendations (Nordic Council of Ministers and Secretariat 2012) CS:

current scenario, NI: no imports, PB-S: elimination of domestic animal production, R30-D25: reduction of ruminant meat by 30% and dairy by 25%, R50-D30: reduction of ruminant meat by 50% and dairy by 30%, RM30: reduction of red meat and pork by 30%. FIGURE S2 Dairy nutrient ratios for minerals. Colored bars show supply by food group. Horizontal colored lines denote demographically weighted target intakes (green), safe upper intake levels (red), and safe lower intake levels (gray) based on the Nordic Nutrition Recommendations (Nordic Council of Ministers and Secretariat 2012). CS: current scenario, NI: no imports, PB-S: elimination of domestic animal production, R30-D25: reduction of ruminant meat by 30% and dairy by 25%, R50-D30: reduction of ruminant meat by 50% and dairy by 30%, RM30: reduction of red meat and pork by 30%. FIGURE S3 Dairy nutrient ratios for vitamins. Colored bars show supply by food group. Horizontal colored lines denote demographically weighted target intakes (green), safe upper intake levels (red), and safe lower intake levels (gray) based on the Nordic Nutrition Recommendations (Nordic Council of Ministers and Secretariat 2012). CS: current scenario, NI: no imports, PB-S: elimination of domestic animal production, R30-D25: reduction of ruminant meat by 30% and dairy by 25%, R50-D30: reduction of ruminant meat by 50% and dairy by 30%, RM30: reduction of red meat and pork by 30%. FIGURE S4 Dairy nutrient ratios for indispensable amino acids. Colored bars show supply by food group. Horizontal colored lines denote demographically weighted target intakes (green), safe upper intake levels (red), and safe lower intake levels (gray) based on the Nordic Nutrition Recommendations (Nordic Council of Ministers and Secretariat 2012). CS: current scenario, NI: no imports PB-S: elimination of domestic animal production, R30-D25: reduction of ruminant meat by 30% and dairy by 25%, R50-D30: reduction of ruminant meat by 50% and dairy by 30%, RM30: reduction of red meat and pork by 30%. FIGURE S5 Dairy nutrient ratios for fatty acids. Colored bars show supply by food group. Horizontal colored lines denote demographically weighted target intakes (green), safe upper intake levels (red), and safe lower intake levels (gray) based on the Nordic Nutrition Recommendations (Nordic Council of Ministers and Secretariat 2012). CS: current scenario, NI: no imports PB-S: elimination of domestic animal production, R30-D25: reduction of ruminant meat by 30% and dairy by 25%, R50-D30: reduction of ruminant meat by 50% and dairy by 30%, RM30: reduction of red meat and pork by 30%.