

**This is an electronic reprint of the original article.**

**This reprint *may differ* from the original in pagination and typographic detail.**

**Author(s):** Venla Kyttä, Hafiz Usman Ghani, Kim Lindfors, Jaakko Heikkinen, Taru Palosuo

**Title:** Integrating policy targets into product environmental impact assessments: A case study with Finnish agricultural products

**Year:** 2025

**Version:** Published version

**Copyright:** The Author(s) 2024

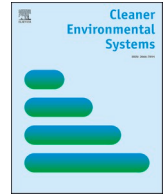
**Rights:** CC BY 4.0

**Rights url:** <https://creativecommons.org/licenses/by/4.0/>


**Please cite the original version:**

Venla Kyttä, Hafiz Usman Ghani, Kim Lindfors, Jaakko Heikkinen, Taru Palosuo, Integrating policy targets into product environmental impact assessments: A case study with Finnish agricultural products, *Cleaner Environmental Systems*, Volume 16, 2025, 100252, <https://doi.org/10.1016/j.cesys.2024.100252>.

All material supplied via *Jukuri* is protected by copyright and other intellectual property rights. Duplication or sale, in electronic or print form, of any part of the repository collections is prohibited. Making electronic or print copies of the material is permitted only for your own personal use or for educational purposes. For other purposes, this article may be used in accordance with the publisher's terms. There may be differences between this version and the publisher's version. You are advised to cite the publisher's version.



# Integrating policy targets into product environmental impact assessments: A case study with Finnish agricultural products

Venla Kytä , Hafiz Usman Ghani , Kim Lindfors, Jaakko Heikkinen, Taru Palosuo 

Natural Resources Institute Finland (Luke), Latokartanonkaari 9, FI-00790, HELSINKI, Finland

## ARTICLE INFO

### Keywords:

Sustainable production  
PB-LCA  
Emission budget  
Environmental targets  
Sustainable food

## ABSTRACT

Political objectives aimed at reducing environmental impacts currently face challenges in effectively assessing achievement at product level. Applying the principles of Absolute Environmental Sustainability Assessment (AESA, or Planetary Boundaries-based Life Cycle Assessment, PB-LCA) to these targets could be a way forward to evaluate a product's performance against political targets. Here, we explore the possibilities of assigning emission budgets for agricultural products based on political and scientific targets utilising the principles of PB-LCA. We tested these principles by assessing a few Finnish agricultural products; wheat, peas, milk, and beef. First, we identified national and EU-level political targets relevant to agricultural products produced in Finland. Then these targets alongside scientific planetary boundary targets were translated to emission budgets for products by first sharing the targets equal per capita and then using two different sharing principles; calorie-based and nutrition-based. In the last step, the environmental impacts of the products were compared with the emission budget assigned to each product. The results demonstrated that the method used to assign the emission budgets affects the results, nutrition-based sharing leading to better performance compared to calorie-based sharing. Beef exceeded its budget in almost all impact categories, while the results for milk and peas depended on the sharing principle used. Wheat's impacts were within the budget across all categories. The results show that both political and scientific targets can evaluate a product's sustainability performance, and comparing environmental impacts against political targets can provide new insights for decision-makers.

## 1. Introduction

The escalating concerns regarding global environmental degradation, characterized by climate change, air pollution, and resource depletion, have necessitated a strategic shift towards effective strategies to mitigate environmental impacts. To this end, a variety of political targets, such as the Sustainable Development Goals (SDGs), have been set with the aim of decreasing environmental impacts and ensuring a sustainable future (UN, 2015). Conventional environmental targets often operate at a macro-level, lacking linkages to specific products or supply chains where emissions are generated. For instance, the concept of planetary boundaries outlines the global processes that maintain the stability and resilience of the Earth system, within which humanity can thrive sustainably (Richardson et al., 2023; Rockström et al., 2009; Steffen et al., 2015). Currently, nine of these boundaries have been assessed, and six of them have been crossed (Richardson et al., 2023). For many of them, the food system is responsible for significant impacts, for example in terms of greenhouse gas emissions, pollution, resource

use, and biosphere integrity (Campbell et al., 2017). As a consequence, a variety of scientific as well as political targets have been set to reduce the environmental impacts arising from the food system (UN, 2015; Willett et al., 2019). Achieving ambitious environmental targets demands a transition towards a product-centred approach that comprehensively addresses emissions across supply chains.

Life cycle assessment (LCA) is widely used to assess the environmental impacts of products throughout their life cycle (ISO, 2006). It includes multiple environmental impact categories and is often employed to guide decision-making processes aimed at reducing environmental burdens. However, LCA's relative approach only allows for comparisons between products with similar functionalities, without assessing the sufficiency of impact reduction in absolute terms. Recently, this issue has led to the emergence of Absolute Environmental Sustainability Assessment (AESA or Planetary Boundaries-based Life Cycle Assessment, PB-LCA) methods within LCA (Bjørn et al., 2016; Guinée et al., 2022). AESA evaluates the overall environmental sustainability of anthropogenic systems against regional or global environmental limits

\* Corresponding author.

E-mail address: [venla.kytta@luke.fi](mailto:venla.kytta@luke.fi) (V. Kytä).

<https://doi.org/10.1016/j.cesys.2024.100252>

Received 30 August 2024; Received in revised form 25 October 2024; Accepted 22 December 2024

Available online 24 December 2024

2666-7894/© 2024 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

or targets, such as the planetary boundaries (Rockström et al., 2009; Steffen et al., 2015).

While planetary boundaries are scientifically defined limits that mark safe operating thresholds for key Earth system processes, beyond which environmental stability is at risk (Rockström et al., 2009), specific political targets are essential for national and local environmental impact reduction. There are, however, indications that global goals do not effectively turn to transformative political impacts (Biermann et al., 2022). If national policy targets are defined, they are typically set and monitored at a sector or national level and there are no means to assess their achievement at the product level. Recently, Clausen et al., 2024 applied PB-LCA approach using the climate change boundary and the 2019 consumption footprint of the EU 27 + UK to analyze policy targets and strategies. Ghani et al. (2023) conducted a resource efficiency analysis of sugarcane, linking PB-LCA with relevant LCA indicators and SDGs. Chandrakumar and McLaren (2018) used the enhanced Driver-Pressure-State-Impact-Response (eDPSIR) framework to classify the indicators of planetary boundaries, LCA, and SDGs, mapping them in a cause-effect chain, and including the area of protection in LCA. Concerning planetary boundaries, the immediate global governance challenges are the interaction between Earth system science and global policies, institutional capacity, the role of international organizations, and framing social-ecological innovation to deal with planetary boundaries (Galaz et al., 2012). Therefore, applying PB-LCA methods to political targets becomes a novel approach, which could provide valuable insights to guide consumers, industries, and policymakers in aligning reduction measures accordingly. Product-level information is crucial for identifying opportunities to improve environmental performance throughout a product's life cycle, comparing different alternatives, informing strategic decisions, and supporting marketing practices and consumer information such as ecolabelling (ISO, 2006). Hence, the product-level quantified assessment based on scientific or political targets would assist the relevant stakeholders in assessing the product performance and support coherent and effective policies promoting the sustainable production and consumption.

Here, we introduce a framework for applying the principles of PB-LCA to political targets in addition to scientifically set planetary boundaries, thereby bridging the gap between achieving broader environmental goals and actions needed at the product level. The aim of the study is to compare how political targets relate to scientific ones and assess how using political targets, instead of planetary boundaries, influences the results and whether this approach provides new insights. First, we outline the main principles of the framework and then demonstrate its application by identifying relevant political and scientific targets. This is followed by an evaluation of the environmental impacts of key Finnish agricultural products representing the key product types—wheat, pea, milk, and beef—against emission reduction targets over various time horizons.

## 2. Materials and methods

The framework relies on the general principles of PB-LCA (Björn et al., 2020b; Chen et al., 2021; Ryberg et al., 2018), where the environmental performance of a product is evaluated against the share of safe operating space assigned for a product. For scientific targets, the budget or assigned share of the safe operating space is calculated based on planetary boundaries (PBs). Here, we describe the method and apply it for agricultural production in Finland and extend the application also for politically set environmental targets. However, for political targets, a similar approach is used as in PB-LCA by developing boundaries and defining the budget based on political targets and comparing them with actual environmental impacts, but it is not PB-LCA. The procedure contains three main steps; i) evaluating the emission budget based on relevant scientific and political targets, ii) assigning emission budgets for products following the chosen sharing principles, iii) assessing the environmental impacts of the products in the impact categories relevant

for the emission budgets chosen in step i, and iv) evaluating the environmental impacts of the product against the assigned emission budgets.

### 2.1. Choice of emission reduction targets

Different environmental targets generally have similar goals – to reduce the environmental impacts – but the magnitude, timeframes, and objects of the reduction targets vary. For example, Europe aims to become climate-neutral by 2050 and to pave the way to achieve this target, a minimum of 55% cut in greenhouse gas emissions by 2030 has been set as a milestone (European Commission, 2020) (Fig. 1). The emission reduction targets that are relevant to the goal of the study should be chosen depending on the case. Commonly scientific targets, i. e., planetary boundaries, have been applied in an LCA context, but also other relevant targets, such as political ones, could be used. The targets should be chosen so, that they are temporally and geographically relevant to the product under study. Here, we focus on the emission reduction targets set for the food system and monitor if they are reached on a product level.

The planetary boundaries framework has defined the safe operating space for the activities of humankind (Rockström et al., 2009; Steffen et al., 2015), i.e., it covers all human actions in all sectors. The EAT-Lancet Commission has further defined the share attributed to the global food system from the total planetary boundaries, thus creating scientific emission budgets for the operation of the food system by 2050 (Willett et al., 2019). Here, we adopt the 2050 targets as defined by the EAT-Lancet Commission for global warming, land occupation, water consumption, marine eutrophication, freshwater eutrophication, and biodiversity loss (Willett et al., 2019) (Table 1).

Several emission reduction targets for agriculture have also been set politically, such as the targets of the European Green Deal (European Commission, 2020). Here, we have identified the political targets set for agriculture in Finland and in the EU. For the emission targets to be possible to include, the targets need to be quantified, or it must be possible to calculate the target based on the starting level and the percentage of reduction. For example, the Farm to Fork Strategy includes targets to reduce the overall use of chemical pesticides by 2030 by 50%, but as there is no information available on current usage levels, this target cannot be adopted. The implementable targets were identified to be the GHG emission reduction target of agricultural greenhouse gas emissions by 29% in Finland by 2035 (Ministry of Agriculture and Forestry of Finland, 2023) and the EU level targets of 55% GHG emission reduction, and 20% nitrogen (N) use, and phosphorus (P) use reduction by 2030 set in the Farm to Fork strategy (European Commission, 2020) (Table 1).

### 2.2. Environmental impacts of the case study products

For the demonstration of the methods, we chose common agricultural products of the Finnish food system: wheat, peas, milk, and beef. Beef and milk are widely consumed in Finland and have significant

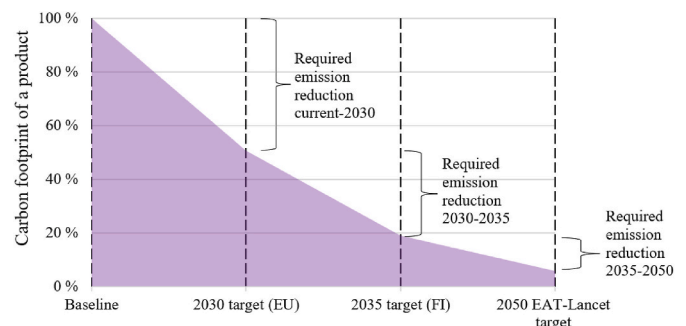


Fig. 1. Illustration of different emission reduction targets and their timeframes.

**Table 1**

Summary of the emission reduction targets considered in this study, by Ministry of Agriculture and Forestry of Finland (2023), European Commission (2020), and Willett et al. (2019).

Impact category	Target type	Target year	Geographical coverage	Target quantity	Unit
GHG emissions	political	2035	Finland	11.36	Mt CO <sub>2</sub> eq/yr
GHG emissions (incl. LULUCF)	political	2030	EU	2455	Mt CO <sub>2</sub> eq/yr
N use	political	2030	EU	8 348 155	t/yr
P use	political	2030	EU	882 894	t/yr
Global warming	scientific	2050	Global	5	Gt CO <sub>2</sub> eq/yr
Land occupation	scientific	2050	Global	13	million km <sup>2</sup>
Water consumption	scientific	2050	Global	2500	Km <sup>3</sup> /yk
Marine eutrophication	scientific	2050	Global	90	Tg N/yr
Freshwater eutrophication	scientific	2050	Global	8	Tg P/yr
Biodiversity loss	scientific	2050	Global	10	extinctions per million species-yr

environmental impacts, making their assessment crucial in the Finnish context (Kyttä et al., 2023; Saارينen et al., 2023). The production area of wheat is not very large, but it is a key cereal for food products consumed in Finland. Pea as a leguminous crop is important currently with acute aims to improve nitrogen self-sufficiency. Promoting legumes as a more sustainable alternative for meat can also help reduce environmental impacts, and hence, peas were included in this study. Additionally, given that cereals are a staple in Finnish diets, wheat was included in the assessment to evaluate its sustainability. The environmental impacts were assessed with cradle to farm gate system boundaries using economic allocation. The environmental impacts of harvested and dried wheat and peas produced in Finland were derived from the Agri-footprint database (Wheat grain, dried, at farm/FI Economic; Peas, dry, at farm/FI Economic) and the impacts of Finnish raw milk from the World Food LCA Database (Raw milk, production mix, at farm (WFLDB)/FI U), as these databases have data on Finnish production. For beef, German production (Beef cattle, mixed system, live weight, at farm (WFLDB)/DE U, World Food LCA database) was used as a proxy. The environmental impacts per live weight beef were converted to meat using factors provided in the guidance of the Product Environmental Footprint (PEF) method (Zampori and Pant, 2019). Because we wanted to study how current production relates to different environmental targets, the possible future development of environmental impacts of the products was not considered.

To assess the environmental impacts corresponding with the selected emission reduction targets, the environmental impacts were calculated using ReCiPe 2016 midpoint (H) LCIA-method (Huijbregts et al., 2017) to assess the GHG emissions (CO<sub>2</sub> eq), water consumption (m<sup>3</sup>), marine eutrophication (N eq), and freshwater eutrophication (P eq), and ReCiPe 2016 endpoint (H) method (Huijbregts et al., 2017) to assess the biodiversity impact (species.yr). Because the ReCiPe method applied characterization factors to land use, the land use was separately calculated using a characterization factor of 1 for all land occupation since the ReCiPe method assessed land use as crop equivalents.

### 2.3. Assigning the share of emission budgets for products

The most critical step of the assessment is assigning the share of emission budgets for the products. Several different sharing principles have been applied in previous absolute environmental sustainability assessments (Bjørn et al., 2020a). In a technical sense, several methods can be used, but depending on the industry, some methods might be more relevant than others. The sharing principles can be based on the benefits obtained from the products, such as economic value added or caloric content (Bjørn et al., 2020a). Here, we have selected the sharing principles based on the assumption that the primary function of food products is to provide energy and nutrition for people, and we therefore apply two alternative sharing principles: calorie-based, and nutrition-based. Overview of the procedure to share emission budgets to individual products is presented in Fig. 2.

The politically set environmental targets were first shared equally

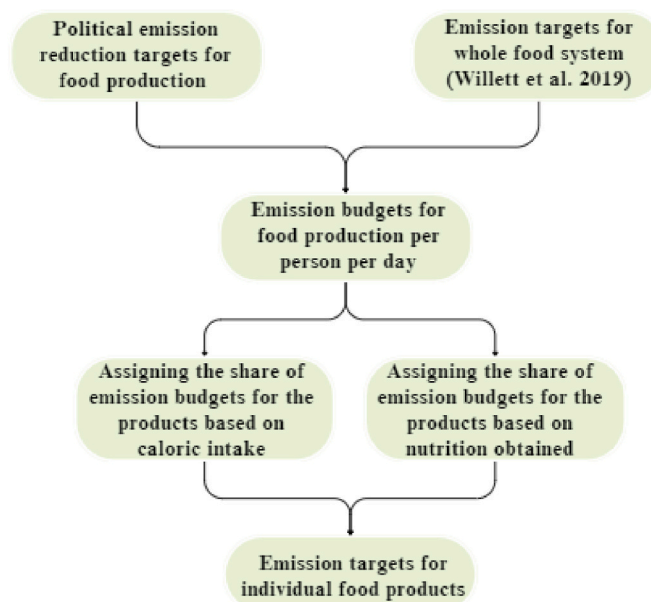


Fig. 2. Overview of the steps of the procedure to share emission budgets to individual products.

per capita per day, by dividing the budget of Finnish targets by the population of Finland (5 563 970 inhabitants; OSF, 2023) and the budget of EU targets by the population of the EU (448.4 million inhabitants; European Union, 2023), and the per capita budgets by 365 days (Table 2).

The scientific emission budgets were adopted from the EAT-Lancet Commission (Willett et al., 2019), which have defined the share attributed to the food system from the total planetary boundaries. These boundaries have been widely adapted as the boundaries for food system in many other studies (e.g., Chaudhary and Krishna, 2019; Hallström et al., 2022; Potter and Röö, 2021). The boundaries were downscaled equally per capita per day, by dividing the boundary by a global population of 8 billion (UN, 2022) and 365 days (Table 2).

The emission budgets per capita per day were further shared for each of the studied food products using two sharing principles, based on calorie and nutrient contents. The calorie-based method has been previously applied also in other food PB-LCA studies, such as (Chandrakumar et al., 2019; Ghani et al., 2023). Several other sharing principles have also been developed, but as the differences between these principles are extensively covered in other studies (e.g. (Bjørn et al., 2020a; Ghani et al., 2023)), we applied only the two methods described below.

#### 2.3.1. Sharing based on calorie intake

The calorie-based sharing method is based on the calorie intake by

**Table 2***Emission budget for food, based on political and scientific targets, per cap per day.*

Impact category	Target type	Target year	Geographical coverage	Emission budget per cap per day	Unit
GHG emissions	political	2035	Finland	6	kg CO <sub>2</sub> eq
GHG emissions (incl. LULUCF)	political	2030	EU	15	kg CO <sub>2</sub> eq
N use	political	2030	EU	0.007	kg N <sup>a</sup>
P use	political	2030	EU	0.0005	kg P <sup>a</sup>
Global warming	scientific	2050	Global	1.71	kg CO <sub>2</sub> eq
Land occupation	scientific	2050	Global	4.45	m <sup>2</sup> a
Water consumption	scientific	2050	Global	856	l
Marine eutrophication	scientific	2050	Global	0.00401	kg N <sup>a</sup>
Freshwater eutrophication	scientific	2050	Global	0.00027	kg P <sup>a</sup>
Biodiversity loss <sup>b</sup>	scientific	2050	Global	5.34E-08	species.yr

<sup>a</sup> Values of P and N application multiplied with a factor of 0.1 and 0.13 for P and N, respectively, reflecting the fraction which ends up in the environment (Huijbregts et al., 2017), to match the budget with the LCA results.

<sup>b</sup> Boundary defined by (Wolff et al., 2017).

the use of assessed foods (Ghani et al., 2023). The daily emission budget of food is further shared between different food products based on the historic calorie intake per day from the assessed food in relation to the historic total daily caloric intake. The information on the calorie supply (kcal/capita/day) of the assessed food product and the total daily intake were derived from the food balance statistics of the Food and Agricultural Organization of the United Nations for years 2017–2022 (FAO, 2022). The food balance statistics and the calorie content of the assessed products is presented in the supplementary information.

### 2.3.2. Sharing based on nutrition obtained

The nutrition-based sharing is based on the nutrient content of foods in relation to daily recommended intakes. The nutrition provided by the products was assessed by dividing the nutrient content of foods with the recommended daily intake of nutrients given in the Finnish nutrition recommendations (VRN, 2014). This score was then used to assign the share of emission budgets for the products by multiplying the emission budget per person per day with the nutrient index score. Following this procedure, a value of 1 would mean that on average the product provides all the nutrients needed, and lead to assigning the whole emission budget per person per day to the product in question.

The Finnish nutrition recommendations include recommended intake values for 23 beneficial nutrients for 15 different population groups. Because the nutritional requirements differ between population groups, the average provision of nutrition ( $N_{mean}$ ) of a studied product was calculated for each population group using equation (1) (Fulgoni et al., 2009) presented below, and then aggregated into for the whole population as population weighted average score (values provided in the Supplementary information).

$$N_{mean} = \left( \sum_{i=1}^n \frac{c_i}{DRI_i} \right) / n \quad \text{Eq. (1)}$$

$$\sum_{i=1}^{23} \frac{\text{nutrient } i}{DRI_i} / 23,$$

Where  $c_i$  is the content of nutrient  $i$  in the studied product and  $DRI_i$  is the daily recommended intake of the nutrient derived from the Finnish nutrition recommendations (VRN, 2014). The total number of nutrients (23 in the Finnish recommendations) is denoted with  $n$ . The nutrient contents of foods were derived from the national Food Composition Database in Finland (Fineli) (THL, 2019). The nutrient compositions of foods and the recommended nutrient intakes, as well as the provision of nutrition of the assessed foods are presented in the supplementary information.

### 2.4. Comparing the environmental impacts to the assigned emission budget

The final step of the procedure is to compare the actual environmental impacts of the product under study with the emission budget assigned for the product by dividing the environmental impact by the emission budget. Thus, values under one mean that the environmental impact is within the assigned budget, and values over one that the environmental impact is higher than the assigned emission budget.

## 3. Results

### 3.1. Assigned emission budgets

The emission budgets assigned for the products were somewhat higher when assigned based on recommended nutrition provision instead of actual calorie intake (Tables 3 and 4). The emission budgets based on the political targets were higher than scientific targets, but also the target timeframes were shorter for the political targets than scientific ones.

### 3.2. Comparing the actual environmental impacts to political targets 2030–2035

The actual environmental impacts of wheat and peas were below the 2030 emission budget assigned to the products in all the assessed impact categories (Fig. 3.). When using nutrition-based emission budget sharing, the impacts of milk were below the budget in all impact categories, but when using the calorie-based sharing method GHG emission

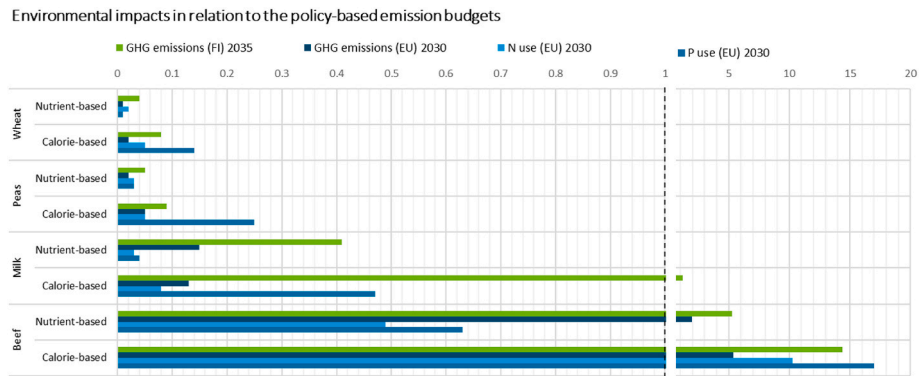
**Table 3**

Assigned policy-based (2030 and 2035) emission budgets per kg of product using nutrition- and calorie intake-based sharing methods.

Policy-based targets		GHG emissions (FI) 2035	GHG emissions (EU) 2030	N use (EU) 2030	P use (EU) 2030
Product	Emission budget sharing method	kg CO <sub>2</sub> eq	kg CO <sub>2</sub> eq	kg N	kg P
Wheat	Calorie-based	5.99	16.60	0.05	0.0006
	Nutrition-based	13.10	35.10	0.12	0.01
Peas	Calorie-based	6.42	17.90	0.06	0.0006
	Nutrition-based	12.00	32.30	0.11	0.01
Raw milk	Calorie-based	1.11	3.09	0.01	0.0001
	Nutrition-based	3.24	8.70	0.03	0.00
Beef	Calorie-based	3.50	9.73	0.02	0.0003
	Nutrition-based	9.51	25.60	0.09	0.01

**Table 4**  
Assigned science-based (2050) emission budgets per kg of product using nutrition- and calorie intake-based sharing methods.

Science-based targets		Climate change	Land-system change	Freshwater use	Nitrogen cycling	Phosphorus cycling	Biodiversity loss
Product	Emission budget sharing method	kg CO <sub>2</sub> eq	m <sup>2</sup>	l	kg N	kg P	EMSY
Wheat	Calorie-based	1.83	4.76	916	0.0043	0.0003	5.72E-08
	Nutrition-based	4.00	10.40	2000	0.0094	0.0006	1.25E-07
Peas	Calorie-based	1.97	5.11	983	0.0046	0.0003	6.13E-08
	Nutrition-based	3.68	9.58	1840	0.0086	0.0006	1.15E-07
Raw milk	Calorie-based	0.34	0.88	170	0.0008	0.0001	1.06E-08
	Nutrition-based	0.99	2.58	496	0.0023	0.0002	3.09E-08
Beef	Calorie-based	1.07	2.79	536	0.0025	0.0002	3.34E-08
	Nutrition-based	2.91	7.57	1460	0.0068	0.0005	9.09E-08



**Fig. 3.** The environmental impacts of assessed products in relation to the policy-based 2030 emission budget assigned to the product using nutrition- and calorie intake-based sharing methods. The impacts below the assigned budget are the ones with values under 1 (dashed line).

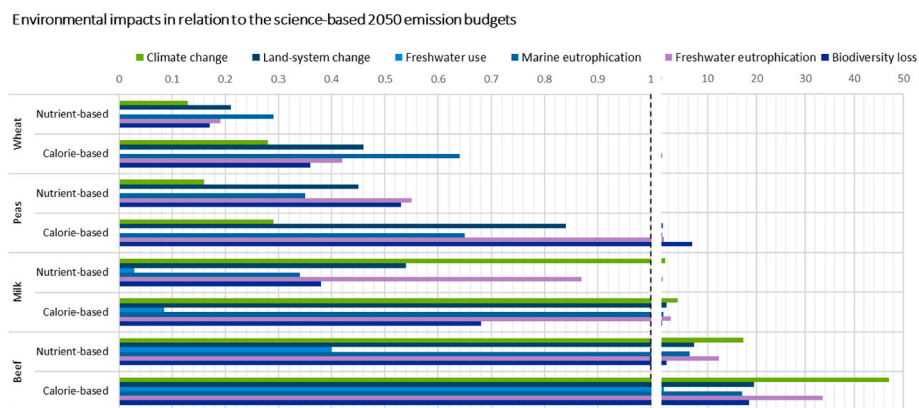
(FI) and P use (EU) exceeded the budget. Beef exceeded the allocated budget in all impact categories, except N use (EU), when using the nutrition-based sharing method.

**3.3. Comparing the current environmental impacts to scientific targets 2050**

When evaluating the current environmental impacts against the scientific targets for year 2050 more products exceeded the assigned emission budget than in the case of political targets (Fig. 4.). The impacts of wheat were below the budget in all of the assessed impact categories, but for peas, the budgets for freshwater eutrophication and biodiversity loss were exceeded when the emission budget was set based on calorie intake.

**4. Discussion**

The interplay between production, consumption, and environmental sustainability underscores the urgency for precise assessment mechanisms that measure the performance of individual products in relation to predefined emission reduction targets. By linking the wider sustainability targets to a product level, companies can monitor their environmental performance, and evaluate if their emission reduction measures are enough to be in line with wider targets. Such assessments are critical not only for enhancing the accountability of manufacturers but also for facilitating informed consumer choices and guiding policy formulation towards sustainability. The results obtained from the procedure presented in this study demonstrate a potential approach for companies to monitor and evaluate the environmental performance of their products. By quantifying emission reductions and aligning them with broader environmental targets, businesses can enhance their sustainability efforts and ensure compliance with national, international



**Fig. 4.** The environmental impacts of assessed products in relation to the science-based 2050 emission budget assigned to the product using nutrition- and calorie intake-based sharing methods. The impacts below the assigned budget are the ones with values under 1 (dashed line).

and industry-specific environmental goals. This aligns with the growing demand for transparency and accountability in corporate environmental performance (European Commission, 2024). From companies' internal operational perspective, the proposed procedure can serve as a tool for continuous improvement, helping companies identify where emissions are generated and how they could be reduced. This allows businesses to not only meet regulatory requirements but also set ambitious targets. In addition to internal use, assessment anchoring the environmental performance of the product to some wider targets could serve as a basis for consumer communication, such as labelling. Labels grounded in recognized environmental targets could be more transparent and easier to communicate and understand than rating systems with absolute or relative impact scales.

As demonstrated in this study, both the political and scientific targets can be used to evaluate the sustainability of a product. The political targets usually have a shorter timeframe, or they include mid-term targets, which can act as milestones on a way towards greater emission reductions. Political targets are also usually more geographically limited than planetary boundaries, and thus they can be aimed at issues that are of high importance for the area in question. Therefore, evaluating the environmental impacts against political targets can bring new information on aspects that are a point of interest in the decision making in this specific context. While planetary boundaries provide a global framework for understanding environmental limits, they may not fully reflect the regional dynamics and localized conditions of processes like land use, freshwater use, and nutrient cycles. Downscaling global planetary boundaries to the regional level may not always align with local realities, as regional processes are influenced by distinct biophysical and socio-economic factors. Policy targets tailored to these specific regional contexts would likely result in more precise and effective management of environmental pressures and could serve as a relevant monitoring tool for local companies, ensuring more context-appropriate sustainability efforts.

Whether emission reduction targets are based on scientific principles or political state of will, setting a target itself is a step towards taking action. However, the extent of political targets can be rather limited, as most of them focus, for example, only on climate impacts, nor do they provide clear numeric targets which could be utilized for assigning emission budgets for products, for example, 50% reduction of the use of chemical pesticides by 2030 in Farm to Fork Strategy. Considering several different environmental impact categories can provide more holistic view on the areas of improvement, as emissions in one category can be within the budget while exceeded in another. Based on the assessments done in this study, the categories related to GHG emissions, phosphorous, and biodiversity are the most critical ones, and their budgets were exceeded more easily than those in other categories. This result aligns with the fact that these categories are assessed to currently be the planetary boundaries with the highest pressures (Richardson et al., 2023), which shows that the PB-LCA is able to highlight the most critical issues when assessing the environmental sustainability of a product.

The product level results obtained in this study are in line with the previous studies showing that shift in the Finnish diets towards a more plant-based consumption would lead to a lower environmental impacts without compromising the nutrient intake (Kyttä et al., 2023; Saarinen et al., 2023). Within the products assessed in this study, wheat and peas performed better than milk and beef. The environmental impacts of the animal source foods were higher than the ones of plant-based foods, but also the emission budgets assigned for milk and beef were lower than the ones for wheat and peas. Hence, the animal source foods exceeded the emission budgets, especially when the emission budget was set based on calorie intake. It is important to notice that the results of this type of analysis should not be interpreted as meaning that no improvement of environmental performance of the products already within the targets should be made. From a holistic perspective it may still be cost efficient to seek for further improvements also from the production chains that

are already performing well.

As indicated in this study, the results are dependent on the method used to share the emission budget to the products. The different methods to share the safe operating space to products in PB-LCA have been studied previously (Bjørn et al., 2020a, 2020b; Ryberg et al., 2020; Teah et al., 2016) and the fact that the boundaries of "absolute sustainability" are also relative is acknowledged (Guinée et al., 2022). The common practice is to apply more than one method to show and test the sensitivity of results depending on the sharing method (e.g. Chandrakumar et al., 2019; Ghani et al., 2023; Mahmood et al., 2023). Here, we have applied two different methods, which have very different starting points. The sharing based on calorie content considers the historic calorie intake from the assessed foods and assumes that the same share of calories is obtained from the foods also in the future. This principle leads to favouring products that are currently consumed in high amounts. In turn, the nutrient content sharing method is based on the recommended intake of nutrients, and thus favours foods that fulfil a larger share of the daily recommended nutrient intakes, i.e., it gives weight to products that should be favoured also from the health point of view. As the choice of a sharing principle unavoidably affects the results, it is of high importance to choose the method based on the relevance in the context of the study. To ensure accuracy, it's recommendable to test the sensitivity of the results using additional methods and clearly communicate the chosen methods.

## 5. Conclusions

A framework was developed following the basic principles of planetary boundary-based life cycle assessment approach to assess the environmental performance of wheat, peas, milk, and beef of Finnish food system based on the political and scientific targets. The results showed that when considering both future political targets and scientific, the plant-based products, here wheat and pea, were already within their allocated budgets for almost all impact categories with both calorie and nutrition based sharing principles. Beef exceeded its budget in almost all impact categories when considering both political and scientific targets and in the case of milk, the result is highly dependent on the sharing principle.

The selection of sharing principles is subjective, calorie and nutrition based principles were adopted in this study but other principles such as economic principles could be used for a more complete assessment. The results are sensitive to what sharing principle is used, as demonstrated in this study.

This study demonstrated that, in addition to planetary boundaries, political targets can effectively serve as a basis for setting emission reduction targets for individual products. The method presented provides a valuable tool for tracking and evaluating the environmental performance of products over time, allowing for an assessment of how their impacts evolve as we approach the target years of various emission reduction goals. While planetary boundaries offer a global perspective, regionalized policy targets could be more suitable for addressing local environmental conditions, providing relevant monitoring tools for local operators. The developed framework would also support the coherent and effective product policies, enabling the product performance evaluation in meeting quantified targets—whether scientific, political (global, regional, national, or local), or at the company level.

In conclusion, this study highlights the importance of target driven studies in guiding efforts towards sustainable food production and consumption. By integrating holistic metrics, assessing multiple impact categories, and considering the entire life cycle of food products, we can develop more targeted strategies to mitigate environmental impacts and enhance the resilience of food systems. However, to effectively evaluate and refine the framework outlined, testing with real-life products and user needs is essential.

## CRedit authorship contribution statement

**Venla Kytä:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Hafiz Usman Ghani:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Kim Lindfors:** Writing – review & editing. **Jaakko Heikkinen:** Writing – review & editing. **Taru Palosuo:** Writing – review & editing, Writing – original draft, Conceptualization.

## 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.

## Acknowledgements

This work was supported by the Natural Resources Institute Finland strategic funding.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cesys.2024.100252>.

## Data availability

The authors do not have permission to share data.

## References

- Biermann, F., Hickmann, T., Sénit, C.-A., Beisheim, M., Bernstein, S., Chasek, P., Grob, L., Kim, R.E., Kotzé, L.J., Nilsson, M., Ordóñez Llanos, A., Okereke, C., Pradhan, P., Raven, R., Sun, Y., Vijge, M.J., van Vuuren, D., Wicke, B., 2022. Scientific evidence on the political impact of the sustainable development goals. *Nat. Sustain.* 5, 795–800. <https://doi.org/10.1038/s41893-022-00909-5>.
- Björn, A., Chandrakumar, C., Boulay, A.-M., Doka, G., Fang, K., Gondran, N., Hauschild, M.Z., Kerkhof, A., King, H., Margni, M., McLaren, S., Mueller, C., Owsianiak, M., Peters, G., Roos, S., Sala, S., Sandin, G., Sim, S., Vargas-Gonzalez, M., Ryberg, M., 2020a. Review of life-cycle based methods for absolute environmental sustainability assessment and their applications. *Environ. Res. Lett.* 15, 083001. <https://doi.org/10.1088/1748-9326/ab89d7>.
- Björn, A., Margni, M., Roy, P.-O., Bulle, C., Hauschild, M.Z., 2016. A proposal to measure absolute environmental sustainability in life cycle assessment. *Ecol. Indic.* 63, 1–13. <https://doi.org/10.1016/j.ecolind.2015.11.046>.
- Björn, A., Sim, S., King, H., Patouillard, L., Margni, M., Hauschild, M.Z., Ryberg, M., 2020b. Life cycle assessment applying planetary and regional boundaries to the process level: a model case study. *Int. J. Life Cycle Assess.* 25, 2241–2254. <https://doi.org/10.1007/s11367-020-01823-8>.
- Campbell, B.M., Beare, D.J., Bennett, E.M., Hall-Spencer, J.M., Ingram, J.S.I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J.A., Shindell, D., 2017. Agriculture production as a major driver of the Earth system exceeding planetary boundaries. *Ecol. Soc.* 22.
- Chandrakumar, C., McLaren, S.J., 2018. Towards a comprehensive absolute sustainability assessment method for effective Earth system governance: defining key environmental indicators using an enhanced-DPSIR framework. *Ecol. Indic.* 90, 577–583. <https://doi.org/10.1016/j.ecolind.2018.03.063>.
- Chandrakumar, C., McLaren, S.J., Jayamaha, N.P., Ramilan, T., 2019. Absolute sustainability-based life cycle assessment (aslca): a benchmarking approach to operate agri-food systems within the 2°C global carbon budget. *J. Ind. Ecol.* 23, 906–917. <https://doi.org/10.1111/jiec.12830>.
- Chaudhary, A., Krishna, V., 2019. Country-specific sustainable diets using optimization algorithm. *Environ. Sci. Technol.* 53, 7694–7703. <https://doi.org/10.1021/acs.est.8b06923>.
- Chen, X., Li, C., Li, M., Fang, K., 2021. Revisiting the application and methodological extensions of the planetary boundaries for sustainability assessment. *Sci. Total Environ.* 788, 147886. <https://doi.org/10.1016/j.scitotenv.2021.147886>.
- Clausen, C.A., Björn, A., Sanyé-Mengual, E., Ryberg, M., 2024. Applying environmental sustainability boundaries for climate change in life cycle assessment: A review of approaches and implications for policymaking. *J. Ind. Ecol.* <https://doi.org/10.1111/jiec.13481> n/a.
- European Commission, 2024. Corporate sustainability and responsibility. [https://single-market-economy.ec.europa.eu/industry/sustainability/corporate-sustainability-and-responsibility\\_en](https://single-market-economy.ec.europa.eu/industry/sustainability/corporate-sustainability-and-responsibility_en), 10.24.24.
- European Commission, 2020. Farm to Fork Strategy for a Fair, Healthy and Environmentally-Friendly Food System.
- European Union, 2023. Facts and figures, EU demographics | European Union. [https://european-union.europa.eu/principles-countries-history/key-facts-and-figures/life-eu\\_en](https://european-union.europa.eu/principles-countries-history/key-facts-and-figures/life-eu_en), 8.14.24.
- FAO, 2022. Food balance sheets. <https://www.fao.org/faostat/en/#data/FBS>.
- Fulgoni, V.L., Keast, D.R., Drewnowski, A., 2009. Development and validation of the nutrient-rich foods index: a tool to measure nutritional quality of foods. *J. Nutr.* 139, 1549–1554. <https://doi.org/10.3945/jn.108.101360>.
- Galaz, V., Biermann, F., Crona, B., Loorbach, D., Folke, C., Olsson, P., Nilsson, M., Allouche, J., Persson, Å., Reischl, G., 2012. ‘Planetary boundaries’ — exploring the challenges for global environmental governance. *Curr. Opin. Environ. Sustain.* (4), 80–87. <https://doi.org/10.1016/j.cosust.2012.01.006>.
- Ghani, H.U., Ryberg, M., Björn, A., Hauschild, M.Z., Gheewala, S.H., 2023. Resource efficiency analysis through planetary boundary-based life cycle assessment: a case study of sugarcane in Pakistan. *Int. J. Life Cycle Assess.* <https://doi.org/10.1007/s11367-023-02185-7>.
- Guinée, J.B., de Koning, A., Heijungs, R., 2022. Life cycle assessment-based Absolute Environmental Sustainability Assessment is also relative. *J. Ind. Ecol.* 26, 673–682. <https://doi.org/10.1111/jiec.13260>.
- Hallström, E., Davis, J., Håkansson, N., Ahlgren, S., Åkesson, A., Wolk, A., Sonesson, U., 2022. Dietary environmental impacts relative to planetary boundaries for six environmental indicators – a population-based study. *J. Clean. Prod.* 373, 133949. <https://doi.org/10.1016/j.jclepro.2022.133949>.
- Huijbregts, M.A.J., Steinmann, Z.J.N., Elshout, P.M.F., Stam, G., Veronesi, F., Vieira, M.D.M., Hollander, A., Zijp, M., van Zelm, R., 2017. ReCiPe 2016 v1.1. A harmonized life cycle impact assessment method at midpoint and endpoint level. *Rep. IBM: Character*.
- ISO, 2006. Environmental Management. Life Cycle Assessment. Requirements and Guidelines. ISO 14044:2006.
- Kytä, V., Hyvönen, T., Saarinen, M., 2023. Land-use-driven biodiversity impacts of diets—a comparison of two assessment methods in a Finnish case study. *Int. J. Life Cycle Assess.* <https://doi.org/10.1007/s11367-023-02201-w>.
- Mahmood, A., Ghani, H.U., Gheewala, S.H., 2023. Absolute environmental sustainability assessment of rice in Pakistan using a planetary boundary-based approach. *Sustain. Prod. Consum.* 39, 123–133. <https://doi.org/10.1016/j.spc.2023.05.016>.
- Ministry of Agriculture and Forestry of Finland, 2023. Government Report on the Climate Plan for the Land Use Sector (Serial Publication). Maa- ja metsätalousministeriö.
- OSF, 2023. Official statistics of Finland. Population Structure - Population According to Age (1-year 0–112) and Sex.
- Potter, H., Rööös, E., 2021. Multi-criteria evaluation of plant-based foods – use of environmental footprint and LCA data for consumer guidance. *J. Clean. Prod.* 280, 124721. <https://doi.org/10.1016/j.jclepro.2020.124721>.
- Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S.E., Donges, J.F., Driike, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummer, M., Mohan, C., Nogués-Bravo, D., Petri, S., Porkka, M., Rahmstorf, S., Schaphoff, S., Thonicke, K., Tobian, A., Virkki, V., Wang-Erlandsson, L., Weber, L., Rockström, J., 2023. Earth beyond six of nine planetary boundaries. *Sci. Adv.* 9, eadh2458. <https://doi.org/10.1126/sciadv.adh2458>.
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J., 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecol. Soc.* 14.
- Ryberg, M.W., Andersen, M.M., Owsianiak, M., Hauschild, M.Z., 2020. Downscaling the planetary boundaries in absolute environmental sustainability assessments – a review. *J. Clean. Prod.* 276, 123287. <https://doi.org/10.1016/j.jclepro.2020.123287>.
- Ryberg, M.W., Owsianiak, M., Richardson, K., Hauschild, M.Z., 2018. Development of a life-cycle impact assessment methodology linked to the Planetary Boundaries framework. *Ecol. Indic.* 88, 250–262. <https://doi.org/10.1016/j.ecolind.2017.12.065>.
- Saarinen, M., Heikkinen, J., Kotoja, E., Kytä, V., Hartikainen, H., Silvennoinen, K., Valsta, L., Lång, K., 2023. Soil carbon plays a role in the climate impact of diet and its mitigation: the Finnish case. *Front. Sustain. Food Syst.* 7.
- Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sörlin, S., 2015. Planetary boundaries: guiding human development on a changing planet. *Science* 347, 1259855. <https://doi.org/10.1126/science.1259855>.
- Teah, H., Akiyama, T., San Carlos, R., Rayo, O., Khew, Y., Zhao, S., Zheng, L., Onuki, M., 2016. Assessment of downscaling planetary boundaries to semi-arid ecosystems with a local perception: a case study in the middle reaches of heihe river. *Sustainability* 8, 1233. <https://doi.org/10.3390/su8121233>.
- UN, 2015. Global Sustainable Development Report.
- UN, 2022. Data Portal. Population Division.
- VRN, 2014. Terveystä ruoasta - suomalaiset ravitsemussuosittelukset 2014. (Health from food – the Finnish nutrition recommendations). Valtion ravitsemusneuvottelukunta. In Finnish.
- Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., Majele Sibanda, L., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Srinath

- Reddy, K., Narain, S., Nishtar, S., Murray, C.J.L., 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492. [https://doi.org/10.1016/S0140-6736\(18\)31788-4](https://doi.org/10.1016/S0140-6736(18)31788-4).
- Wolff, A., Gondran, N., Brodhag, C., 2017. Detecting unsustainable pressures exerted on biodiversity by a company. Application to the food portfolio of a retailer. *J. Clean. Prod.* 166, 784–797. <https://doi.org/10.1016/j.jclepro.2017.08.057>.
- Zampori, L., Pant, R., 2019. Suggestions for updating the product environmental footprint (PEF) method. EUR 29682 EN. Publications Office of the European Union, Luxembourg. <https://doi.org/10.2760/424613>, 2019.