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Integrating nutrition into environmental impact assessments reveals limited sustainable food options within planetary boundaries☆

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ABSTRACT

Environmentally sustainable and nutritionally adequate food consumption and production can include a wide selection of foods, which requires detailed information on individual food products to enable sustainable food choices. The aim of this study was to integrate nutritional aspects in the assessment of environmental sustainability of food products against the planetary boundaries. Methodologically, the model was built on the approaches of nutritional Life Cycle Assessment (LCA) and a planetary boundary-based LCA (PB-LCA) that compares environmental impacts against the assigned share of planetary boundaries. Thus, the model can identify food products that provide sufficient nutrition in relation to their environmental impacts, in accordance with the criteria of the planetary health diet. As a result, we developed Nutrient Index-based Sustainable Food Profiling Model (NI-SFPM) and tested its applicability in an assessment of 559 food products across various food categories, considering the impact categories corresponding to the planetary boundaries of climate change, nitrogen cycling, phosphorus cycling, freshwater use, land-system change, and biodiversity loss. The results demonstrated the model's effectiveness in discerning between food products and food categories based on their environmental performance and nutrient composition. The resulted sustainability ranking of different food categories was in accordance with the current understanding of healthy and sustainable diets. By evaluating the sustainability of food products, the NI-SFPM enables informed decision-making for consumers, policymakers, and food industry stakeholders, assisting in optimizing production processes, sourcing sustainable ingredients, and enhancing product formulations. Through these insights, the NI-SFPM has the potential to drive positive changes in food industry by promoting the development and consumption of environmentally and nutritionally sustainable food products.

1. Introduction

Currently, the triple challenge of this half century is addressing the interlinked issues of food and nutrition security, limiting climate change, and reversing biodiversity loss, which is crucial for the survival of humanity (Baldwin-Cantello et al., 2023). The pursuit of healthier and sustainable food systems is outlined, for instance, in initiatives such as the Sustainable Development Goals (UN, 2015) and the European Union's Farm to Fork strategy (European Commission, 2020). Several studies have shown the potential to reduce the environmental impacts of food systems by shifting consumption towards low-emission diets and products, (e.g. (Chaudhary and Krishna, 2019; Kyttä et al., 2023a; Mazac et al., 2022; Poore and Nemecek, 2018; Saarinen et al., 2023).

However, the question is whether this shift is sufficient for humanity to remain within the safe operating space (SOS) defined by the planetary boundaries concept (Richardson et al., 2023; Rockström et al., 2009; Steffen et al., 2015). The issue of keeping global food production and consumption within an SOS has been addressed in the EAT-Lancet

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Commission's framework for a planetary healthy diet (Willett et al., 2019). In the framework, a global healthy and environmentally sustainable reference diet, including recommended intake of several product groups, is a core element of the framework, complemented by needed improvements in production chains. Achieving the reference diet requires drastic changes in food consumption worldwide. These changes manifest on a product level, either as a consumer purchasing decision or as environmental impacts of producing a food product. Indeed, decisions at the product level are a prerequisite for progress in reducing environmental impacts at the higher dietary level, which requires product level consumer information.

The environmental impacts of products are commonly assessed using a Life Cycle Assessment (LCA) (ISO, 2006). However, in LCA, the environmental impacts of products are mainly assessed as a measure of relative sustainability by comparing them across products. An absolute environmental sustainability assessment (AESA) or planetary boundary-based life cycle assessment (PB-LCA), has been applied in the past few years to connect product LCA with the planetary boundaries (Bjørn et al., 2020a,c; Sandin et al., 2015). The core idea of a PB-LCA is to compare the environmental impacts of a product under consideration with the share of safe operating system (SoSOS) assigned to the product, and thus determine whether the product is environmentally sustainable or not.

In this paper, we develop a novel Sustainable Food Profiling Model (SFPM) to identify environmentally sustainable food products while taking nutritional composition of foods into account. This is achieved by combining the approaches of the PB-LCA with the recently introduced nutritional LCA (nLCA) methodology, the background of which is described in the Literature review section below. In the model, the share of safe operating space (planetary boundaries) is assigned for products based on the nutrients provided by the product. Since the novelty of the model is rooted in the use of nutrient indices, we call it the Nutrient Index-based Sustainable Food Profiling Model (NI-SFPM). In this study, we present the principles of and methods for the NI-SFPM and apply the model to assess 559 foods across different categories to demonstrate its practical implementation and evaluate its functionality.

2. Literature review

In terms of food products, PB-LCA applications are limited, covering studies on tomatoes (Bjørn et al., 2020b), rice (Mahmood et al., 2023), sugarcane (Ghani et al., 2023), and from a wider perspective, a set of plant-based products from different product groups (Potter and Röös, 2021) and different agri-food systems (Chandrakumar et al., 2019). Since the PB-LCA approach is relatively new, the implementation practices are developing and thus they vary among studies, although mostly following the study by Steffen et al. (2015) and Bjørn et al. (2020a). The difficulty of finding a justified sharing principles to downscale SOS to the product level (Perdomo Echenique et al., 2022), and the challenge of recommending a single principle due to the unique applicability of each one has been highlighted (Ghani et al., 2023). None of the downscaling methods introduced this far have considered the fundamental function of food as a provider of nutrition, even though good nutrition is part of the principles of a healthy sustainable diet (Willett et al., 2019) and global Sustainable Development Goals (UN, 2015). The only methods related to nutrition have been based on energy content of food (Chandrakumar et al., 2019; Ghani et al., 2023).

Recent methodological developments in nLCA have integrated nutrient indices in LCA as a nutritional functional unit (nFU), allowing for a broader inclusion of (positive) nutritional quality of food in the assessment (McLaren et al., 2021; Saarinen et al., 2017). This approach has been proposed to be utilised in defining sustainable products in terms of environmental and nutritional aspects after setting threshold values for environmental impacts and linking nutrients to be limited as a separate index (Saarinen et al., 2017). Considering nutrients could be a preferable approach to downscaling of the SOS because nutrient-rich foods should be preferred over energy-dense foods to avoid the intake of excess calories (Drewnowski, 2005, 2009).

Sustainable food choices and the improvement of production chains require integrated information about the nutritional quality and environmental impacts of products. SFPMs aim to identify and rank foods based on their nutritional composition and environmental impact trying to facilitate and support product reformulation, marketing, labelling, taxation and other actions or regulation towards sustainability manifested at a product level (Bunge et al., 2021). However, the previous product level assessments, which have included both nutritional quality and environmental impacts, have not considered any criteria for the absolute environmental sustainability (e.g., Clark et al., 2022; Leach et al., 2016; Mozaffarian et al., 2021; Stylianou et al., 2021) and models reviewed by Bunge et al. (2021), and in turn, the studies applying planetary boundaries for absolute sustainability assessment have not utilised the method for food profiling purposes.

3. Materials & methods

3.1. The principles of NI-SFPM

First, we developed the concept of NI-SFPM, which can be used to assess the environmental sustainability of food products from different product groups. The starting point for the model was that to be sustainable, a food product must i) provide adequate nutrition, and ii) be environmentally sustainable. We applied the same criteria for sustainable food products as Willett et al. (2019) used for a sustainable diet. In our model, these aspects are assessed on a product level and combines two recent developments in LCA methodology: the product's function as provider of nutrition assessed through using nutrient indices as a functional unit (FU), (McLaren et al., 2021; Saarinen et al., 2017) and the downscaling of the SOS to product level by using a PB-LCA approach (Bjørn et al., 2020a).

We used product-group-specific nFUs to capture the distinct nutritional roles of different food groups. Many nLCA studies have used an across-the-board approach, which assess overall nutritional quality across a wide range of foods. However, generic nFUs overlooks the specific nutritional purposes and contexts of different food categories, while the product-group-specific approach recognizes the unique contributions of each food group to a balanced diet, aligning more closely with how foods are selected and consumed based on their intended use (McLaren et al., 2021; Saarinen et al., 2017). We have recently applied nutrient index-based nFUs in an nLCA of food products using product groups specific nutrient indices (Kårlund et al., 2024; Kyttä et al., 2023b, c), and in this study we also applied them to downscaling the SOS. The general framework of the model is described in Fig. 1.

The NI-SFPM can be summarised into a single algorithm presented in Eq. (1) below.

$$\text{Sustainability score} = \textit{Environmental impact}_i \Bigg/ \left(\sum \frac{\textit{nutrienti}}{\textit{DRIi}} \times 100 \Big/ \textit{number of nutrients in the index} \right) \Bigg/ \left(\frac{\textit{SoSOS for daily diet per person}/100}{\textit{total no.of nutrients with DRI}} {}^{*}\textit{number of nutrients in the nutrient index}_i \right) \quad (1)$$

In the formula, *Environmental impact*$_i$ is the environmental impact in the studied impact category expressed per 100 g of product, *nutrient*$_i$ is the amount of a selected nutrient in 100 g of a product and *DRI*$_i$ is the recommendation for the daily intake of the nutrient, the *SoSOS* is the assigned share of the SOS (planetary boundary) for the food consumption per cap per day in the environmental impact category under study, *total number of nutrients with DRI* is the number of nutrients with

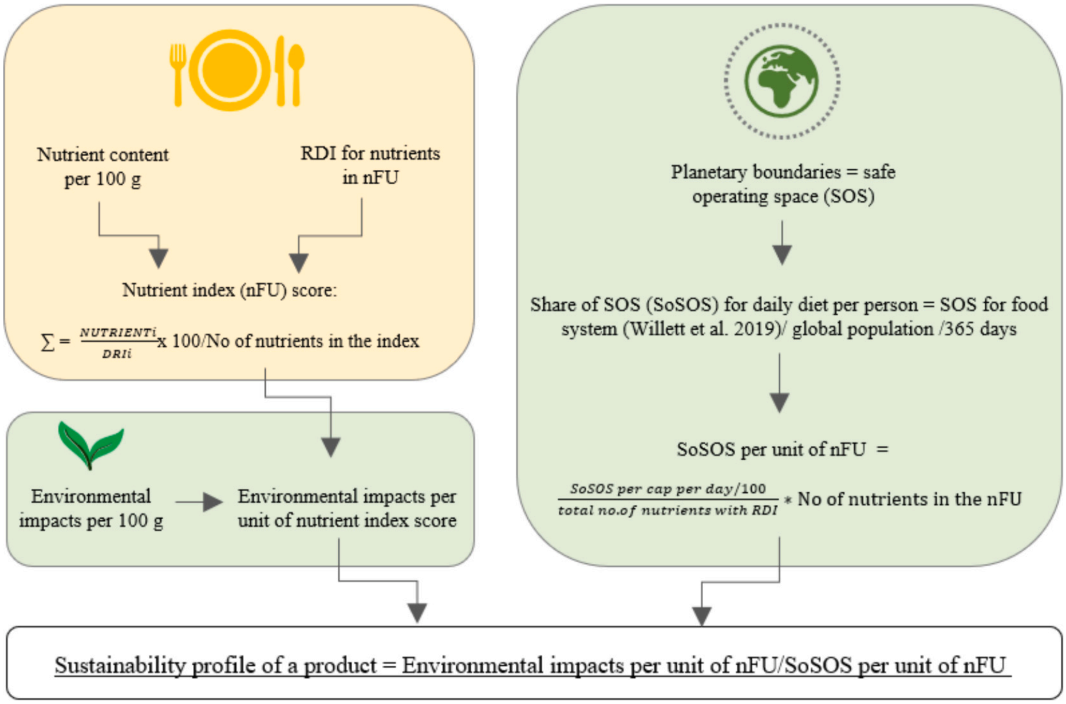


Fig. 1. The general framework of the NI-SFPM.

recommended daily intake in nutrition recommendations for the population under study, and $index_i$ is the nutrient index used as an FU.

Methodological details are further described in the following sections, alongside with the description of the implementation of the model.

3.2. Products in practical implementation

We tested the NI-SFPM by assessing a total of 559 foods from three product groups, representing three different meal components: protein rich foods, sources of carbohydrates, and vegetables (including fruits, and berries). The selection of the products was derived by the Food Composition Database Fineli® maintained by the Finnish Institute for Health and Welfare (THL, 2019). Following the food use classification in Fineli®, egg dishes, fish dishes, pulses and pulse dishes, milk dishes (cheeses only), and meat dishes were included in the product group of protein rich foods, cereals, cereal products, and potatoes in the sources of carbohydrates, and vegetables, fruits, and berries, as well as vegetable, fruit, and berry dishes in the product group of vegetables, fruits, and berries. The list of products from the Fineli database (THL, 2019), including both branded and general products, was combined with the Agribalyse 3.1 database (Asselin-Balençon et al., 2022). The products for which the environmental impacts were available in the Agribalyse database, were included in the final assessment. The full list of the included products is provided in the Supplementary material.

Table 1
The product group specific NR-FI indices (Kyttä et al., 2023c) used in this study as FUs, and the nutrients included in each index.

Index	Nutrients included
NR-FI_{prot}	Protein, Ca, Fe, Se, Zn, vitamins B6 and B12, niacin, riboflavin, and thiamine
NR-FI_{carb}	Carbohydrates, fibre, Fe, Mg, P, K, and folate
NR-FI_{veg}	Fibre, K, thiamine, vitamins C, K, and A

3.3. The nutrient indices used as nFUs

We used the Finnish product group specific nutrient indices that contain the key beneficial nutrients for the product group in question introduced by Kyttä et al. (2023c) and validated by Kårlund et al. (2024) (Table 1). The rationale behind product group specific nutrient indices lies in the idea of the substitution of products: different types of foods are consumed differently as a part of meals, and therefore comparing only foods that are consumed similarly is more reasonable than comparing all foods with each other (Saarinen et al., 2017).

The nutrient compositions of the assessed foods were derived from the Fineli® Food Composition Database maintained by the Finnish Institute for Health and Welfare (THL, 2019). The nutrient index scores were calculated for the studied products using Eq. (2):

$$\text{Nutrient index} = \sum \frac{NUTRIENTi}{DRIi} \times 100 \Big/ \text{number of nutrients in the index}, \quad (2)$$

where $NUTRIENT_i$ is the amount of a selected nutrient in 100 g of a product and DRI_i is the recommendation for the daily intake of the nutrient. The nutrient index scores were calculated without capping (McLaren et al., 2021), separately for all sexes and age groups, which have their own intake recommendations in the Finnish nutrition recommendations (VRN, 2014): men and women aged 10–13, 14–17, 18–30, 31–60, 61–74, and over 75; and children aged 12–23 months, 2–5, and 6–9. The DRI for each population group and the population (OSF, 2023) weighted average of the nutrient index scores for all assessed foods are presented in the Supplementary material and were used in the further calculations.

3.4. Downscaling the share of the safe operating space (SoSOS) to the product level

We applied the PB-LCA approach (Bjørn et al., 2020a) to downscale the safe operating space (SOS) for all activities of mankind (Rockström et al., 2009; Steffen et al., 2015) to the product level following a stepwise procedure: first we adapted the SoSOS assigned for the food system from

Willett et al. (2019) as has also been done in previous studies, e.g. Potter and Röös (2021).

In this study, we considered all the environmental impact categories to which the EAT-Lancet Commission have defined the SoSOS for food system; climate change, nitrogen cycling, phosphorus cycling, freshwater use, land-system change, and biodiversity loss (Willett et al., 2019). To make the SoSOS compatible with the life cycle impact assessment method ReCiPe 2016 method (Huijbregts et al., 2017) the SoSOS for N application was multiplied by factor of 0.13 and the SoSOS for the application of P multiplied by a factor of 0.1 based on the fate factors of N and P used in the ReCiPe 2016 method. Similar conversions have also been done in previous PB-LCA studies (Ghani et al., 2023). The planetary boundary for biodiversity is expressed in extinctions per million species per year (EMSY) (Steffen et al., 2015; Willett et al., 2019), whereas the ReCiPe 2016 endpoint (H) LCIA-method (Huijbregts et al., 2017) uses a global species richness of 1.95 million known species (Goedkoop et al., 2009; Huijbregts et al., 2017), and therefore the boundary given in EMSY was multiplied by a factor of 1.95.

After these conversions, the SoSOS assigned for the food system were downscaled equally per capita per day by dividing the boundary by the global population of 8 billion (UN, 2022) and 365 days resulting in the SoSOS for the average daily diet per person. Finally, the SoSOS for the average daily diet was downscaled to the SoSOS for an nFU using the Eq. (3):

$$\text{SoSOS per nFU} = \frac{\textit{SoSOS for daily diet per person}/100}{\textit{total no.of nutrients with DRI}} \text{*number of nutrients in the nutrient index}_i, \tag{3}$$

where the SoSOS is the assigned share of the SOS (planetary boundary) for the food consumption per cap per day, total number of nutrients with DRI is the number of nutrients with recommended daily intake in nutrition recommendations for the population under study, and index$_i$ is the nutrient index used as an FU.

Using Eq. (3), the SoSOS for a daily diet is first divided by 100 to convert it to 1 %. This equates to the nFU, because when nutrient index is used as an nFU, the FU equals 1 % of the average nutrient intake from the DRI of the nutrients included in the index (Saarinen et al., 2017; Eq. (1)), and because a sustainable daily diet should provide the DRI of all nutrients (and the diet provides all the nutrients a person can get).

In our case, the sharing of the SoSOS for each nutrient index was done using Eq. (2), based on the 23 different nutrients and 15 population groups given the daily recommended intake in the Finnish nutrition recommendations (VRN, 2014). We used nutrient indices belonging to the NR-FI family, but it must be noted that the nutrition recommendations vary between countries, and thus the relevant one for the studied population should be selected, when this approach is followed. In general, a nutrient index should be calculated for a target population and based on the population specific dietary conditions and nutrient reference values (Kyttä et al., 2023b; McLaren et al., 2021).

Each of the NR-FI indices include different number of nutrients; an index for protein rich foods NR-FIprot including 10, an index for carbohydrate sources including 7, and the NR-FIveg index for vegetables, fruits, and berries including 6 nutrients. Therefore, the SoSOS was calculated separately for each nFU index as follows:

$$\text{SoSOS per unit of NR} - \text{FIprot index} = \frac{\textit{SoSOS per cap per day}/100}{23} * 10 \tag{4}$$

$$\text{SoSOS per unit of NR} - \text{FIcarb index} = \frac{\textit{SoSOS per cap per day}/100}{23} * 7 \tag{5}$$

$$\text{SoSOS per unit of NR} - \text{FIveg index} = \frac{\textit{SoSOS per cap per day}/100}{23} * 6 \tag{6}$$

The resulting assigned SoSOS for each nFU is presented in the Results section.

3.5. The environmental impacts of foods

To showcase the NI-SFPM, the environmental impacts for each product were derived from the Agribalyse 3.1 database as it contains extensive repertoire of food products and covers all the impact categories considered in the NI-SFPM (Asselin-Balençon et al., 2022). The data represents the environmental impacts of food consumed in France, but we have used it as a proxy in this study due to the lack of equally comprehensive datasets for products consumed in Finland in all the studied impact categories. As a sensitivity analyses, we assessed the climate impacts using recently published extensive climate impact dataset of ingredients consumed in Finland (Lindfors et al., 2024). The sensitivity analyses and its results are fully described in the Supplementary material.

The system boundary of the assessment was from the cradle to supermarket, except for a few products for which consumption mix data were used. Ideally, the system boundary should cover the life cycle from cradle to plate, i.e., including also the preparation and consumption phases (McLaren et al., 2021), but due to lack of data the system boundary in this study was limited to supermarket.

We used the ReCiPe 2016 midpoint (H) LCIA-method (Huijbregts et al., 2017) to assess the GHG emissions (CO_2 eq), water consumption (m^3), marine eutrophication (N eq), and freshwater eutrophication (P eq), and the ReCiPe 2016 endpoint (H) LCIA-method (Huijbregts et al., 2017) to assess the biodiversity impact. Because the ReCiPe method applies different characterization factors to different land use types, the land use was separately calculated using a characterization factor of 1 for all types of land occupation.

The nutrient indices calculated in the previous section were used as nFUs by dividing the environmental impact per 100 g by the nutrient index score (per 100 g) of the product.

3.6. Evaluating the absolute environmental sustainability of a product

In the final step, the environmental impacts assessed per nFU were compared to the assigned SoSOS per nFU. The impacts were divided by the SoSOS assigned for the nFUs of each product group. Therefore, final score below one means that the environmental impact is below the assigned SoSOS, i.e. environmentally sustainable.

3.7. Analysis of functionality of the model

To evaluate the functionality of the NI-SFPM, we used the food classifications of the Fineli database (THL, 2019) to aggregate the results of individual products into broader categories and evaluate how the model ranks different food categories within the product groups. The performance of the NI-SFPM was evaluated by examining which individual products the model ranks as the best and the worst performing foods, and how the different product categories in the different product groups rank in relation to each other.

4. Results

We assessed the sustainability of 559 products using the NI-SFPM, resulting in product sustainability scores that indicate environmental impacts of products (per unit of nutrient index score) in relation to the assigned SoSOS. These are presented in Table 2.

All together 226 protein-rich foods, 186 sources of carbohydrates, and 165 products belonging to product group of vegetables, fruits and berries were analysed. The sustainability profiles of the 15 best and the 15 worst performing products in each product category are presented in Tables 3–5, ranked based on their average performance. The sustainability profiles of all the assessed products are presented aggregated to

Table 2
The SoSOS for each product group specific nFUs used in this study (nFUs are presented in Table 1). The lower and upper limits are derived from the uncertainty ranges set by EAT-Lancet (Willett et al., 2019). GHG = greenhouse gas, N = nitrogen, P = phosphorous.

The SoSOS of protein rich foods (NR-FI_{prot})

Planetary boundary	Indicator	Average	Lower	Upper	Unit
Climate change	GHG emissions	7.44×10^{-3}	7.00×10^{-3}	8.04×10^{-3}	kg CO_2 eq
Nitrogen cycling	Marine eutrophication	1.74×10^{-5}	1.26×10^{-5}	2.52×10^{-5}	kg N
Phosphorus cycling	Freshwater eutrophication	1.19×10^{-6}	8.93×10^{-7}	2.38×10^{-6}	kg P
Freshwater use	Consumptive water use	3.72	1.49	5.96	l
Land-system change	Land use	1.94×10^{-2}	1.64×10^{-2}	2.23×10^{-2}	m^2
Biodiversity loss	Extinction rate	2.90×10^{-14}	2.90×10^{-15}	2.32×10^{-13}	species.yr

The SoSOS of sources of carbohydrates (NR-FI_{carb})

Planetary boundary	Indicator	Average	Lower	Upper	Unit
Climate change	GHG emissions	5.21×10^{-3}	4.90×10^{-3}	5.63×10^{-3}	kg CO_2 eq
Nitrogen cycling	Marine eutrophication	1.22×10^{-5}	8.81×10^{-6}	1.76×10^{-5}	kg N
Phosphorus cycling	Freshwater eutrophication	8.34×10^{-7}	6.25×10^{-7}	1.67×10^{-6}	kg P
Freshwater use	Consumptive water use	2.61	1.04	4.17	l
Land-system change	Land use	1.94×10^{-2}	1.64×10^{-2}	2.23×10^{-2}	m^2
Biodiversity loss	Extinction rate	2.03×10^{-14}	2.03×10^{-15}	1.63×10^{-13}	species.yr

The SoSOS of vegetables, fruits, and berries (NR-FI_{veg})

Planetary boundary	Indicator	Average	Lower	Upper	Unit
Climate change	GHG emissions	4.47×10^{-3}	4.20×10^{-3}	4.82×10^{-3}	kg CO_2 eq
Nitrogen cycling	Marine eutrophication	1.05×10^{-5}	7.55×10^{-6}	1.51×10^{-5}	kg N
Phosphorus cycling	Freshwater eutrophication	7.15×10^{-7}	5.36×10^{-7}	1.43×10^{-6}	kg P
Freshwater use	Consumptive water use	2.23	8.93×10^{-1}	3.57×10	l
Land-system change	Land use	1.94×10^{-2}	1.64×10^{-2}	2.23×10^{-2}	m^2
Biodiversity loss	Extinction rate	1.74×10^{-14}	1.74×10^{-15}	1.39×10^{-13}	species.yr

product classes (Figs. 2–4) to provide an overview of the whole product selection and functioning of the NI-SFPM. Detailed results for individual products and the intermediate results of nutrient index scores of each assessed food is presented in the Supplementary material.

5. Discussion

Evaluating the environmental sustainability of individual food products by combining PB-LCA and nLCA approaches can be instrumental in developing policies and strategies to address the current environmental and nutritional challenges of our food system at the/a product level. The NI-SFPM introduced in this study can serve as a framework for interpreting and communicating the LCA results against criteria for nutritionally adequate and environmentally sustainable foods. Here, we have adopted a static approach by maintaining consistent boundaries over time and providing clear targets for immediate policy interventions (Clausen et al., 2024). As the aim of this study was to present the fundamental idea of a novel SFPM, there are still several limitations and uncertainties in the proposed procedure, which requires critical evaluation in the future research.

5.1. *Performance of a new sustainable food profiling model*

The NI-SFPM was able to distinguish between sustainable and unsustainable products in each product group for all other impact categories except species extinction. This is largely in accordance with the EAT-Lancet's dietary level assessment, where the SoSOS was also most exceeded in the species extinction category, and the impacts of diet on species extinctions was close the SoSOS only in the most ambitious dietary scenarios (Willett et al., 2019), highlighting biodiversity loss as the most critical impact category for food. However, in our study, all assessed food items surpassed the SoSOS threshold for species loss. This small inconsistency in the results was due to methodological differences as our impact assessment method includes species loss resulting from not only land use but also other drivers, whereas the EAT-Lancet assessment includes species loss resulting only from land use. We consider that our approach aligns more effectively with the SOS, as discussed also in prior research (Wolff et al., 2017).

Overall, in all the studied impact categories relatively few products stay within the SoSOS. We used the thresholds of the SOS for the food system set by the EAT-Lancet commission (Willett et al., 2019). Especially for the GHG emissions, the SOS assigned for food production by the EAT-Lancet commission (Willett et al., 2019) is ambiguously low. It is based on an estimate of the minimum amount of GHG emissions from biological activities associated with agriculture that are considered difficult if not impossible to avoid over the next 30 years. The fact that only a few products are within the SoSOS for a product group raises the question of whether the SOS assigned for the food system (or diet) have been set too narrowly for the start. Food competes for those limits with the production and consumption of other commodities. In the current situation of a serious sustainable crisis, it is important to also reflect on the importance and justification of different consumption areas. Based on our result, it must be asked whether the SOS for the food system should be relatively wider than it was in this study.

Here, we have demonstrated the NI-SFPM using environmental impact data from LCA databases. As shown by the sensitivity analyses (presented in the Supplementary material), the NI-SFPM is sensitive to the environmental impact data used and is therefore able to distinguish similar end products originating from different supply chains and produced with different production methods. Therefore, product chain specific LCA data on actual products is needed to fully utilise the model as a tool to identify environmentally sustainable food products. In addition to the environmental impact data, also the representativeness of the nutrient composition data affects the results. Hence, product specific data should be used also for the calculation of the nutrient indices.

In any case, the results also underline the need for action both on the consumer and production side, as emphasized also in previous studies

Table 3
The 15 best and the 15 worst performing products in the product group of protein rich foods in descending order. The scores indicate the environmental impacts (per unit of nutrient index score) in relation to the assigned SoSOS (Table 2). A value of 1 is equal to the average of the safe operating space. Colour coding; green = below the lower boundary, yellow = between the lower and upper boundary, red = above the upper boundary of the assigned share of safe operating space (Table 2).

Protein rich foods

Best performing products	GHG emissions	Freshwater eutrophication	Marine eutrophication	Water use	Land use	Extinction rate
FISH, FATTY, SMOKED	0.31	0.20	0.0017	0.0028	0.0037	440
FISH, AVERAGE, GRILLED	0.32	0.21	0.0018	0.0029	0.0039	462
FISH, OVEN-BAKED	0.35	0.22	0.0019	0.0032	0.0042	503
FISH, AVERAGE, FRIED	0.36	0.23	0.0020	0.0033	0.0043	514
FISH, BREADED, OVEN-BAKED	0.36	0.23	0.0020	0.0033	0.0043	515
FISH, WARM SMOKED, AVERAGE	0.36	0.23	0.0020	0.0033	0.0043	516
FISH, WEIGHTED AVERAGE, BAKED	0.37	0.24	0.0020	0.0034	0.0045	537
FISH, AVERAGE, BOILED	0.38	0.24	0.0021	0.0035	0.0046	544
FISH, WEIGHTED AVERAGE, BOILED	0.38	0.25	0.0021	0.0035	0.0046	550
EUROPEAN SPRAT	0.33	0.21	0.0017	0.0025	0.0030	554
FISH, WEIGHTED AVERAGE, FRIED	0.39	0.25	0.0021	0.0036	0.0047	560
FISH, AVERAGE, FRIED IN BUTTER	0.39	0.25	0.0022	0.0036	0.0048	567
FISH, AVERAGE, BALTIC HERRING/VENDACE/PERCH/PIKE	0.41	0.27	0.0023	0.0038	0.0050	595
FISH, FILLET, SALT-CURED	0.43	0.28	0.0024	0.0039	0.0052	618
FISH, WEIGHTED AVERAGE	0.43	0.28	0.0024	0.0040	0.0052	619

Worst performing products	GHG emissions	Freshwater eutrophication	Marine eutrophication	Water use	Land use	Extinction rate
LAMB, FILLED WITH LEEK AND PARSLEY	30	12	10	0.4	24.9	147892
LAMB	24	9	8	0.3	19.2	114403
LAMB, LOW-FAT	23	9	7	0.3	18.7	111250
LAMB, LOW-FAT, BOILED	23	9	7	0.3	18.5	109895
LAMB, LOW-FAT, BOILED WITHOUT SALT	21	8	7	0.3	17.0	101365
CHILI CON CARNE	21	8	6	0.2	11.3	72305
PANGASIUS, FILLET	15	174	2	19.4	1.6	61440
PANGASIUS, FILLET, FRIED	14	171	2	19.0	1.5	60276
PANGASIUS, BREADED, FRIED	14	166	2	18.5	1.5	58501
PANGASIUS, FILLET, OVEN-BAKED	13	157	2	17.4	1.4	55264
BEEF, CANNED	15	5	4	0.1	8.3	52337
BEEF, AVERAGE	14	5	4	0.1	7.8	49400
BEEF, CURED, 2.8% FAT	14	5	4	0.1	7.8	49085
BEEF, MEDIUM FAT, 13% FAT	14	5	3	0.1	7.3	46349
BEEF, ASSORTMENT E, MEAT FOR GRAVY	14	5	3	0.1	7.3	46284

(Poore and Nemecek, 2018; Willett et al., 2019). Indeed, the NI-SFPMs provide valuable information not only for consumers, but also for producers, as they establish clear numerical targets for individual products instead of larger entities such as diets. The NI-SFPM identify unsustainable products and categories indicating how far safe limits are exceeded and thereby helping to prioritize resources for technological advancements to improve performance.

5.2. Ranking of products and product classes

The results of the NI-SFPM also indicates that the profiling model ranks foods in accordance with the latest Nordic nutrition recommendations, promoting and discouraging similar products (Blomhoff et al., 2023), namely promoting various vegetable, fruit and berries, whole-grain products, fish and seafoods, and legumes, and discouraging red meat, meat products, rice, and cheese products. The product classes which were ranked as most sustainable and the least sustainable are also in line with those whose intake is recommended to be increased or decreased to achieve the planetary healthy diet presented by the EAT-Lancet commission (Willett et al., 2019).

In the protein-rich food group, fish and pulse products were the most sustainable, while cold meat cuts, steaks, chops, and cheeses were the least sustainable. Considerable variability existed, with some consistently sustainable options and others significantly exceeding predefined sustainability limits. On average, carbohydrate sources demonstrated better environmental performance compared to protein-rich foods. Breads, flours, and cooked/fried potatoes were among the most sustainable carbohydrate sources, while rice and pasta, sweet biscuits, and savoury and sweet bakery were often ranked less sustainable. Within the group of vegetables, fruits, and berries, fresh and cooked vegetables were the most sustainable, while fresh cultivated berries, fruit juices, fruit salads, and canned vegetables performed less sustainably. While there was variation within classes, this group exhibited relatively sustainable rankings compared to other product categories.

Our approach is product group specific, but the NI-SFPM is still able to compare products across product group boundaries while considering the nutritional role of the product in the dietary context (Kyttä et al., 2023c; Saarinen et al., 2017). Keeping in mind the general nutrition requirements, this does not mean that one should shift the consumption of one product group totally to another, but it allows consideration of the relative burden of each group and perhaps balancing the sustainability requirements for product groups. According to nutrition science, each nutrient in the nutrient recommendation and the nutrient indices applied in this study are important for health and well-being, and thus each product group is invaluable. In principle, selecting sustainable products from each product group leads to the best result as whole, but the question arises as to whether the repertoire of sustainable products is enough to satisfy the modern consumer's desire for variety. This is also

Table 4
The 15 best and the 15 worst performing products in descending order in the product group of sources of carbohydrates. The scores indicate the environmental impacts (per unit of nutrient index score) in relation to the assigned SoSOS (Table 2). A value of 1 is equal to the average of the safe operating space. Colour coding; green = below the lower boundary, yellow = between the lower and upper boundary, red = above the upper boundary of the assigned share of safe operating space (Table 2).

Sources of carbohydrates

Best performing products	GHG emissions	Freshwater eutrophication	Marine eutrophication	Water use	Land use	Extinction rate
RYE BREAD, WHOLEGRAIN RYE, WHEAT FLOUR, RUISPALAT	0.61	1.00	0.73	0.019	0.46	624
MUESLI, CRUNCHY, WITH YOGHURT AND STAWBERRY	2.01	3.60	3.78	0.066	1.03	686
RYE BREAD, WHOLEGRAIN RYE, JYVÄROUHEA	0.58	0.94	0.69	0.018	0.43	703
WHEAT BRAN	0.05	0.07	0.03	0.001	0.03	756
RYE BREAD, WHOLEGRAIN RYE, POTATO, RUISIISAKKI	0.67	1.10	0.81	0.021	0.50	858
RYE BREAD, OULULAINEN JÄLKIUUNIPALA	0.47	0.77	0.56	0.015	0.35	951
RYE BREAD, TAIKARUIS RUISVIIPALE, 100% RYE	0.63	1.03	0.75	0.020	0.47	1180
RYE BREAD, TOSI RUKIINEN, VAASAN	0.68	1.11	0.81	0.022	0.51	1209
RYE BREAD, WHOLEGRAIN RYE, 100% RYE	0.57	0.93	0.68	0.018	0.43	1421
RYE BREAD, RUISKAKKO, ULLAN PAKARI	0.83	1.36	1.00	0.026	0.62	1428
MUESLI, CRUNCHY, WITH DRIED BERRIES, AVERAGE	1.74	3.13	3.29	0.057	0.89	1444
BISCUIT, GINGERBREAD, GLUTEN-FREE	11.64	11.72	5.00	0.385	5.24	1421
MUESLI, WHEAT, RAISINS, CORN, OATS AND DRIED FRUITS	1.66	2.98	3.13	0.054	0.85	1700
RYE BREAD, OULULAINEN REILU	0.69	1.12	0.83	0.022	0.52	1986
MUESLI, CRUNCHY, WITH FRUIT	2.00	3.59	3.78	0.066	1.02	1985

Worst performing products	GHG emissions	Freshwater eutrophication	Marine eutrophication	Water use	Land use	Extinction rate
RICE, QUINOA AND MULTIGRAIN MIX, BOILED, SALT	10.46	13.23	8.22	18.61	1.70	119695
RICE, QUINOA AND MULTIGRAIN MIX, BOILED, WITHOUT SALT	10.45	13.21	8.22	18.59	1.70	119356
BISCUIT, POTATO FLOUR, SWEETENED WITH FRUCTOSE	8.42	8.48	3.62	0.28	3.79	89932
BISCUIT	8.42	8.48	3.62	0.28	3.79	85885
CROISSANT, HOME-MADE, GLUTEN-FREE	4.94	3.54	1.84	0.10	2.02	79784
BISCUIT, INDUSTRIAL, AVERAGE	10.11	10.19	4.35	0.33	4.55	79321
BISCUIT, GINGERBREAD, INDUSTRIAL	9.30	9.37	4.00	0.31	4.19	69605
BISCUIT, GINGERBREAD, HOME-MADE	8.24	8.30	3.54	0.27	3.71	62172
FRESH PASTA, CONTAINS EGG, BOILED WITHOUT SALT	21.25	22.80	9.09	0.60	9.05	53763
RICE, LONG-GRAIN, BOILED, VEGETABLE BOUILLON	9.90	12.53	7.79	17.63	1.61	48457
BISCUIT, AUNT HANNA'S COOKIES	7.76	7.81	3.33	0.26	3.49	47044
BISCUIT, RAPESEED OIL-BASED, AVERAGE	4.66	4.70	2.00	0.15	2.10	44136
BISCUIT, AVERAGE OF INDUSTRIAL PRODUCTS	6.87	6.92	2.95	0.23	3.09	42804
BISCUIT, SWEETENED WITH FRUCTOSE	7.21	7.26	3.10	0.24	3.25	39420
FRUIT CAKE	5.35	5.93	2.20	0.29	2.25	39259

related to the above discussion on the SOS for food. In addition, there may be dietary situations where the intake of one nutrient is in a specific position, for example due to a deficiency, and the nutrient indices are not able to highlight this with sufficient weight. Such situations require special consideration of the most sustainable nutrient sources (Saarinen et al., 2017). Additionally, a product level assessment inevitably breaks the link between products in a diet and neglects the fact that a diet that stays within the assigned SOS can also include some products that cross the product level boundaries. The product level assessment does not allow burden-shifting between products, i.e. compensating high impacts from one product with low impacts from another and is therefore stricter that diet level assessments.

5.3. Role of nutrition in the assessment of environmental sustainability

Here, we have used the product-group-specific nFUs as the foundation of our profiling model. The choice of the nFUs inevitably affects both the nutritional index scores and the SoSOS assigned for the nFU, leading to different results. In our earlier study we demonstrated that including all the nutrients with recommended intakes to the index used as nFU leads to lower index scores, and thus higher environmental impacts per nFU (Kyttä et al., 2023c). However, using index with all the beneficial nutrients considered in the NI-SFPM, would also lead to higher SoSOS assigned to the nFU in question. The extent to which these factors together actually influence the final results obtained with the approach presented here needs to be studied in future research. However, the choice of a nutrient index, especially the nutrients it contains, should be based on logical principles that are relevant to the dietary context, not on anticipated results. Taking this into account, future research should be undertaking to thoroughly understand the methodology, not suggest the most appropriate set of nutrients for the index.

The NI-SFPM is developed to profile the environmental sustainability

Table 5
The 15 best and the 15 worst performing products in descending order in the product group of vegetables, fruits, and berries. The scores indicate the environmental impacts (per unit of nutrient index score) in relation to the assigned SoSOS (Table 2). A value of 1 is equal to the average of the safe operating space. Colour coding; green = below the lower boundary, yellow = between the lower and upper boundary, red = above the upper boundary of the assigned share of safe operating space (Table 2).

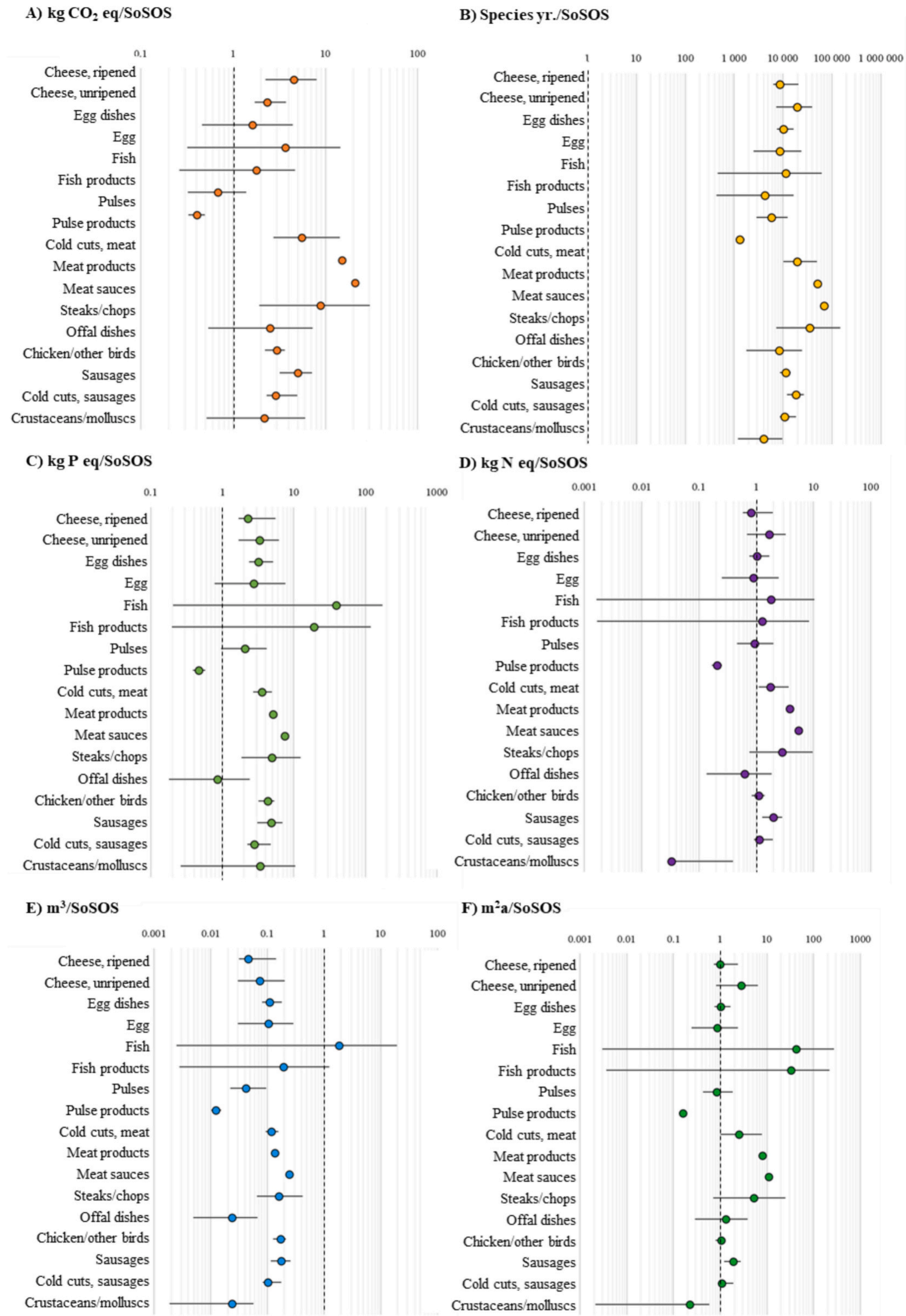
Vegetables, fruits, and berries

Best performing products	GHG emissions	Freshwater eutrophication	Marine eutrophication	Water use	Land use	Extinction rate
SWISS CHARD	0.04	0.04	0.02	0.002	0.002	50
SPINACH	0.09	0.09	0.04	0.004	0.006	122
SPINACH, FROZEN	0.09	0.09	0.04	0.004	0.006	124
SPINACH, FRIED	0.12	0.12	0.06	0.006	0.008	171
GARDEN CRESS	0.12	0.11	0.02	0.024	0.013	222
CORIANDER, FRESH	0.18	0.25	0.09	0.018	0.018	303
BASIL, FRESH	0.09	0.19	0.06	0.041	0.039	383
CARROT, FRIED	0.07	0.13	0.07	0.053	0.035	417
CARROT, BAKED	0.07	0.13	0.07	0.054	0.035	421
HORSERADISH	0.19	0.34	0.05	0.041	0.029	429
BRUSSELS SPROUT	0.13	0.10	0.11	0.001	0.049	439
DILL, FRESH	0.11	0.22	0.07	0.047	0.045	441
BROCCOLI	0.29	0.29	0.22	0.022	0.024	452
CARROT	0.08	0.14	0.08	0.058	0.038	458
SWEET PEPPER, RED	0.37	0.73	0.04	0.030	0.017	463

Worst performing products	GHG emissions	Freshwater eutrophication	Marine eutrophication	Water use	Land use	Extinction rate
PLUM, WITH STONE	2.32	6.28	0.27	4.73	19.44	91860
PLUM, WITHOUT STONE	2.13	5.77	0.25	4.35	17.88	84511
COCONUT WATER, UNSWEETENED	6.97	21.73	4.77	2.88	4.93	32783
PINEAPPLE JUICE, UNSWEETENED, VITAMIN C	16.96	31.35	4.54	0.11	2.71	30236
OLIVE, AVERAGE, WITH STONE, IN OIL, GREEN/BLACK	0.39	23.31	2.28	0.81	5.52	25354
OLIVE, AVERAGE, WITHOUT STONE, IN BRINE, GREEN	0.38	22.58	2.21	0.78	5.35	24557
BAMBOO SHOOTS, CANNED	4.11	7.65	2.95	1.85	2.89	22664
OLIVE, AVERAGE, WITHOUT STONE, IN OIL, GREEN/BLACK	0.32	18.65	1.82	0.65	4.42	20284
BLUEBERRY, BILBERRY	2.28	8.66	7.95	0.16	3.86	20250
PEACH, CANNED, IN SYRUP	6.98	22.47	1.97	4.27	1.50	19098
GRAPEFRUIT, AVERAGE, WITH SKIN	1.63	3.39	1.09	7.05	0.75	17597
BLUEBERRY	1.89	7.16	6.57	0.13	3.19	16745
GRAPEFRUIT JUICE, UNSWEETENED, VITAMIN C	2.37	5.02	0.97	5.73	0.63	15629
SWEET CORN, CORN ON THE COB	3.92	6.22	1.65	0.63	1.62	15050
ASPARAGUS, CANNED	1.58	2.30	1.94	1.28	2.01	14648

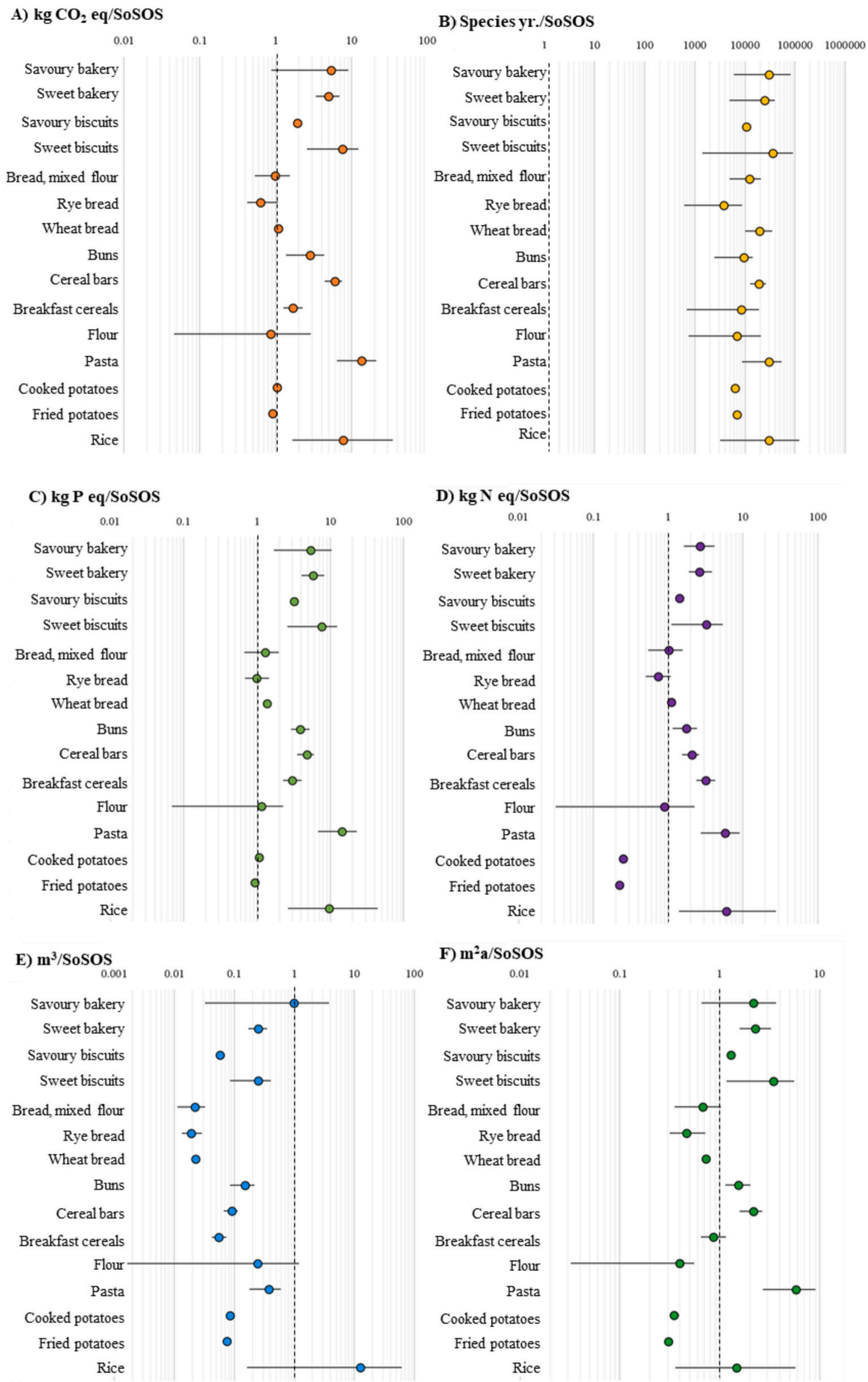
of foods, while also considering the nutritional function of foods. As the model is based on beneficial role of nutrients, we have excluded the nutrients that should be limited, such as saturated fatty acids, salt, and added sugar. From the health point of view these nutrients are of high importance (Afshin et al., 2019), and should be considered separately (McLaren et al., 2021; Saarinen et al., 2017), if the NI-SFPM is used to produce information to guide consumers. Future research should evaluate this; could for example existing nutrient profiling models developed from the health point of view (Martin et al., 2023) be utilised.

However, the nLCA methods for handling nutrients to limit are still under development (McLaren et al., 2021) as they represent a potential cause of adverse health impact rather than nutritional function (Kyttä et al., 2023b; Saarinen et al., 2017). Indeed, the nutrients to limit affect the nutritional quality of foods, and for nutritional profiling purposes the nutrients to limit can be included in the nutrient index, such as in the NRF9.3 index (Drewnowski, 2009). However, this type of indices easily results to negative index scores, which consequently lead to negative environmental impacts —an outcome that is neither realistically valid nor useful (Saarinen et al., 2017). For this reason, the nutrients to discourage cannot be incorporated directly into the SPFM's formula. Adding a separate indicator would diverge from the model's intended purpose, which is to provide a consistent framework for assessing environmental sustainability based on planetary boundaries. However, the NI-SFPM could potentially be used to produce the environmental



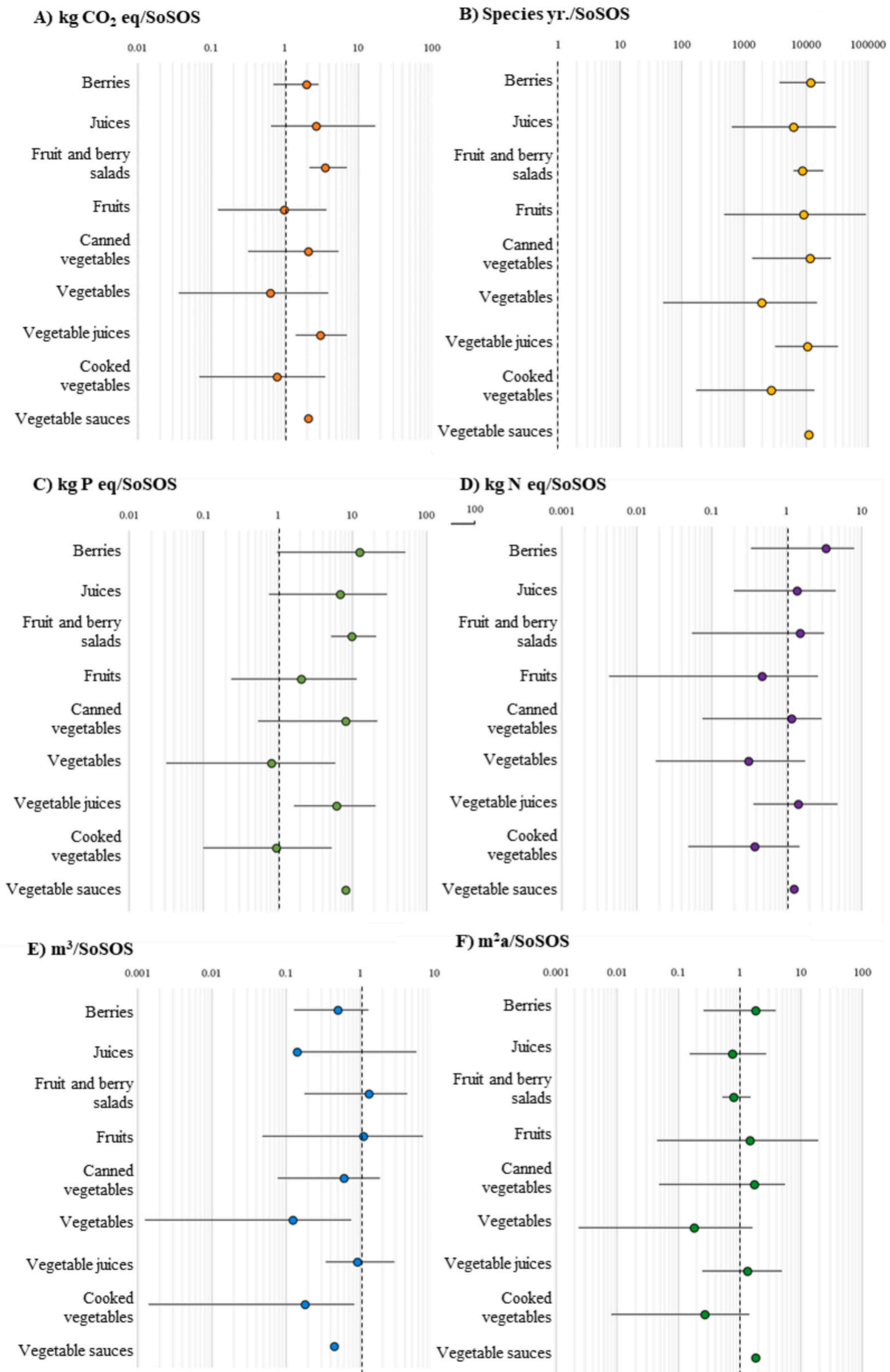
roduct class	N	Product class	N	Product class	N	Product class	N
heese, ripened	24	Fish	45	Cold cuts, meat	5	Offal dishes	16
heese, unripened	17	Fish products	9	Meat products	1	Chicken/other birds	6
ig dishes	12	Pulses	4	Meat sauces	1	Sausages	18
ig	18	Pulse products	2	Steaks/chops	36	Cold cuts, sausages	5
						Crustaceans/molluscs	7

Fig. 2. The environmental sustainability profile of different product classes in the product group of protein rich foods, presented as the min, average and max of the scores of individual products. The scores indicate the environmental impacts regarding Climate change (A), Biodiversity loss (B), Phosphorus cycling (C), Nitrogen cycling (D), Freshwater use (E), and Land-system change (F) (per unit of nutrient index score) in relation to the assigned SoSOS (Table 2), score 1 (dashed line) being equal to the average of the SoSOS. Note the logarithmic scale.



Product class	N	Product class	N	Product class	N	Product class	N
Savoury bakery	4	Bread, mixed flour	9	Cereal bars	3	Cooked potatoes	12
Sweet bakery	5	Rye bread	46	Breakfast cereals	18	Fried potatoes	2
Savoury biscuits	1	Wheat bread	3	Flour	8	Rice	26
Sweet biscuits	20	Buns	9	Pasta	2		

Fig. 3. The environmental sustainability profile of different product classes in the product group of sources of carbohydrates, presented as min, average and max of the scores of individual products. The scores indicate the environmental impacts regarding Climate change (A), Biodiversity loss (B), Phosphorus cycling (C), Nitrogen cycling (D), Freshwater use (E), and Land-system change (F) (per unit of nutrient index score) in relation to the assigned SoSOS (Table 2), score 1 (dashed line) being equal to the average of the SoSOS. Note the logarithmic scale.



Product class	N	Product class	N	Product class	N
Berries	6	Fruits	34	Vegetable juices	5
Juices	18	Canned vegetables	12	Cooked vegetables	36
Fruit and berry salads	7	Vegetables	46	Vegetable sauces	1

Fig. 4. The environmental sustainability profile of different product classes in the product group of vegetables, fruits, and berries, presented as the min, average and max of the scores of individual products. The scores indicate the environmental impacts regarding Climate change (A), Biodiversity loss (B), Phosphorus cycling (C), Nitrogen cycling (D), Freshwater use (E), and Land-system change (F) (per unit of nutrient index score) in relation to the assigned SoSOS (Table 2), score 1 (dashed line) being equal to the average of the SoSOS. Note the logarithmic scale.

sustainability information as a part of wider criteria-based sustainability assessment.

Because the downscaling method presented here is based on the beneficial function of food as a provider of adequate nutrition, it is in principle applicable using also other nFUs which include only beneficial nutrients. However, the formation of the indices used as a nFU inevitably affects the results, which should be considered when implementing the NI-SFPM. More in-depth discussions on the considerations related to formatting nutrient indices as nFUs is presented in other publications (Hallström et al., 2018; McAuliffe et al., 2020; McLaren et al., 2021; Saarinen et al., 2017).

The principles of the NI-SFPM can be applied to other contexts by using nFUs suitable for the population under study and environmental and nutrient composition data which are representative of the foods consumed. In this study, we have focused on developing profiling model for individual food products, but the principles of the NI-SFPM could possibly be adapted also to assess meals and diets by using across the board indices. For example, as diets include the whole food consumption of a person or a population under study, the nutrient index should be chosen accordingly, for example using index with all the nutrients with DRI (with capping). This way, the index and the consequent SoSOS per index, be consistent with dietary viewpoint.

5.4. Choices in assigning the SoSOS

In our study, we adopted the equal per capita approach for downscaling of the boundaries based on the principle that nutrition is a fundamental human need (O'Neill et al., 2018), and adequate nutrition for everyone is desirable state of the food system highlighted in UN's sustainable development goals (UN, 2015). We consider nutrition as a solid base for downscaling the SOS in terms of food consumption, but in general, also other approaches could be adapted. The previous studies combining PBs with traditional LCA have applied for example equal per capita, economic, agriland, caloric, grandfathering (Chandrakumar et al., 2019; Ghani et al., 2023), and nutrient-based (Kyttä et al., 2025) sharing principles to evaluate the SoSOS. The choice of the sharing principle significantly influences the results and the results of the NI-SFPM are also sensitive to the downscaling methodology used. The chosen downscaling methodology unavoidably includes value-based choices (Sandin et al., 2015), leading to the fact that the absolute environmental sustainability assessment method is not fundamentally absolute (Guinée et al., 2022). Therefore, a sensitivity analysis with various sharing principles including regional and socio-economic perspectives is recommended for future research.

In this study the planetary boundaries were adopted as global boundaries, but many of the control variables, such as biosphere integrity, phosphorus (P) and nitrogen (N) cycles, land-system change, freshwater use, and atmospheric aerosol loading have strong sub-global distributions (Steffen et al., 2015). As alternatives to global boundaries, also geographically resolved boundaries could be adopted, as demonstrated by earlier studies (Bjørn et al., 2020c; Ghani et al., 2023). The localised boundaries could be used especially when assessing the environmental sustainability from the production point of view, to define which products could be considered sustainable produced in different regions. For more holistic sustainability assessments, also social aspects, e.g. social thresholds (O'Neill et al., 2018), could be considered.

In PB-LCA studies one potential source of uncertainty relates to the temporal differences between the LCA results and the SOS, which have to be aligned (Guinée et al., 2022). In most PB-LCA studies, the FU lacks a temporal dimension, which makes it incompatible with the planetary boundaries (Guinée et al., 2022). In this study, this issue has been addressed as the FU and the SOS include the same temporal dimension of one day (Weidner et al., 2022). We consider this as a strength of the NI-SFPM compared to other models.

5.5. Limitations

As discussed in the previous sections, the NI-SFPM itself as well as the assessments implemented in this study has some uncertainties and limitations, which should be considered when using the profiling model or interpreting the results. The results obtained with NI-SFPM are only as accurate as the nutrient composition and environmental impact data used in the assessment. Because both the nutrient composition data and the environmental impact data can include notable uncertainties or might not be representative of the products studied, integrating these both aspects into one assessment further increases the uncertainty of the results. For example, in this study, we have used data from the Finnish food composition database and environmental impact data from the French LCA database, and the combination of these two datasets might not present the actual food products on the markets. Therefore, the results should be interpreted carefully.

6. Conclusions

The novel NI-SFPM introduced in this study represents an important step forward in providing a framework for interpreting the environmental impacts of foods. The model integrates the nutrient composition of foods into the environmental impact assessment and evaluates the resulting impacts against the sustainability thresholds drawn from the planetary boundaries. The model assigns planetary boundaries to individual food products based on the nutrition they provide. This allows foods that effectively fulfil their nutritional role to have a higher environmental impact than less nutritious foods. The model enables the identification of the absolute sustainability of various food products and determines how far they exceed the limits thereby helping relevant stakeholders make informed decisions and prioritize their efforts accordingly. In general, vegetable, fruit, and berry-based food products performed better, followed by carbohydrate-rich foods and then protein rich food products. However, the product level results show that for most products, the environmental impacts exceed the planetary boundary, and only few products are within the safe operating space. This shows that there are unsustainable products also within the product groups, which are generally considered sustainable. Especially the impact category of biodiversity loss is critical - all the studied products crossing the boundary. This highlights the need for changes both in food production and consumption.

As demonstrated here, the model is sensitive to changes in the source data, and thus is able to distinguish between similar products with differences in production systems or nutrient composition. The model and knowledge based on its application can be used to guide both production and consumption, such as in product development, sustainability reporting, or as a basis for labelling. To further the use of the model to guide target setting for companies and informing consumers, more research is needed to perfect the details of the model and its use in different dietary contexts and decision-making situations. Future research should pay attention especially to the share of planetary boundaries assigned for food system in relation to other consumption areas, improvement and clarification of the biodiversity impact assessment, and dealing with uncertainty originating from various sources. Furthermore, we suggest following a spatially resolved approach in NI-SFPM model by quantifying the regionalized safe operating spaces especially for the regional impact categories. Also, to utilise the model as basis for labelling, criteria for the aspects not considered in the NI-SFPM, such as allowed limits for disqualifying nutrients in a product, needs to be developed for more holistic label supporting healthy and environmentally sustainable food choices.

CRediT authorship contribution statement

Venla Kyttä: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Hafiz Usman Ghani:** Writing – review & editing, Writing – original draft, Methodology. **Tiina Pellinen:** Writing – review & editing. **Anna Kårlund:** Writing – review & editing. **Marjukka Kolehmainen:** Writing – review & editing. **Anne-Maria Pajari:** Writing – review & editing. **Hanna L. Tuomisto:** Writing – review & editing. **Merja Saarinen:** Writing – review & editing, Supervision, Methodology, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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