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Implementing sustainability frameworks at a product-level – Exploring the usability

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ABSTRACT

Product-level assessments are for targeted and effective sustainability improvements both in downstream and upstream agrifood supply chains. Current frameworks for sustainability assessments often lack the integration of both social and environmental considerations for product-specific assessment. This study explores the usability of existing frameworks designed for both social and environmental assessments, with a focus on their application at the product level. Based on the development of usability criteria and applying a waterfall selection process, we identified two frameworks (Food System Sustainable framework and Sustainable Nutrition Security framework) for further analysis. To test against usability, both frameworks were applied towards a case study of seven food products produced in Norway: milk, greenhouse tomatoes, greenhouse cucumbers, wheat, beef, sheep and pork. The criteria included the following: data availability, data correctness, ease of use, transparency, effectiveness or relevance, and complexity of use. The selected frameworks provided a holistic and comprehensive approach to assessing social and environmental sustainability. However, their usability was limited due to lower data accuracy and a lack of user-friendliness for researchers, who were the primary target user group. The study revealed a trade-off: frameworks with higher usability tended to sacrifice depth and comprehensiveness in the information provided about food products. Both frameworks faced significant challenges in distinguishing social and ethical issues at the product level, largely due to data limitations. These findings underscore the need for the development of a purpose-built framework that accounts for these trade-offs, while enhancing usability, is essential to progress toward a more sustainable food supply chain.

1. Introduction

One of the most defining challenges of the twenty-first century will be to meet the world's growing demand for food without depleting natural resources and compromising the equity of actors involved in the food supply chain. Where improving yields and respecting planetary boundaries in food production are crucial to food security, the participation of the civil society and encouraging changes in dietary preferences are instrumental to utilize and support solutions to sustainability-related issues (Foley et al., 2011), (Godfray et al., 2010), (Duffy and Marcus, 2014). As a result, a variety of sustainability-focused food labels have been developed in the past decades to guide consumers in making informed decisions by taking into account environmental, social and ethical impacts of their food choices (Annunziata et al., 2019). Typically, sustainability food labels are divided into two separate categories: environmental or social concerns (Asioli et al., 2020). Environmental food labels consider the environmental care that has been put into producing a product, such as organic labels and water or carbon footprint labels. Social labels tackle social and ethical issues related to the production of a food item, such as fairtrade or animal welfare (Asioli et al., 2020).

Over the years, several frameworks have been developed to assess food sustainability for food labeling purposes. Life cycle assessment (LCA) methodology is the main approach for assessing environmental impact of a product or service throughout its life cycle (Guinée et al., 2011). This method serves as the foundation for the Product Environmental Footprint (PEF) framework developed by the European Commission, which aims to standardize environmental impact assessment

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across European Member States (European Commission, 2011). However, it is currently only applied to a few products (i.e., dairy products, pasta, beer, wine, bottled water, and livestock feed) due to the time and resource consuming process of developing PEF product category rules (PEFCR) in supply chains (FoodDrinkEurope, 2022). Recently, the Enviroscore was developed as a 5-point scale label based on the PEF methodology, quantifying products' environmental impact relative to the European food basket (Ramos et al., 2022), listing commonly consumed food products. Furthermore, some EU member states are developing own national frameworks or product labels to address environmental sustainability such as Italy, with the 'Made Green in Italy' National Scheme (Ministero della Transizione Ecologica), and Denmark, which is developing a carbon footprint methodology for labelling food products (Zhen et al., 2024). Several studies support the effect of introducing food labelling, reporting that traffic-light labelling of environmental impact increase consumer awareness of the impact of their consumption and influence their choices for environmentally-friendly foods (e.g., (Arrazat et al., 2023), (Hughes et al., 2024)).

An important gap in current methodologies is the lack of social indicators for product-specific assessment. Efforts have been made to integrate various life cycle-based methodologies into one sustainability framework, Life Cycle Sustainability Assessment (LCSA). Synthesizing the results from environmental LCA, social LCA, and life cycle costing approaches, involves a systematic process of normalization and weighting into a single score. Most likely due to extensive data requirements, there are not many LCSA case studies on food products available in literature (Costa et al., 2019).

There are other frameworks addressing the multiple dimensions of sustainability, such as the Initiative for Sustainable Productive Agriculture (INSPIA) which advocate for agricultural management practices that prioritize ecosystem conservation alongside maintaining high levels of on-farm productivity (Trivino-Tarradas et al., 2019). Similarly, the Sustainable Assessment of Food and Agriculture systems (SAFA) guidelines, proposed by the FAO, provides a holistic global framework to assess the sustainability of the food and agriculture supply chain, at varying scales (F. and A. O. of the U. N. FAO, 2013). While these frameworks measure and enhance progress towards sustainable production at the farm and organization level, they are not designed to assess at product level.

Product-level assessments are essential for both downstream and upstream sustainability efforts. On one hand, these evaluations enhance researchers and academia's understanding of how product information influences consumers' purchasing behaviors. On the other hand, they facilitate discussions with government bodies and companies on how product information impacts the supply chain and the environmental and social impacts of food production. Thus, product-level assessment is a crucial data-driven approach to addressing sustainability challenges.

NewTools is a Norwegian research project aiming to develop a comprehensive, multi-dimensional framework for assessment of the nutritional, social and environmental impact of food products (Abel et al., 2024). The economic dimension of sustainability is indirectly included, as the social impact categories partly cover socio-economic issues (Woodhouse et al., 2024). In the context of NewTools, this paper explores the usability of existing frameworks designed for these assessments, focusing specifically on their application at the product level. Investigating the usability of frameworks is crucial for bridging the gap between accumulated scientific knowledge and real-world applications, thereby providing valuable insights for food labeling initiatives. This paper contributes to identifying both the primary usability challenges and key success factors involved in product-level assessment through a usability assessment of these frameworks. Our approach involves assessing the usability of relevant frameworks that integrate social and environmental dimensions into product-level assessments. These frameworks are then applied to a case study involving seven food products produced in Norway: milk, greenhouse tomatoes, greenhouse cucumbers, wheat, beef (suckler-based system), sheep and pork.

2. Method and material

2.1. Usability assessment of frameworks

We defined the usability of framework by the ease to use, prepare data for, and interpret results of sustainability assessment by end-users (Au et al., 2008). In this context, the end-users are researchers evaluating frameworks for food labeling purposes. We used the 'Critical Success Factors' (CSF) conceptualized by De Mey et al. (De Mey et al., 2011) and adapted by Marchand et al. (2014) to evaluate usability. These factors represent those influencing the effectiveness of application and usability of frameworks. In this study, usability assessments were based on components of the CSF: data availability, data correctness, ease of use, transparency, and effectiveness or relevance (Table 1). Additionally, we incorporated the simplicity/complexity aspect proposed by Binder et al. (2010) which suggests that a framework should be as simple as possible while representing the necessary complexity to capture systems intricacies. Framework identified as relevant were applied on the seven food products and assessed on each usability characteristics on a scale: negative (−), neutral (0), or positive (+) score.

2.2. Framework selection

Snowballing sampling was used to identify relevant frameworks for this study. This method involves searching for references through referral to identify other pertinent materials (Parker et al., 2019). The foundation of the snowballing sampling method is based on the reviews and scientific articles on sustainable food system assessment by De Olde et al. (De Olde et al., 2016), Desiderio et al. (2022), and Zou et al. (2022). De Olde et al. (De Olde et al., 2016) conducted their own snowball methodology based on a literary search on the search engine Scopus, while Desiderio et al. (2022) and Zou et al. (2022) used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines in their literature research, ensuring a systematic review process.

Collectively, these studies identified 103 individual frameworks (see Appendix 1 for an overview of the sources), after eliminating 12 duplicates. To refine the selection, ten specific criteria representing our research goal were applied in three phases (Table 2) to identify the most relevant frameworks for the context of this study.

In the initial search, we included all frameworks that assessed sustainability at any level – product, farm, regional, or national. This broad inclusion of criterion allowed us to evaluate the usability of existing frameworks at the product level, regardless of their original scope. In the first phase, a screening of the articles' abstracts was conducted to address the first five criteria: publication in English, open access availability, relevance to the research objective, peer-reviewed status, and

Table 1
Characteristics of 'usability' assessment, based on De Mey et al. (De Mey et al., 2011) and adapted by Marchand et al. (2014) and Binder et al. (2010).

Characteristics	Description
Data availability	- Availability of necessary data for indicator calculations. - Preference for using readily available data.
Data correctness	- Researchers' perception of the correctness of the data used to calculate the indicators.
Ease of use	- Extent to which frameworks are flexible and user-friendly, including understanding the framework, ease of assessment and calculation, and time requirement.
Transparency	- Transparency of the use and data, and uncertainties of the results. - Transparency of the framework's calculation and weighing.
Effectiveness or relevance	- Extent to which frameworks are perceived as being relevant to use and implement by researchers.
Simplicity/ Complexity	- Extent of which the framework and indicators simplify the complexity of food systems.

Table 2
Description and justification three phases and ten inclusion criteria used to identify relevant frameworks.

Selection phases	Inclusion Criteria	Justification	Remaining frameworks
Phase 1	Language	Published in English.	23 frameworks
	Availability	Articles have open and free access.	
	Primary objective is sustainability assessment of food systems	Frameworks must address the evaluation of food system sustainability. We excluded frameworks concentrating on other topics, e.g., COVID-19, national dietary guidelines, and food system vulnerability.	
	Peer-reviewed publication	Published in peer-reviewed journals or reports to uphold scientific rigor.	
	Date of publication	Published after 2010 to ensure their contemporary relevance.	
Phase 2	Inclusion of both environmental and social dimension	To understand how frameworks address the chosen dual perspectives of sustainability and how the scoring system handles mixed data.	11 frameworks
	Practical/real-life application of framework	Selected frameworks should have demonstrable real-world applications, thereby ensuring their practicality and relevance.	
	Clearly defined indicators	Inclusion of clearly defined indicators to ensure transparency.	
	Transparent and readily available method for calculating indicators	To facilitate the implementation and to ensure the reproducibility of the scoring process.	
Phase 3	Applicable on product level	Indicators and data required are applicable and suitable on a product-level.	2 frameworks

publication after 2010. In the second phase, a more in-depth evaluation was conducted to ensure the inclusion of environmental and social perspectives of sustainability, practical applicability, inclusion of clearly defined indicators, and availability of methods for calculating the indicators. The final phase assessed the feasibility of applying the frameworks at the product level based on their data requirements. Nine frameworks were excluded during this phase because their data requirements were too specific for product-level assessments. These frameworks relied heavily on farm-level data, such as on-site observations, field measurements, or farm management records, which would necessitate extensive primary data collection. Since the objective of this study was to evaluate frameworks using readily available data sources, these frameworks were deemed unsuitable for product-level application without significant modifications or additional data collection efforts.

The justification for the exclusion of each framework was documented to ensure transparency and accountability in the selection process (see details in Appendix 1). The selection process resulted in the identification of two frameworks: Food System Sustainability framework (FSS) and Sustainable Nutrition Security framework (SNS) (Table 3). Both frameworks required adaptation for product-level application to be used in our case studies of the seven domestic food products.

2.3. Summary of original methodology of selected frameworks

2.3.1. FSS framework

The FSS framework consisted of 56 individual indicators grouped into five categories: 'Environmental Performance', 'Socio-ecological Resilience', 'Food Security', 'Right to Food' and 'Poverty and Inequality' (see Appendix 2 and Supplementary File, tab 'FSS'). Each indicator had unique data requirement, using quantitative and qualitative data collection methods such as interviews, workshops, surveys, and observations. The collection of data was done according to Jacobi et al. (2020) as described in the Supplementary File. A 5-point scoring system was used to evaluate both quantitative and qualitative indicators, with scores ranging from 0 (lowest or 'undesirable') to 4 (highest or 'desirable'). The scoring was based on defined benchmarks where available, for example the minimum wage in a country. When the use of benchmarks was not feasible, the scoring was determined by comparing values against the highest value found within the sample of food products, representing 100% performance. Each category's score was calculated as the average of its indicators, and these scores were then averaged to produce an overall score, with all categories weighted equally.

2.3.2. SNS framework

The SNS framework included 23 indicators separated in seven categories which were characterized as important factors to environmental, social, and economic sustainability: 'Food Nutrient Adequacy', 'Ecosystem Stability', 'Affordability and Availability', 'Food Safety', 'Waste and Loss Reduction' 'Sociocultural Wellbeing' and 'Resilience' (see Supplementary File, tab 'SNS'). One of the key components of the conceptualization of the framework, according to Gustafson et al. (2016), is that the metrics and indicators were all chosen based on their existing availability in literature or practical use. As a result, the SNS often relied on established databases and indexes, such as the GINI coefficient (World Bank Group) and the Environmental Performance Index (Yale Center for Environmental Law & Policy). Each category and indicator were scored on a 0 to 100 scale. A higher value meant a more desirable score, and all categories were weighted equally in the total score. Indicators not presented on a 0 to 100 scale were standardized according to the formula provided by Gustafson et al. (2016):

$$\textit{Metric Indicator}_i = 100 \times \exp\left[\ln(0.5) \times (F_i / F_{50})\right]$$

In the formula, F_i represents the factor (e.g., land use) for a unit of measure (i) (e.g., country) and F_{50} is the median of the full range of values measured during a specific year (e.g., 2024). The equation assigns a score of 100 to the best potential scenario (e.g., no resources used or emissions), and a score of 50 to the median or average performance. As

Table 3
Overview of the two selected frameworks for evaluating the sustainability of food.

Framework	Authors	Year	Country applied	Scope of assessment	Objectives
Food System Sustainability (FSS) Framework	Jacobi et al.	2020	Kenya and Bolivia	Food supply chain level	Evaluating sustainability in different food systems (i.e., agro-industrial food system, regional food system and local food system).
Sustainable Nutrition Security (SNS) Framework	Gustafson et al.	2016	Argentina, Bangladesh, Brazil, Cameroon, China, India, Netherlands, Senegal, and United States	National level	Assessment of sustainable nutrition security on a national level using seven metrics based on food systems outcomes.

resource use or emissions increase, the score gradually decreases toward 0, but never fully reaches it, allowing even poor performance to be distinguished.

2.4. Modifications and application on product-level

Both the FSS and SNS frameworks were modified to be applied on product-level and tested on different food items produced in Norway: milk, greenhouse tomatoes and cucumbers, wheat, suckler beef, sheep, and pork. The purpose of selecting a variety of products to be tested by the identified frameworks is to have wide enough selection that simulate realistic results for food labeling purposes.

We created two versions of the two frameworks; one with the original unit of measure as described in their respective articles, and a second one using 1 kg of produced product as unit of measure. Evaluating products on a kilogram of product basis is crucial, considering that font-of-package nutrition labelling in Europe typically used units like per 100 g or per 100 ml. Aligning frameworks with these labeling standards enhances their compatibility and potential application alongside nutritional value labels. By doing so, we aimed to provide sustainability-related insights into how frameworks can integrate with existing nutritional labeling schemes. In the second version, sheep, suckler beef and pork were calculated based on a 1 kg of animal carcass, milk was calculated per kg of whole-milk, wheat as flour, while cucumbers and tomatoes were assessed as fresh and unprocessed produce.

We adapted the FSS framework on product-level using a mix of expert assessment, benchmarks and indexes to score the social indicators, i.e., Global Food Security Index (Economic Impacts) and The Global Competitiveness Report (Schwab, 2017). In the 'Environmental Performance' category, we used data from Bonesmo et al. (2013) for the milk, Verheul and Thorsen (2010) for cucumbers and tomatoes, Korsaeth et al. for wheat, Møller and Samsonstuen (Møller and Samsonstuen, 2023) and Bonesmo and Enger (2021) for pork, Samsonstuen et al. (2019) for suckler beef, and Åby et al. (Åby et al., 2024) for sheep. Following the original unit of measures of the FSS, indicators in this category were often calculated on a per 2500 kcal basis. To facilitate comparison between frameworks, we converted the FSS framework results on a 0 to 100 scale. Detailed information on the data source, data type, and scoring system used to rank the seven food items for each indicator is documented in the Supplementary File (see 'FSS' tab).

For the SNS framework, most indicators did not require standardization, except for three indicators in the 'Ecosystem Stability' category, which were standardized according to the same formula as the SNS framework: GHG emissions, non-renewable energy use and land use. As per the original unit of measures, indicators in this category (except for the ecosystem status and net freshwater withdrawals) were calculated based on per capita consumption of a food product (Schwab, 2017; Møller and Samsonstuen, 2023; Korsaeth et al., 2012; Samsonstuen et al., 2019; Åby et al., 2024). Similar to the FSS framework, we used data from Bonesmo et al. (2013), Verheul and Thorsen (2010), Korsaeth et al. (2012), Møller and Samsonstuen (Møller and Samsonstuen, 2023), Bonesmo and Enger (2021), Samsonstuen et al. (2019), and Åby et al. (Åby et al., 2024Åby et al., 2024) to adapt the 'Ecosystem Stability' category on product-level for the seven food products. For the 'Food Nutrient Adequacy' category, only the indicator on 'Nutrient Density Score' was applicable at a product level. In the original version of the SNS, the 'Nutrient Balance Score' was used, using 2000 kcal as the function of unit for each product. In the adapted version of the framework, the Nutrient Density Score was used, with 1 kg of product serving as the unit of measurement. For both versions of the framework, data from the Norwegian Food Safety Authority (Mattilsynet) was used. For suckler beef, sheep, and pork, we used the averages of various cuts of meat produced for human consumption. Organic wheat flour was used for wheat, whole 3.5% fat milk represented milk, and tomatoes and cucumbers were assessed as fresh and unprocessed produce. Information on the data sources, data types and scoring system used are available in Supplementary File (see 'SNS' tab).

3. Results

The following section will present results of the usability assessment of the FSS and SNS frameworks on product-level, followed by the results of the case study at a product level.

3.1. Usability assessment

3.1.1. Data availability

The data availability was scored positively for SNS framework (Table 4), as it relied on existing indicators with open-access databases, simplifying the data collection process. For the FSS framework, finding data was challenging due to the framework's extensive data requirements for social dimensions, posing challenges in collecting both quantitative and qualitative data from various sources, especially without any recommended databases. Additionally, we had to seek alternative data sources to compensate for on-site observations or interviews, such as expert knowledge or judgement, and encountered instances of missing data.

3.1.2. Data correctness

Data correctness was assessed as positive for the SNS framework (Table 4), as the framework often relied on pre-established databases for social indicators and published studies for environmental categories. In contrast, ensuring data accuracy proved more difficult for the FSS framework, considering that many of the social indicators were qualitative questions assessed using expert judgement or knowledge, which could influence the accuracy of the results.

3.1.3. Ease of use

Both frameworks represented different learning curves, impacting their ease of use. The FSS had an extensive data requirement and necessitated understanding all 56 indicators as the scoring system varied depending on the type of indicators and data. As a result, the framework had a negative ease-of-use score (Table 4). In contrast, the SNS scored a higher ease-of-use to the FSS, as it had fewer and simple indicators, and offered guidance to calculate the indicators. However, we still needed to consult their supplementary material document to understand the formula used, which converted results on a 0–100 scale. The main impediment regarding the ease of use of the SNS was its inconsistent approach when calculate the median of environmental indicators based on data availability, which speaks to the transparency of the framework. Consequently, the SNS scored a neutral ease-of-use score.

3.1.4. Transparency

In this context, transparency refers to the extent to which the framework users can understand the design and results of the framework (Marchand et al., 2014). Both frameworks received negative scores for transparency (Table 4). For the FSS, this was due to the varied scoring methods for the different indicators and the complex calculations involved in the Agroecosystem Service Capacity Index (ASCI) (see Supplementary File, 'ASCI' tabs). The SNS framework handled data for the 'Ecosystem Stability' category in two ways based on data availability

Table 4
Overview of results of usability assessment of frameworks on product-level.

Characteristics	FSS	SNS
Data availability	0	+
Data correctness	–	+
Ease of use	–	0
Transparency	–	–
Effectiveness and relevance	–	–
Simplicity/Complexity	–	0

without disclosing it in their article. Additionally, it was unclear how to calculate the 'Nutrient Density' score based on the methodology described in the article.

3.1.5. Effectiveness and relevance

Both frameworks received a negative score in terms of effectiveness and relevance (Table 4), due to their limitation in assessing social issues at a product-level, as evident with the similar scores across social dimensions for the different food products (Section 3.2). The lack of variation in the social categories for both frameworks highlight their ineffectiveness in capturing complexities and nuances of social challenges between food production systems.

3.1.6. Simplicity/complexity

The SNS received a neutral score for its simple assessment and calculation process but failed to account for all aspects or perspectives of sustainability (Table 4). In contrast, the FSS received a negative score as the framework was more complex with its numerous indicators and different method of scoring, it still did not provide a complete picture of sustainability.

3.2. Product-level assessment

In the FSS' original framework (Fig. 1), sheep had the highest overall sustainability score, with an average score of 87 points (see Appendix 2). The main factors influencing its high score were the categories on 'Environmental Performance, 'Socio-Ecological Resilience' and 'Right to Food'. From an environmental perspective, the sheep production system demonstrated low energy use and agrochemical inputs, and had high capacities to provide agroecosystem services, especially through integrated farming systems and the use of outfields (i.e., uncultivated semi-natural communal pastures in the mountains, forests and coastal areas) for grazing. This improves circular-based agroecosystems by enhancing ecological synergies (Bonesmo et al., 2013; Verheul and Thorsen, 2010) and maintaining landscape heterogeneity (Rodríguez-Ortega et al., 2014). Furthermore, sheep production received the highest score in the 'Right to Food' category (89 points) due to its contribution to Norwegian food traditions and food diversity. The overall lowest sustainability score was obtained by the greenhouse tomatoes, with 76 points. This was due to its poor scores in the 'Environmental Performance' and 'Socio-Ecological Resilience' categories; it demonstrated low capacity to provide agroecosystem services (being cultivated indoors), high use of pesticides, elevated GHG emissions, and poor landscape heterogeneity. Additionally, tomato production had a low score in the 'Right to Food' category due to its low crop diversity and low contribution to local food traditions.

In the original SNS framework (Fig. 2), 'Ecosystem Stability' was the highest for cucumbers (81 points) due to the limited land use for cultivation, low GHG emissions, and limited use of non-renewable energy. Suckler beef had the lowest 'Ecosystem Stability' score (31 points), because of its extensive land use (due to the use of outfields for grazing), high GHG emissions, and significant use of non-renewable energy (see Appendix 4). In the 'Food Nutrient Adequacy' category, cucumbers had the highest scores, with 100 points, due to their ability to provide a wide variety of nutrients (protein, fiber, calcium, iron and vitamin A and C). In contrast, pork had the lowest score of 32 points, due to its limited ability to provide a diverse range of nutrients. The remaining categories had uniform scores across all food products due to the data requirement of aggregated data on national level: 'Waste and Loss Reduction' (93 points), 'Affordability and Availability' (76 points), 'Sociocultural Wellbeing' (94 points), 'Resilience' (75 points), and 'Food Safety' (100 points).

In the version of the FSS and SNS frameworks assessed on a kilo-basis, all social indicators had identical scores to the original framework version (see Appendix 3 and Appendix 5). However, there were differences in environmental indicators using quantitative data and the 'Food Nutrient Adequacy' score in the SNS. In both frameworks, wheat had the highest environmental scores, for its low GHG emissions, and energy and agrochemical use in the FSS (Fig. 3), and for its low GHG emissions, consumption of non-renewable energy and land use in the SNS. Sheep had the lowest environmental score in both frameworks on a kilo-basis, due to its high GHG emission, extensive fuel and agrochemical use in the FSS, and extensive land use, high GHG emissions and significant use of non-renewable energy in the SNS. For the 'Food Nutrient Adequacy' category in the SNS, beef had the highest 'Nutrient Density Adequacy' score on a kilo-basis, with 100 points, as it is rich in protein and iron, and provides calcium and vitamin A. On the other hand, cucumber had the lowest score (33 points) due to its limited ability to provide high levels of nutrients.

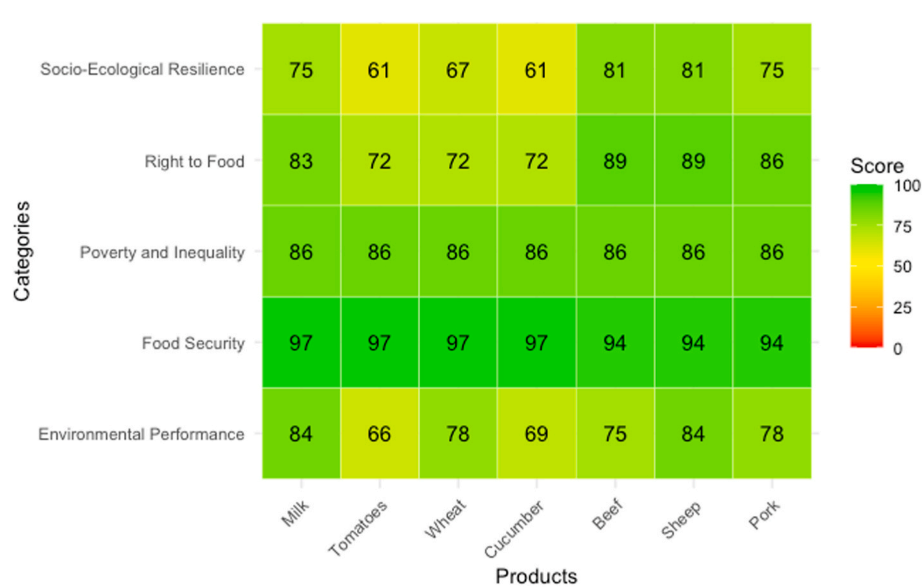

Fig. 1. Sustainability score for the Norwegian milk, greenhouse tomatoes, wheat, greenhouse cucumber, suckler beef, sheep, and pork according to the FSS framework using the original unit of measures described in the article by Jacobi et al. (Jacobi et al., 2020).

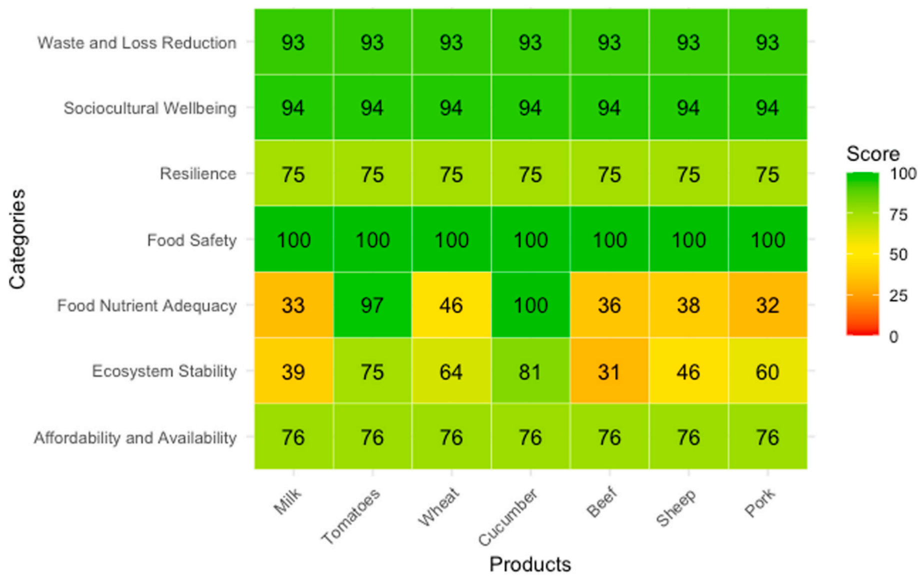

Fig. 2. Sustainability score for the Norwegian milk, greenhouse tomatoes, wheat, greenhouse cucumber, beef, sheep, and pork using the original unit of measures described in the article by Gustafson et al. (Gustafson et al., 2016). Here, the food nutrient adequacy is represented by Nutrient Balance Score per 2000 kcal.

4. Discussion

Following the implementation of the two frameworks at a product level, differences become apparent between their methodological and assessment approaches. The FSS framework provides a full sustainable assessment (FSA) (Marchand et al., 2014), given the representation of various sustainability themes with numerous indicators, integration of both farm-level data and expert knowledge, and that it was time demanding to implement. Additionally, the framework used a context-specific assessment approach (Gasso et al., 2015), as it was developed in collaboration with and applied in countries from the Global South. In contrast, the SNS offered a rapid sustainability assessment (RSA) (Marchand et al., 2014), as it had an easy data collection process by using readily available data, had fewer indicators, and took a relatively short time to apply. The framework also used a context-generic approach (Gasso et al., 2015), considering that in its conceptualization, sustainability themes and indicators had to be general enough to be applied in different countries across the world (e.g., Argentina, Bangladesh, Cameroon, China, and the Netherlands) (Gustafson et al., 2016). The following section will discuss the challenges and success regarding the usability of product-level assessment using those two approaches.

4.1. Trade-offs of usability

The current study demonstrated greater usability for the SNS at a product level compared to the FSS (Table 4). However, considering the trade-offs between the usability of frameworks and the comprehensiveness of assessment remains important. According to Asioli et al. (2020), one of the main challenges in sustainable food labels is to effectively reduce the gap in information between consumers and producers. In the case of the SNS, the data availability and positive ease of use due to the inclusion of fewer number of indicators that were more understandable appear to have been achieved at the expense of its relevance and ability to provide a comprehensive view of sustainable issues. Such limitation echoes critique with context-generic assessment approach, which often miss important sustainability issues.

Conversely, the FSS seems to have compromised its usability in favor of providing a more thorough assessment by using an FSA approach. Only indicators related to food traditions and biodiversity showed variations in the 'Right to Food' and 'Socio-Ecological Resilience' categories. While the incorporation of cultural heritage and preservation aspect into food products assessment was a distinctive feature of the FSS, the accuracy of this perspective was affected by the reliance on expert judgement to assign scores, considering that there were no established databases or studies related to this topic. Moreover, the integration of biodiversity-related indicators was a noticeable strength, particularly through the ASCI, which evaluates the resilience and ecological contribution of production systems (Augstburger et al., 2018). In this indicator, sheep and suckler beef had the highest ASCI scores, since they utilize Norway's favorable landscape for grass fodder crops and outfield pastures, reflecting the integral role of livestock in Norwegian agriculture (Stålnacke and Nordheim, 2020). This emphasis is significant, especially given the main critique of the PEF framework, one of the most established environmental product-level assessment frameworks, is the lack of biodiversity-related indicators (Ramos et al., 2022; Samsonstuen et al., 2024). However, ASCI's evaluation of the capacities to provide ecoservices relied on expert assessment rather than established databases, introducing a level of subjectivity in the analysis.

Therefore, while the inclusion of less commonly used indicators enhanced the FSS's relevance by providing a more nuanced overview of food production and sustainability, it potentially compromised the framework' usability by reducing data accuracy due to the reliance on expert knowledge when data is unavailable which hinders the ease of use and scalability of the framework, particularly when applied to a broader range of food items with less utilized metrics. Such results echo criticism on FSA, which are seen as less attractive to use than other faster assessment approaches, as they are often perceived as being too complex to be used on a large scale (Marchand et al., 2014).

4.2. Scalability of methodological approach

An essential consideration for the applicability of framework at a product level for food labeling is their methodological scalability. In the FSS, environmental indicators (such as landscape heterogeneity, energy use, GHG emissions, and ASCI) calculate scores based on the maximum value in a sample. This means the scale is relative to the most resource-intensive food item, impacting the score of all indicators that use this scoring system and the overall score of each food product. For the SNS, indicators that are not initially on a 0 to 100 scale are normalized using Formula 1, which calculates scores relative to the median in the sample.

In a real food market context, these scoring methodologies would

Fig. 3. Differences in the sustainability scores for Norwegian milk, greenhouse tomatoes, wheat, greenhouse cucumbers, suckler beef, sheep, and pork under the FSS framework (left) and SNS framework (right) when measured using a 1 kg product unit compared to their original units of measurement.

prove impractical given the rapid evolution and globalization of the agrifood industry, driven by expanding consumer demands and changing dietary trends (Saitone and Sexton, 2017). Maintaining and updating scores continuously would be neither cost-efficient nor practical over time, particularly with the introduction and removal of new products from the market. A broader application or market adaption of these frameworks could be facilitated with a shift towards scoring relative to a reference value (such as a benchmark or standard), rather than another food product would enhance the usability of both the FSS and SNS.

4.3. Benefits of a 1 kg approach

The version of the framework that uses a 1 k of product is notably more compatible with product-level assessments. This is largely because 1 kg is an established and widely used unit of measure across Europe, ensuring consistency and comparability across various food product and assessment frameworks. By adopting this standard unit, both frameworks align with existing practices, making it easier to understand.

Furthermore, when comparing the original and adapted frameworks, the overall scores did not change drastically, indicating that the core assessment remained consistent. The most significant changes occurred in the environmental indicators and the 'Food Nutrient Adequacy' category in the SNS. Despite these changes, the relative ranking of the products remained largely stable. For instance, in the original FSS framework, sheep had the highest overall score with 87 points, followed by beef and milk (with 85 points), while tomatoes and cucumbers had the lowest, with 79 and 78 points respectively. In the adapted version, although milk had a slightly better average score than sheep (with 2 points difference), the overall trend remains the same: high-scoring products continued to score high, and low-scoring products remained on the lower end. This observation is also seen in the SNS framework, implying that the stability across the frameworks suggests that the 1 kg basis does not significantly alter the ranking of the products.

4.4. Challenges in adapting social assessment at a product level

In both framework product assessment, social indicators often failed to distinguish social issues on product-level across the different food items, as evident in the limited variation between food items in both frameworks, particularly the SNS. This limitation not only impacts their efficacy in addressing social issues, but also their relevance on product-level.

In the SNS, the tendency stems from to the framework's methodological approach and original intended use, which conducts food assessment at a country-level (Gustafson et al., 2016). Given Norway's high-income status and having the third highest overall Global Food

Security Index score (80.3 out of 100) (Economic Impacts), the country's high status on food sustainability is reflected in the consistently high scores of the framework's social indicators. The lack of variation between food products originates from the reliance on national indexes as sole data source for social indicators, which aligns with the intended use of the framework. However, such an approach proves less effective in this study, as it focuses exclusively product-level assessment of domestically produced items. As a result, five of the seven categories (i.e., 'Waste and Loss Reduction', 'Affordability and Availability', 'Sociocultural Wellbeing', 'Resilience', and 'Food Safety') had identical scores across all food products since they were based on the same national-level data. When applied to both domestically produced and imported foods, variations between countries would be evident, but the same issue would occur; five of the seven categories would not show variation at the product level, as they are using the same data across food products from the same origin. Given the limited variation on product level, it seems that the data necessary to assess the extent of social issues on a product-to-product basis is either unavailable or too data-intensive. We are prompted to ask: could challenges related to data unavailability and complexity be why sustainable labels on food products are more commonly associated with certification schemes (Brown et al., 2020), with a binary labeling strategy, rather than showing a scale of the extent of a social issue?

When it comes to nutrient adequacy, there are many dietary quality scores (e.g. Hallström et al. (Hallström et al., 2018)) which all give different results depending on methodological factors, such as choice of dietary quality indicators, reference amount, reference intake levels, and capping, etc. The Nutrient Balance Concept (NBC) (Fern et al., 2015) used in the SNS framework for nutrient adequacy refers to the idea of evaluating the overall nutritional quality of food based on the balance and diversity of nutrients it contains, as the ratio of each nutrient contained in 2000 kcal of a given food relative to its Dietary Reference Intake (DRI) value. The NBC prioritizes food items that offer a variety of nutrients at levels that help meet daily nutritional requirements. For example, a food like milk, which contains a wide array of nutrients (e.g., proteins, vitamins, and minerals), would be considered nutritionally balanced. In contrast, foods that are rich in only a few nutrients, such as orange juice (which is high in vitamin C but lacks other essential nutrients), might be considered less balanced according to this concept. By only including qualifying nutrients, and excluding disqualifying nutrients, the NBC aims to evaluate food based on its potential to provide a comprehensive range of nutrients necessary for a balanced diet, rather than penalizing foods for containing potentially harmful components. This can be seen as a more positive or inclusive approach to nutritional evaluation, as it seeks to promote nutrient diversity and balance rather than focusing on nutrient limitations or risks. However, this also means that the concept may overlook certain aspects.

For the FSS, the lack of variation might be indicative to a lack of relevance or pertinent social indicators in the socio-economic context of an industrialized country such as Norway. When looking at the results of the social assessments on product-level for both frameworks, all food items had scores above the 55th percentile when applied to Norwegian food products. For the FSS, the this might be because the framework's methodology was initially intended for case studies in developing countries like Kenya and Bolivia (Jacobi et al., 2020). As a result, many social indicators in the FSS were deemed not relevant by experts consulted (e.g., access to seeds, access to water for consumption and proportion of women with access to agricultural credits) due to well-established infrastructures, regulations, social norms, and cultural practices in Norway. This aligns with criticism of context-specific frameworks, which tend to focus on issues relevant locally or within a specific context, and therefore do not fully consider broader sustainability challenges (Gasso et al., 2015).

4.5. Considerations for social sustainability assessment

The study revealed that both frameworks lacked important social and ethical considerations, specifically animal welfare and farmers' wellbeing. Animal welfare-related indicators are increasingly pertinent in sustainable food systems in Western countries, given the growing consumer demand for animal-friendly products (Schwab, 2017; Bonesmo et al., 2013). Although the SNS included the Animal Protection Index (API), which measures animal sentience, animal welfare in legislations, commitment of government bodies to animal protection and support for international animal welfare standards, the API only has data for 50 countries, which did not include Norway. While political commitment to animal protection is crucial for animal welfare, this index is less relevant at a product level, due to data limitation and its inability to attribute different scores across food products. Instead, product-level indicators could focus on animal health and conditions, such as the use of antibiotics, access to outdoors or outfields, and infant mortality rate.

In the FSS, farmers' and workers' conditions were often address from monetary and gender perspective, without addressing the broader issues of wellbeing. This lack of consideration is crucial given the ageing farming population in Western countries (Zagata and Sutherland, 2015). Wellbeing is multidimensional and subjective concept that includes health, happiness, social connections, work-life balance, and life satisfaction (Wassell and Dodge, 2015). In a recent Norwegian study on dairy producers, Hansen (2022) found occupational stress, isolation and loneliness significantly impacted producers' wellbeing, increasing the likelihood of farm abandonment and succession. Such findings underscores the importance of monitoring and enhancing the wellbeing of producers to ensure the continuity of the food industry and the stability of food supplies (Brennan et al., 2023). Indicators related to wellbeing could include reasonable working hours, compliance with working conditions, workers representation and freedom of association.

5. Conclusion

This study explored the usability of frameworks assessing social and environmental sustainability at a product level. The Sustainable Nutrition Security (SNS) framework, with its rapid and context-generic approach, demonstrated better usability compared to the Food System Sustainability (FSS) framework, which provided a full, context-specific approach. However, our findings suggest that while the SNS offers greater usability, it does so by compromising the depth and detail of its assessment. In contrast, the FSS delivers a more comprehensive analysis, but has poorer usability due to data inaccuracy and user-unfriendliness, limiting its practical application by researchers.

It is important to note that the results of the product assessment of this study reflect the specific design and weighting of the SNS and FSS frameworks and should be interpreted as endorsement of specific products or production systems. These results highlight both frameworks' emphasis on different dimensions of sustainability, which inherently favor certain types of products. At the same time, these outcomes underscore the significant limitation of existing frameworks when applied to product level, particularly their ability to assess and balance environmental and social dimensions of sustainability effectively.

Our usability analysis indicated that the frameworks applied at a product level overlooked the inherent trade-offs between usability and complexity of information. In this regard, the development of a purpose-built framework that accounts for these trade-offs, while prioritizing usability becomes essential. Without such approach, actionable insights into the sustainability of food products remains elusive for researchers and consumers alike, restricting the ability to make informed purchasing decisions and limiting progress toward more sustainable food supply chain.

CRediT authorship contribution statement

Paule Bhérer-Breton: Writing – original draft, Formal analysis, Conceptualization. **Anna Woodhouse:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis. **Bente Aspeholen Åby:** Writing – review & editing, Supervision, Formal analysis. **Hilke Bos-Brouwers:** Writing – review & editing. **Melanie Kok:** Writing – review & editing. **Hanne Fjerdingby Olsen:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used ChatGPT in order to provide feedback on the readability of the language. After using this tool/service, the author reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Declaration of competing interest

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

Appendix ASupplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indic.2025.100593.

Appendix 1. Identified food system sustainability frameworks and exclusion phase.

Authors	Year	Framework	Exclusion phase
Aarts et al.	2015	The Annual Nutrient Cycling Assessment (ANCA) model quantifies the main performance indicator related to the nutrient cycles	2
Ahmed et al.	2020	Food typology framework to evaluate the effects of the COVID-19 pandemics on food system resilience.	1
Ahmed et al.	2019	Integrated framework that evaluates the sustainability of national dietary guidelines.	1
Allen et al.	2019	Sustainable food system framework	2
Bastian et al.	2007	European Analytical Framework for the local development of local agri-environmental programmes	1
Béné et al.	2019	To support the transition toward sustainable food system	2
Benoît et al.	2010	Social Life Cycle Assessment (S-LCA)	2
Biehl et al.	2018	A framework for conceptualizing food system vulnerabilities	2
Bizikova et al.	2016	A framework that applies a systems perspective to food security with an assessment of the food system's resilience in the context of climate change.	2
Breitschuh	2009	Kriteriensystem Nachhaltige Landwirtschaft (KSNL)	1
Brimblecombe et al.	2015	A framework to facilitate collective appraisal of the food system and identify opportunities for food system improvement of Indigenous Australian remote communities	2
Butler et al.	2021	Food system shock	1
Cadillo-Benalcazar et al.	2020	A multi-scale integrated analysis of the factors characterizing the sustainability of FS	1
Carlsson et al.	2017	Conceptualization of a framework to measure sustainable food systems	1
Chen and Antonelli	2020	Understanding food choice	1
Coteur et al.	2013	Development of an on-demand tool, a term that is assigned to tools that are initiated by the end users	2
Cullen et al.	2015	A framework that situates food literacy at the intersection between community food security and food skills	1
Dantsis et al.	2010	A methodological approach to assess and compare the sustainability level of agricultural plant production systems	3
Dora et al.	2021	An interdisciplinary conceptual framework for waste utilization practices that contribute.	2
Downs et al.	2020	Food environment typology.	1
Downs et al.	2017	Policy analysis framework to assess components of sustainable diet.	1
Elsaesser et al.	2015	Sustainability assessment of dairy farms.	3
Ericksen	2008	Framework on interactions of food systems with global environmental change and assessing societal outcomes.	1
Fagioli et al.	2017	Framework to assess level of multi-functionality along entire food value chain.	1
FAO	2013	SAFA guidelines provide a holistic interpretation of major themes of sustainability	3
Flores and Villalobos	2018	Modelling framework for strategic design of local fresh food system.	1
Gaitán-Cremaschi et al.	2018	Framework based on Multi-Level Perspective on Socio-Technical Transition to characterize the diversity of food system in view of sustainable transition.	1
Gaviglio et al.	2017	4AGRO: tool for sustainability assessment of farms	3
Gerrard et al.	2012	Public Good (PG) Tool	3
Guarnaccia et al.	2020	Bioregional Strategic Framework in Sicily.	3
Committee on Sustainable Assessment (COSA)	2013	System that offers multiple tools for gathering, comparing, and sharing information.	1
Gustafson et al.	2016	Seven Food System Metrics of Sustainable Nutrition Security	–
Haas et al.	2000	Life Cycle Assessment (LCA)	1
Halbe and Adamowski	2019	Methodological framework for vision design and assessment (VDA) to analyse sustainability of future visions on multiple scales.	1
Heller and Keoleian	2003	Food system sustainability through life cycle perspective.	1

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Authors	Year	Framework	Exclusion phase
Ingram	2011	Framework for structuring dialogues aimed at enhancing food security.	1
Jackson et al.	2020	Food system causal disaster vulnerability framework	1
Jacobi et al.	2020	A new understanding and evaluation of food sustainability in six different food systems in Kenya and Bolivia	–
James et al.	2021	Framework for food system transformation after COVID-19	1
Johnston et al.	2014	Sustainable diets	1
Kanter et al.	2015	Framework for understanding the impact of agriculture and food systems policies on nutrition and health.	1
Lambrou et al.	2021	Global food systems framework for pandemic prevention, response, and recovery.	1
Le Rohellec and Mouchet	2008	Efficacité économique de systèmes laitiers herbagers en agriculture durable (RAD)	1
Lewis and Bardon	1998	Measuring the environmental performance by evaluating an eco-rating that compares actual farm practices and site-specific details.	1
López-Ridaura et al.	2002	Framework for Assessing the Sustainability of Natural Resource Management Systems (MESMIS)	1
López-Ridaura et al.	2005	Multiscale Methodological Framework	1
Ma et al.	2019	Modeling framework for analyzing the effects of changes in food production-consumption system of China whose results are linked to 8 SDGs.	1
Marshall	2015	Socio-ecological framework systems framework for food system research.	1
Mayton et al.	2020	Framework for sustainable diets that is locally relevant to Vietnam.	2
Mazac et al.	2021	Sustainability in food-based dietary guidelines framework.	1
Melesse et al.	2020	Updated analytical framework on food system.	1
Meul et al.	2008	MOTIFS, a user-friendly and strongly communicative indicator-based monitoring tool that allows the measurement of progress towards integrated sustainable dairy farming systems	1
Moragues-Faus and Marceau	2018	Sustainability assessment framework to evaluate food system performance in the UK.	2
Nemecek et al.,	2011	Swiss Agricultural Life Cycle Assessment	2
Nesheim et al.	2015	Framework for assessing effects of food systems	1
OECD	2007	Driving Force State Response (DSR) - Sustainability Guidelines	1
Pacini et al.	2011	Agro-Environmental Sustainability Information System (AESIS)	2
Paloviita et al.	2016	Food system vulnerability	1
Paracchini et al.	2015	The SOSTARE model (analysis of farm technical efficiency and impacts on environmental and economic sustainability)	3
Park et al.	2020	Two-dimensional food literacy conceptual framework	1
Pervanchon	2004	A diagnostic method for assessing agricultural operations in the context of sustainable agriculture.	1
Pottiez et al.	2012	Method to assess the sustainability of the organic poultry industry.	2
Raza et al.	2020	Food system framework for children and adolescents	1
Rigby et al.	2001	Indicators of sustainable agricultural practice (ISAP). Farm-level indicator of agricultural sustainability, based on patterns of input use	1
RISE	2003	Database with carbon footprints of approx. 750 products	1
Rodrigues et al.	2010	Instrument for the environmental management of agricultural activities.	3
Rosenzweig et al.	2020	Framework enabling integrated climate change solutions for production and consumption.	1
Ruiz-Almeida and Rivera-Ferre	2019	Framework for food system sovereignty	1
Saling et al.	2005	Eco-efficiency analysis tool	1
Samaddar et al.	2002	Gastronomic Systems Research' framework to a target population of low-to-middle income household to capture the diversity and cultural drivers of food choice and its nutritional implications in race-based diets in 2 stats in India	1
Schnitter and Berry	2019	Analytical framework to study and response to climate change, food security and human health	1
Slater et al.	2018	Food literacy framework for youth transitioning to adulthood	1
Stentiford et al.	2020	One Health Lens defines success metrics	2
Tendall et al.	2015	Food system resilience	2
Termeer et al.	2018	A framework to assess the food system governance in South Africa.	1
Thiollet-Scholtus and Bockstaller	2015	The INDIGO method	2
Trivino-Tarradas et al.	2019	Sustainability assessment framework for best management practices.	3
Turetta et al.	2021	Community food systems for combating threats to food system in neglected territories.	2
Tzilivakis and Lewis	2004	Development of indicators for farm sustainability.	1
Van Calker et al.	2006	Multi-attribute utility theory (MAUT) is used to develop an overall sustainability function for Dutch dairy farming systems.	1
Van Cauwenbergh et al.	2007	Sustainability Assessment of Farming and the Environment (SAFE) framework	1
Verger et al.	2018	Sustainable food system framework for rethinking food systems toward sustainable consumption and production modes	2
Viglizzo et al.	2006	Assess the environmental performance of commercial farms in the Pampas of Argentina and propose a methodological framework to calculate environmental indicators that can rapidly be applied to practical farming.	1
Wackernagel et al.	1999	Framework for ecological footprint	1
Wang et al.	2021	Conducting a thorough assessment of the foundation, capacity, practices, functions, opportunities, and challenges of the urban agriculture locally.	1
Zahm et al.	2008	The IDEA method (Indicateurs de Durabilité des Exploitations Agricoles or Farm Sustainability Indicators)	1
Zougmoré et al.	2021	Food system transformation framework	1
www.blw.admin.ch	NA	Agrarumweltindikatoren: Environmental assessment on farm-level	1
http://peoplefoodandnature.org/blog/broa/	NA	Biodiversity Risk and Opportunity	1
www.dairysat.com.au	NA	Dairy Self-Assessment	1

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Authors	Year	Framework	Exclusion phase
www.cooperation-agricole.asso.fr/sites/saf/guide/fiches/methodes evaluation systeme individuelles/diage.aspx	NA	DIAgnostic Global d'Exploitation	1
http://dialecte.solagro.org/	NA	DIAgnostic Liant Environnement et Contrat Territorial d'Exploitation	1
www.solagro.org/site/im user/014plaquette dialogue.pdf	NA	Diagnostic agri-environnemental global d'exploitation	1
www.nachhaltigelandwirtschaft.info	NA	DLG – Zertifikat Nachhaltige Landwirtschaft	1
www.oekopunkte.at	NA	Ecopoints	1
www.fieldtomarket.org	NA	Field Print Calculator	1
www.landbrugsinfo.dk/miljoe/natur-ogarealforvaltning/tilskudsordninger/groenneregnskaber	NA	Green Accounts for Farms	1
www.ideals.illinois.edu/handle/2142/13458	NA	Illinois Farm Sustainability Calculator	1
www.nachhaltigelandbewirtschaftung.de/repro/	NA	Reproduction of Soil Fertility	1
www.standardsmap.org/fsa	NA	SAI - SPA: Farmer Self-Assessment 2.0	1
www.fibl.org/en/themes/smart-en.html	NA	SMART: Sustainability Monitoring and Assessment RouTine	1
www.soilandmorefoundation.org/projects/sustainabilityflower	NA	Sustainability Flower Quick Assessment	1
www.triplehelix.com.au/documents/FarmSustainabilityDashboard.pdf	NA	Sustainability Dashboard	1

Appendix 2. Indicators score of product-level assessment score of FSS using original unit of measures.

Categories	Indicators	Milk	Tomato	Wheat	Cucumber	Beef	Sheep	Pork
Environmental performance	Agroecosystem service capacity index (ASCI)	50	25	75	25	75	100	50
	Visual soil assessment of soil quality	x	x	x	x	x	x	x
	Use of agrochemicals	75	0	50	75	75	75	50
	Use of material (plastic and others)	x	x	x	x	x	x	x
	Use of electricity	100	75	100	0	75	100	75
	Use of fuel	75	100	0	100	75	75	75
	Use of heavy fuel oil	100	100	100	100	100	100	100
	Use of aviation turbine fuel	100	100	100	100	100	100	100
	Use of gasoline	100	100	100	100	100	100	100
	Carbon footprint	75	25	100	50	0	25	75
	Water footprint	x	x	x	x	x	x	x
Socioecological resilience	Ecological self-regulation	75	100	75	100	75	75	75
	Diversity of crops and breeds	x	x	x	x	x	x	x
	Landscape heterogeneity	75	25	25	25	100	100	75
	Livable wage	x	x	x	x	x	x	x
	Decentralization and independence	50	50	50	50	50	50	50
	Local consumption of production	100	100	100	100	100	100	100
	Organization in interest groups	100	100	100	100	100	100	100
	Connectivity of food systems and their components	x	x	x	x	x	x	x
	Knowledge of threats and opportunities	75	75	75	75	75	75	75
	Reflective and shared learning	75	75	75	75	75	75	75
	Functioning feedback mechanisms	x	x	x	x	x	x	x
	Knowledge legacy and identity	50	50	50	50	50	50	50
	Shared vision on the food system	x	x	x	x	x	x	x
Food security	Farmers' permanency of ownership of land	75	100	75	100	75	75	75
	Farmers' access to water	100	100	100	100	100	100	100
	Estimate share of food products processed	100	100	100	100	100	100	100
	Estimated share of food produced that can be stored in the food system	100	100	100	100	100	100	100
	Price volatility or inflation rates	75	75	75	75	75	75	75
	Share of locally produced food in the food system	100	100	100	100	100	100	100
	Food availability and food stability	100	100	100	100	100	100	100
	Capacity to respond to the local notion of a good diet	100	100	100	100	75	75	75
	Household food security level	100	100	100	100	100	100	100
Right to food	Access to water for domestic consumption	100	100	100	100	100	100	100
	Water quality for domestic consumption	x	x	x	x	x	x	x
	Food system's impact on overall water accessibility for irrigation	x	x	x	x	x	x	x
	Access to seeds	100	100	100	100	100	100	100
	Perceptions on land tenure/land rights	75	100	75	100	75	75	75
	Proportion of women with land rights	50	50	50	50	50	50	50
	Proportion of women who have access to agricultural credit	100	100	100	100	100	100	100
	Contribution to food diversity	50	25	25	25	100	100	75
	Covering nutritional needs	x	x	x	x	x	x	x
	Promotion of local food traditions	75	0	0	0	75	75	75
	Perception on access to food-related information	75	75	75	75	75	75	75
	Perception on participation in decision-making related to food	x	x	x	x	x	x	x
	Remedies for violations of the right to food	100	100	100	100	100	100	100
	Child labour	100	100	100	100	100	100	100
Poverty and inequality	Farmers' incomes	x	x	x	x	x	x	x
	Wages of large-farm employees	x	x	x	x	x	x	x

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Categories	Indicators	Milk	Tomato	Wheat	Cucumber	Beef	Sheep	Pork
	Wages of employees at processing and storage levels	x	x	x	x	x	x	x
	Wages of employees at retail level	x	x	x	x	x	x	x
	Food expenditure and consumption baskets	75	75	75	75	75	75	75
	Financial capital	100	100	100	100	100	100	100
	Human capital	100	100	100	100	100	100	100
	Social capital	75	75	75	75	75	75	75
	Physical capital	75	75	75	75	75	75	75
	Natural capital	x	x	x	x	x	x	x
	Decent and safe working conditions	75	75	75	75	75	75	75
	Social protection	100	100	100	100	100	100	100
Overall average		85	79	80	80	84	86	83

Appendix 3. Indicators score of product-level assessment score of FSS using 1 kg of product as unit of measure.

Categories	Indicators	Milk	Tomato	Wheat	Cucumber	Beef	Sheep	Pork
Environmental performance	Agroecosystem service capacity index (ASCI)	50	25	75	25	75	100	50
	Visual soil assessment of soil quality	x	x	x	x	x	x	x
	Use of agrochemicals	75	75	75	100	50	0	50
	Use of material (plastic and others)	x	x	x	x	x	x	x
	Use of electricity	75	75	100	0	50	100	50
	Use of fuel	75	100	75	100	50	0	75
	Use of heavy fuel oil	100	100	100	100	100	100	100
	Use of aviation turbine fuel	100	100	100	100	100	100	100
	Use of gasoline	100	100	100	100	100	100	100
	Carbon footprint	75	75	75	75	0	25	75
	Water footprint	x	x	x	x	x	x	x
Socioecological resilience	Ecological self-regulation	75	0	50	0	100	100	75
	Diversity of crops and breeds	x	x	x	x	x	x	x
	Landscape heterogeneity	75	25	25	25	100	100	75
	Livable wage	x	x	x	x	x	x	x
	Decentralization and independence	50	50	50	50	50	50	50
	Local consumption of production	100	100	100	100	100	100	100
	Organization in interest groups	100	100	100	100	100	100	100
	Connectivity of food systems and their components	x	x	x	x	x	x	x
	Knowledge of threats and opportunities	75	75	75	75	75	75	75
	Reflective and shared learning	75	75	75	75	75	75	75
	Functioning feedback mechanisms	75	75	75	75	75	75	75
	Knowledge legacy and identity	50	50	50	50	50	50	50
	Shared vision on the food system	x	x	x	x	x	x	x
Food security	Farmers' permanency of ownership of land	75	100	75	100	75	75	75
	Farmers' access to water	100	100	100	100	100	100	100
	Estimate share of food products processed	100	100	100	100	100	100	100
	Estimated share of food produced that can be stored in the food system	100	100	100	100	100	100	100
	Price volatility or inflation rates	75	75	75	75	75	75	75
	Share of locally produced food in the food system	100	100	100	100	100	100	100
	Food availability and food stability	100	100	100	100	100	100	100
	Capacity to respond to the local notion of a good diet	100	100	100	100	75	75	75
	Household food security level	100	100	100	100	100	100	100
Right to food	Access to water for domestic consumption	100	100	100	100	100	100	100
	Water quality for domestic consumption	x	x	x	x	x	x	x
	Food system's impact on overall water accessibility for irrigation	x	x	x	x	x	x	x
	Access to seeds	100	100	100	100	100	100	100
	Perceptions on land tenure/land rights	75	100	75	100	75	75	75
	Proportion of women with land rights	50	50	50	50	50	50	50
	Proportion of women who have access to agricultural credit	100	100	100	100	100	100	100
	Contribution to food diversity	50	25	25	25	100	100	75
	Covering nutritional needs	x	x	x	x	x	x	x
	Promotion of local food traditions	75	0	0	0	75	75	75
	Perception on access to food-related information	75	75	75	75	75	75	75
	Perception on participation in decision-making related to food	x	x	x	x	x	x	x
	Remedies for violations of the right to food	100	100	100	100	100	100	100
	Child labour	100	100	100	100	100	100	100
Poverty and inequality	Farmers' incomes	x	x	x	x	x	x	x
	Wages of large-farm employees	x	x	x	x	x	x	x
	Wages of employees at processing and storage levels	x	x	x	x	x	x	x
	Wages of employees at retail level	x	x	x	x	x	x	x
	Food expenditure and consumption baskets	75	75	75	75	75	75	75
	Financial capital	100	100	100	100	100	100	100
	Human capital	100	100	100	100	100	100	100
	Social capital	75	75	75	75	75	75	75
	Physical capital	75	75	75	75	75	75	75
	Natural capital	x	x	x	x	x	x	x

(*continued on next page*)

(*continued*)

Categories	Indicators	Milk	Tomato	Wheat	Cucumber	Beef	Sheep	Pork
	Decent and safe working conditions	75	75	75	75	75	75	75
	Social protection	100	100	100	100	100	100	100
Overall average		84	80	81	78	83	83	83

Appendix 4. Indicators score of product-level assessment score of SNS using original unit of measures.

Categories	Indicators	Milk	Tomatoes	Wheat	Cucumber	Beef	Sheep	Pork
Ecosystem stability	Ecosystem status	59	59	59	59	59	59	59
	Per-capita greenhouse gas (GHG) emissions	50	91	63	95	15	19	47
	Per-capita net freshwater withdrawals	x	x	x	x	x	x	x
	Per-capita non-renewable energy use	47.5	50	77	70	47	44	83
	Per-capita land use	0	100	59	100	4	61	50
Waste and loss reduction	Pre- and post-consumer food waste and loss	0	100	59	100	4	61	50
Affordability and availability	Food affordability	93	93	93	93	93	93	93
	Global Food Security Index's (GFSI) food availability score	87	87	87	87	87	87	87
	Poverty Index	60	60	60	60	60	60	60
	Income equality	100	100	100	100	100	100	100
Sociocultural wellbeing	Gender equity	57	57	57	57	57	57	57
	Extent of child labour	88	88	88	88	88	88	88
	Respect for community rights	100	100	100	100	100	100	100
	Animal health and welfare	x	x	x	x	x	x	x
Resilience	Notre Dame Global Adaptation Index (ND-GAIN)	x	x	x	x	x	x	x
	Food production diversity	75	75	75	75	75	75	75
Food safety	Foodborne disease burden	x	x	x	x	x	x	x
	Global Food Security Index's (GFSI) food safety score	100	100	100	100	100	100	100
Food Nutrition Adequacy	Pre- and post-consumer food waste and loss	x	x	x	x	x	x	x
	Shannon Diversity	x	x	x	x	x	x	x
	Modified Functional Attribute Diversity	x	x	x	x	x	x	x
	Nutrient Density Score	33	97	46	100	36	38	32
	Population Share with Adequate Nutrients	x	x	x	x	x	x	x
Overall average		63	84	75	86	62	70	72

Appendix 5. Indicators score of product-level assessment score of SNS using 1 kg of product as unit of measure.

Categories	Indicators	Milk	Tomatoes	Wheat	Cucumber	Beef	Sheep	Pork
Ecosystem stability	Ecosystem status	59	59	59	59	59	59	59
	Per-capita greenhouse gas (GHG) emissions	80	42	82	75	0	0	50
	Per-capita net freshwater withdrawals	x	x	x	x	x	x	x
	Per-capita non-renewable energy use	92	11	96	50	40	19	94
	Per-capita land use	3	100	59	100	4	0	50
Waste and loss reduction	Pre- and post-consumer food waste and loss	0	100	59	100	4	0	50
Affordability and availability	Food affordability	93	93	78	100	63	0	93
	Global Food Security Index's (GFSI) food availability score	87	87	87	87	87	87	87
	Poverty Index	60	60	60	60	60	60	60
	Income equality	100	100	100	100	100	100	100
Sociocultural wellbeing	Gender equity	57	57	57	57	57	57	57
	Extent of child labour	88	88	88	88	88	88	88
	Respect for community rights	100	100	100	100	100	100	100
	Animal health and welfare	x	x	x	x	x	x	x
Resilience	Notre Dame Global Adaptation Index (ND-GAIN)	x	x	x	x	x	x	x
	Food production diversity	75	75	75	75	75	75	75
Food safety	Foodborne disease burden	x	x	x	x	x	x	x
	Global Food Security Index's (GFSI) food safety score	100	100	100	100	100	100	100
Food Nutrition Adequacy	Pre- and post-consumer food waste and loss	x	x	x	x	x	x	x
	Shannon Diversity	x	x	x	x	x	x	x
	Modified Functional Attribute Diversity	x	x	x	x	x	x	x
	Nutrient Density Score	38	66	86	33	100	85	81
	Population Share with Adequate Nutrients	x	x	x	x	x	x	x
Overall average		69	76	79	79	63	55	76

Data availability

The data is available in the supplementary data, and is available due to open access publications.

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