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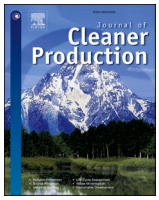

Monitoring nutritional, environmental and social sustainability in school food settings: A three-dimensional score-based assessment tool

M. Petruzzelli [a], S. Amadori [a,*], R. Ihle [b], M. Fridel [c], M. Vittuari [a]

[a] Department of Agricultural and Food Sciences, Alma Mater Studiorum - University of Bologna, Bologna, Italy
[b] Agricultural Economics and Rural Policy Group, Department of Social Sciences, Wageningen University & Research, Wageningen, the Netherlands
[c] Public Health Department, Emilia - Romagna Region, Italy

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ABSTRACT

The UN School Meals Coalition acknowledges that for achieving the transition towards sustainable food systems, school canteens play a vital role. Providing school authorities with tailored and easily applicable approaches enabling them to evaluate and monitor sustainability performance across schools is needed. We develop the to date most comprehensive monitoring tool that can be straightforwardly used to evaluate nutritional, environmental, and social sustainability dimensions of school food environments. The tool has been designed via a replicable and transparent methodological approach implemented via a living lab to strengthen science-society-policy integration. Its 42 indicators and their measurement scales have been defined through a participatory process on the request of the government of Emilia-Romagna - one of the most densely populated regions of Italy. Indicator measurements are heterogenous and aggregated into a single sustainability score ranging from 0 to 75 points grouped into ten sustainability objectives which belong to the three sustainability dimensions. We provide an extensive sensitivity analysis which assesses the tool's transferability, scalability, and adaptability to school food contexts beyond Italy. The tool has been adopted as a binding monitoring framework by the regional government of Emilia-Romagna in September 2023.

1. Introduction

The School Meals Coalition (2024) - launched during the UN Food Systems Summit in 2021 and hosted by the World Food Programme – strives for the recognition of school meals as a key aspect for food system transformation to achieve the Sustainable Development Goals (Oostindjer et al., 2017) since they affect attitudes, knowledge, and behavior of future generations (FAO, 2022). International initiatives such as the Milan Urban Food Policy Pact (MUFPP, 2024) or the Global Child Nutrition Foundation (GCNF, 2024) play a supportive role for the Coalition, mobilizing academic and political actors to monitor the effectiveness of school meals initiatives. Also, the OECD is contributing to this new momentum by stressing school meals as a core constituent for children's education (OECD, 2023). Providing healthy meals and adequate consumption environments at school has been found to lower the risk of diseases connected to dietary inadequacies (Sabinsky et al., 2019) and to address diet inequalities (Bryant et al., 2023). School meals are important moments for children to socialize and gain knowledge (Stone and Murakami, 2021). The promotion of education during school meals has also been shown to increase their awareness of environmental concerns (Black et al., 2015) and food waste (Piras et al., 2023). Last, procurement practices for school meals represent an opportunity to encourage sustainable food production via the inclusion of qualitative standards on raw materials (Tregear et al., 2022).

For this reason, researchers have evaluated the sustainability of school food environments[1] by adopting a variety of methodologies ranging from analyst-designed top-down approaches (Chiaverina et al., 2023; Sundin et al., 2023) to participatory, i.e., bottom-up ones (Bryant et al., 2023; Eustachio Colombo et al., 2021). Most of these methods suggested focus on the impact assessment of specific case studies in terms of food quality and nutrition (Foo and Tan, 2021; Reilly et al., 2021), affordability (Hill et al., 2023; Petruzzelli et al., 2023) and food waste (García-Herrero et al., 2019, 2021). On top of this, Barnard et al. (2020) and Eustachio Colombo et al. (2021) integrate nutritional

* Corresponding author.
E-mail address: simone.amadori4@unibo.it (S. Amadori).

[1] We follow FAO (2019) that defines school food environments as "all the spaces, infrastructure and conditions within and beyond the school premises where food is available, obtained or purchased and consumed (.) and the composition of those foods".

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assessments by analyzing the feedback of families and school staff on menus. Finally, Chiaverina et al. (2023) extend the scope of analysis by coupling the nutritional composition of meals to the quantification of their carbon footprints.

Nevertheless, to track progress on the tangible advancements that school food environments provide towards the global sustainability objectives, pragmatic, but sufficiently differentiated monitoring tools - methods to measure phenomena of interest (Sala et al., 2015) - that ensure tracking the sustainability performance and its comparability in various dimensions are needed (Fanzo et al., 2021). While a broad range of monitoring tools for other food system components have already been developed (Herforth et al., 2022; Schneider et al., 2023), Laurentiis et al. (2019) and Moore et al. (2023) highlight the absence of such evaluation approaches for school food environments. The growing demand within Europe for monitoring approaches to evaluate the nutritional adequacy and sustainability of the meals prepared for children is evidenced by recent research contributions focusing on Southern (Caputo et al., 2017), Central (Gell et al., 2023; Chiaverina et al., 2023) and Northern Europe (Browne et al., 2023; Sundin et al., 2023).

In Italy, school food environments are largely governed by the guidelines of the Italian Ministry of Health (2010). Italian regions translate these guidelines into local legislation, which apply to their entire territories and guarantee a certain degree of homogeneity of food procurement practices and dietary standards (Regional Sanitary Service ER, 2023). The monitoring of menus, food quality, dining spaces and educational food activities is implemented by sanitary districts via a specific framework. The framework is used twice a year both via an off-site and an on-site evaluation. However, the data gathered has been very heterogeneous, so that evaluation results are neither comparable across schools nor suitable for quantifying sustainability advancements (Regional Sanitary Service ER, 2023). Hence, the design of a single monitoring tool which is score-based and, thus, enables comparability across schools and time and which is easily useable by professionals and integrates the evaluation of nutritional, environmental, and social dimensions of school food environments is needed for supporting food system sustainability transitions set out by the Agenda 2030 (UN, 2015).

To address these global and local needs for monitoring tools, this paper contributes to the existing literature a novel score-based assessment tool tailored to school catering. The tool has been designed on the explicit request of the government of Italia's NUTS2 region of Emilia-Romagna and measures and aggregates three sustainability dimensions via 23 nutritional, 10 environmental, and 9 social indicators into a single sustainability score. The tool contains a set of innovative elements. First, it embraces a system perspective where school canteens are not only evaluated for the diet quality, but also for environmental and social aspects they deliver. Second, the tool has been interactively co-developed with food policy practitioners via a participatory process through the Laboratorio di Ristorazione Sostenibile (2023) of the University of Bologna. Therefore, the indicators, the measurement scales and their aggregation mechanism exactly mirror the consensus priorities of these experts. Lastly, the tool offers a ready-to-use application for evaluation and decision making for non-academic and academic actors. Attention has been placed on keeping the tool simple and flexible so that it can be easily implemented and adapted to other contexts. In September 2023, the tool has been adopted as a binding policy commitment across the entire Emilia-Romagna territory (Regional Sanitary Service ER, 2023). Implementation and data collection in schools is currently ongoing.

The article is organized as follows. Section 2 explores differences and similarities between top-down and bottom-up approaches for sustainability monitoring. Section 3 details the methodology used for the design of the tool: the sustainability approach and targets, the context as well as the participatory process conducted. The composition and characteristics of the score-based assessment tool together with a sensitivity analysis of alternative aggregation mechanisms are presented in Section 4. Section 5 offers a discussion of the results compared with previous findings and policy implications. Finally, section 6 highlights the major conclusions.

2. Approaches for sustainability monitoring

A sustainable food system can be characterized as one that *"delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised*" (FAO, 2018, p. 1). Such a concept stresses the importance of shifting to a system thinking approach (von Braun et al., 2020) and to pay attention to the perspectives of practitioners having stakes in the food production and consumption (Sonnino, 2023). As a consequence, any sustainability tool design should ideally integrate various stakeholder groups.

The design of food system sustainability monitoring approaches can be grouped into two classes: top-down vs. bottom-up (Fraser et al., 2006). Top-down design is an expert-driven approach in which sustainability monitoring indicators and their aggregation structure are determined by one or more experts (Khadka and Vacik, 2012) based on existing knowledge and expertise. The resulting sustainability evaluation approaches for aggregating a larger number of indicators into a final score are usually designed in scientific desk-research. Statistical or measurement-theoretical considerations dominate, while practical expertise or heuristic preferences of the stakeholders relevant to the context under analysis are barely considered. Indicators tend to be chosen to enable automatization so that human inputs needed for quantitative assessments are minimized. The resulting tools have a high external validity (Roe and Just, 2009) and are, thus, typically used for monitoring that needs to be reproduced at large scale, across various regional or national contexts. Their main advantage is that they can be optimized to ease automatized gathering and processing of large amounts of data so that collection efforts and costs can be driven down. However, this convenience has often the downside that implementers' preferences do not match policy-makers' views and goals. Additionally, the tools often suffer from a limited capability of capturing and quantifying context-specific priorities (Bonisoli et al., 2018) crucial for stakeholders' ownership attitude and compliance with the data gathering effort and convenience of implementation.

On the other hand, bottom-up approaches are community-driven and offer an alternative paradigm to define indicator structures and aggregation mechanisms via the engagement of relevant stakeholders in an interactive and participatory manner (Khadka and Vacik, 2012). Through involving local communities, bottom-up approaches are powerful to achieve relevance, acceptance, ownership and empowerment of stakeholders for the targeted field of investigation. These approaches are much better capable of identifying priorities and outcomes desired by the community and of tailoring the evaluation to their specific practical needs and objectives. Such evaluation approaches are much better able to close the gap between the desired direction of societal change and the ability of implementers to monitor this change. They also allow for the inclusion of qualitative indicators whose measurement can barely be automatized. The main downside is an often highly complex and time-consuming process. The quality and amount of human inputs needed to stimulate constructive communication between stakeholders and reach consensus between their interests (Muhamad Khair et al., 2021) tend to be high. The resulting tools often succeed in optimally tailoring the evaluation design to the context of interest, which, on the other hand, implies limited external validity.

While an exhaustive exploration of top-down and bottom-up approaches is beyond the scope of this work, the analysis of the selected examples highlighted in Table 1 showcases major benefits and drawbacks of both classes of monitoring tool designs. Table 1 helps in the main differences among these two approaches, ordered from top-down on the right to bottom-up to the left-hand side.

The framework of Herforth et al. (2022) intended for the assessment of the food system sustainability has the advantage to be highly

Table 1
Selected top-down and bottom-up approaches to sustainability monitoring design.

	Top-down approaches		→				Bottom-up approaches	
Paper	Herforth et al. (2022)	Monetti et al. (2021)	Schneider et al. (2023)	Maynard et al. (2021)	Doernberg et al. (2022)	Cirone et al. (2023)	Our paper	Moreira et al. (2022)
Geographical scale	Global	National	Global	National	National	European	Regional	Regional
Transferability and scalability	High	High	High	Medium	Medium	Medium	Medium	Low
Stakeholders' involvement	None	Only in validation	Only after the initial selection of indicators	After initial framework design	After initial framework design	From the beginning of the process	From the beginning of the process	From the beginning of the process
Number of indicators (of sustainability targets)	39 (4)	18 (n.a)	50 (5)	76 (3)	15 (3)	36 (3)	42 (3)	34 (3)
Framework balance: minimum and maximum number of indicators per sustainability target	5–12	n.a.	6–18	22–27	5	10–15	9–23	10–25
Main limitations of the approach	High level of standardization of the tool contrasts with the high data variability at country level (mostly on dietary patterns and GHGs emissions)	Information available to kitchen staff might not be sufficient to quantify the selected indicators	Intensive data requirement	Site-specific: replication in and tailoring to other contexts might be difficult	High variability in the underlying sustainability concept (short food chain) across different territories stemming from stakeholders' perspectives	Selection of indicators follows stakeholder priorities, hence sustainability aspects are not fully explored	Tailored to specific cultural and socio-economic context, which privileges environmental sustainability	Site-specific: replication in and tailoring to other contexts might be difficult

Notes: The approaches are ordered to approach intensity: from top-down on the left-hand side to bottom-up on the right-hand side.
Source: Authors.

standardized and to entail thresholds for comparing sustainability performances across countries. It is hence useful for prioritizing food system transformation actions at national level. However, the lack of stakeholders' perspectives limits the relevance of indicators for country-specific food systems. Monetti et al. (2021) provide an extensive systematic review for analyzing the impacts of the catering sector on biodiversity, compiled in a Driver-Pressure-State-Impact-Response framework. As stakeholders' insights are integrated to validate indicators but not in the design process, data availability is impacted as the framework relies on information that could not be available to kitchen staff.

Maynard et al. (2021) develop a tool for the assessment of environmental and nutritional sustainability of restaurants based on several rounds of expert consultations to assess indicator relevance and test the framework in real-life settings. The resulting approach is very user-friendly but relies on manifold perspectives as it privileges stakeholders' agreement over completeness. It is focused on the upstream part of the value chain and able to tackle highly context-specific issues. Via several iterations with stakeholders, Doernberg et al. (2022) conduct a literature review to design 15 indicators for the assessment of the sustainability in short food supply chains. The final set of indicators is adapted to the specific context through stakeholders' workshops. The many definitions of these chains in various contexts resulted in a framework with high explanatory value, but low comparability among settings. Similarly, Cirone et al. (2023) takes a hybrid approach by integrating desk research with repeated interactions with practitioners and researchers via public consultations, focus groups and surveys to guide the definition of relevant indicators for the sustainability measurement of food initiatives. The resulting framework offers effective and rapid appraisal but might disregard key aspects that were not perceived as relevant by the stakeholders involved.

Full-fledged bottom-up approaches such as Moreira et al. (2022) focus on building context-meaningful indicators by combining stakeholders' perspectives to evaluate the impacts of the water–energy–food nexus in urban and peri-urban settings. The bottom-up approach used consists in the consultation of local stakeholders at every stage of the framework development. Being aware of the shortcomings and advantages of both top-down and bottom-up approaches, our sustainability assessment tool derives the indicator structure, their measurement scales as well as their aggregation mechanism from stakeholders' needs and priorities as we detail in the methodology section 3.4.

3. Methods used for tool design

The assessment tool is designed to provide schools and supervision authorities with an easy-to-use approach to evaluate the sustainability of the food environment in schools. It is composed of a comprehensive set of indicators that provide quantitative and comparable data on three sustainability targets. The design of our tool follows the sustainability assessment procedure of Sala et al. (2015). Its four steps and their adaptation to the present tool are shown in Fig. 1. First, we define the sustainability approach of our tool as outlined in section 3.1, which is characterized by choosing a set of guiding values and principles defining the vision for the food system on which the assessment tool relies. Afterwards, the tool's sustainability targets are chosen as described in section 3.2 to determine the areas of action to be monitored. Thirdly, we document the decision context in which the tool is to be used (section 3.3). The decision context determines the local specificities that the assessment tool must take into consideration. This step is crucial to correctly adapt the assessment tool to any specificity and guarantee its practicality and usefulness. Finally, in section 3.4 we detail the approach chosen for defining, selecting and aggregating the tool indicators.

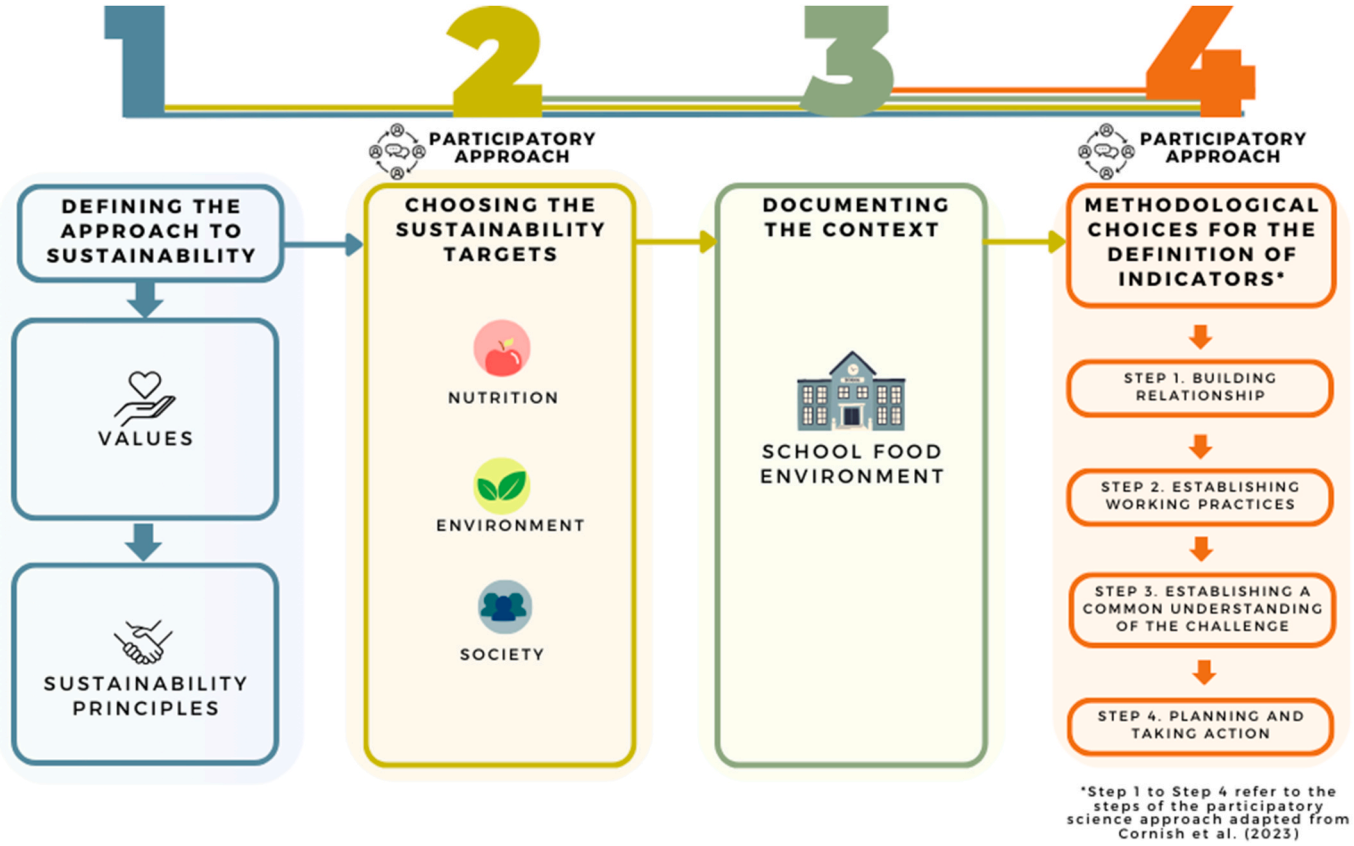

Fig. 1. Methodological flowchart for the development of the sustainability assessment tool.

3.1. Approach to sustainability

The starting point for any sustainability assessment is to define its value judgements to which the tool adheres (Sala et al., 2015). Considering that the Emilia-Romagna authorities asked to develop a framework to promote the transition of food system at regional level in line with the sustainability ambition of the European Union, our tool follows the premise that a sustainable food system "*provides and promotes safe, nutritious and healthy food of low environmental impact for all current and future EU citizens in a manner that itself also protects and restores the natural environment and its ecosystem services, is robust and resilient, economically dynamic, just and fair, and socially acceptable and inclusive*" (SAPEA, 2020, p. 68). Therefore, the tool is based on the guiding values for sustainable food systems suggested by Termeer et al. (2018) which we adapt to the school food environment as shown in Table 2.

For each sustainability assessment developed, values need to be translated into concrete sustainability principles (Sala et al., 2015) that guide the assessment procedure. To translate the abovementioned values into concrete guidance for the tool development, the tool adheres to the two principles of food system thinking (FAO, 2018), and of participatory science (Cornwall and Jewkes, 2010).

By endorsing the sustainable food system definition of the European Union (SAPEA, 2020), the tool supports the multicriteria acceptance of the complexity, which means food systems are considered a result of competing goals and diverse functions (FAO, 2018). Therefore, the tool acknowledges the idea that sustainable food systems should be tackled considering at once their role in delivering nutritious and healthy diets, regenerating ecosystems, leveraging climate change and fostering social justice (Caron et al., 2018). We explicitly address food systems thinking by including in the tool multiple sustainability targets to be measured (see section 3.2). Secondly, we postulate that social sciences and their scientific outputs can benefit from participatory science as defined by Cornwall and Jewkes (2010). The participatory science concept states that linking researchers with society enables the co-production of more comprehensive forms of knowledge increasing the capacity to address global challenges. Therefore, we co-designed the tool indicators via a participatory approach with stakeholders as described in section 3.4.

Table 2
Implications of sustainable food system values for assessment tool design adapted from Termeer et al. (2018).

Value	Implication
System-based problem framing	Consider multiple sustainability targets
Adaptability	Sufficient flexibility to be applied to different environments
Inclusiveness	Involve those actors who daily face the analyzed context
Transformative capacity	Foster the food system transformation as declared by European Union

3.2. Sustainability targets

The consultation with stakeholders suggested that the tool should cover three sustainability targets, namely the nutritional, environmental, and social one. These, along with the economic one, are acknowledged as the base of food system sustainability. The stakeholders consensus was to exclude the economic target from the evaluation because budgetary considerations on the school meals are a prerequisite of any tenders for assigning catering services to schools in Italy (Salvatore et al., 2021). Hence, once the food infrastructures of a school are in place, the monitoring of any economic aspects is not relevant.

3.3. School food environment context

Transparently documenting the school food environment reality for which the monitoring tool is destined in be used is crucial to clarify how that reality behaves (Sala et al., 2015). Exploring these specificities also guarantees that stakeholders wishing to replicate the tool in different contexts are equipped with a full understanding of which aspects of the tool might need adaptations. Following the categorization of Sala et al. (2015), we detail in Table 3 the context for which we develop the assessment tool.

3.4. Methodological choices

Based on the sustainability approach defined and the participatory science principle we adhere to (see section 3.1), we developed the tool using a bottom-up participatory approach and adapting the steps suggested by Cornish et al. (2023) as shown in Table 4. Participatory science is a research design which makes use of the knowledge of individuals acquired by lived experiences of people in specific settings (Born, 2019).

Step 1 **Building relationships.** A participatory living laboratory (Laboratorio di Ristorazione Sostenibile, 2023) has been established with a formal agreement (Emilia-Romagna Region, 2022) and has been coordinated by the Emilia-Romagna government and the University of Bologna. 25 leaders of change (Cornish et al., 2023) directly involved in the regional school food sector participated (Table 5). Most of them are professionals working for the sanitary districts whose task is to conduct evaluations of school food environments.

Step 2 **Establishing working practices.** To formally guide the functioning of the laboratory, a workplan was agreed upon (Laboratorio di Ristorazione Sostenibile, 2021). It includes details on the laboratory's objectives, governance and methods used. More specifically the workplan indicates the Emilia-Romagna government and the University of Bologna representatives are appointed to coordinate the activities and mobilize the participating stakeholders. Regular meetings have been organized monthly to progress on the working plan objectives, among which the development of an evaluation tool for the sustainability of school food. For each activity, the publication of a final deliverable describing the activity results published on the laboratory website (Laboratorio di Ristorazione Sostenibile, 2021) was planned.

Steps 3 **Establishing a common understanding of the challenge.** Three workshops were specifically dedicated to the design of the tool. Workshop I determined the tool scope including the sustainability targets to be reached and chose the software for data collection. The moderator from the University of Bologna illustrated the challenges of sustainability monitoring in school food environments for which the assessment tool was to be developed as a solution. The consensus of the experts was to set up an easy-to-use score-based evaluation tool to monitor the sustainability of school food environments via quantitative measurements and aggregation that would allow comparisons across schools and time and, therefore, enable continuous improvements. After the four most frequently adopted sustainability targets (Fanzo et al., 2021) illustrated by the moderator, the experts selected what to be included. The economic dimension was excluded as budgetary monitoring of school food has not been perceived as an issue since in Italy it is a pre-requisite for assigning catering services to schools. Finally, an open discussion was conducted on the best software to implement the tool. All participants unanimously proposed Microsoft Excel due to their well-established working experience with it.

Step 4 **Planning and taking action.** Workshop II focused on the co-creation of the set of tool indicators. One group of experts was formed for each of the three sustainability targets and offered with a list of potential indicator choices. For the nutritional dimension, the reference for the indicator design were the official school meal guidelines (Regional Sanitary Service ER, 2023) which detail the binding frequency and composition requirements all schools should legally comply with, in accordance with the dietary recommendations of the Italian Society of Human Nutrition (2014). Potential indicators for the social and environmental targets were deduced from Goggins and Rau (2016) as they provide the most comprehensive set of indicators and the most fitting ones for measuring sustainability targets in public catering contexts.[2] Each group was asked to select the most suited indicators or to propose new ones in line with the regional and national guidelines (Regional Sanitary Service ER, 2023) and adapt them to school food catering ensuring their coverage, relevance, interpretability, and usefulness (Schneider et al., 2023, Supplementary Table C). The experts were asked to arrange the proposed indicators in a structured matrix (see Supplementary Table D). As no specific indication has been given on the minimum or maximum number of indicators, the final number of indicators per target is not balanced. The outcome, hence, reflects the stakeholders' consensus on the relative importance and comprehensiveness of each target, i.e., more indicators chosen for a target means that stakeholders, and the regional school system they represent, consider this

Table 3
Fundamental aspects for the assessment tool as defined by Sala et al. (2015).

Aspect	Description of the aspects in the assessment tool developed in this paper
Object to be assessed by the tool	School food environments
Actors using the tool	Primary users: school food professionals Secondary beneficiaries: teachers, public bodies
Assessment scale of the tool	Individual schools
Uncertainty and complexity that the tool faces	Food environments are very heterogenous consisting of many qualitative aspects for which measurement is not always straightforward
Time horizon for using the tool	Twice a year (for the winter and summer menus)
Activities assessed by the tool	Canteen environment, food procurement, transformation, service, and waste, educative supervision
Dimensions considered by the tool	Nutritional, environmental, and social

Source: Authors.

Table 4
The application of the steps of participatory science to the tool development.

Step (S) of participatory approach	Goal	Application
S1. Building relationships	Select the community setting	Setting up the '*Laboratory for sustainable catering*'
S2. Establishing working practices	Agree on working and communication practices	Defining principles and working methods of the laboratory
S3. Establishing a common understanding of the challenge	Define tool aim and principles	Workshop I
S4. Planning and taking action	Develop the tool	Workshops II and III

Source: Authors based on Cornish et al. (2023).

[2] Supplementary tables A and B detail the full list of initial indicators used.

specific target as more complex so that measurement should take place from a higher number of complementary perspectives.

After having collected all indicators proposed, they were reviewed for duplicates. Next, one of three possible scoring mechanisms was assigned to each indicator based on the measurability scale indicated by experts (see Supplementary Table D). Qualitative scoring was implemented for 31 indicators leading to a binary evaluation of the absence or presence of a characteristic. Likert scales with either 3 or 6 options were applied to 10 indicators which need an intensity or a degree-based evaluation following the expert consensuses.[3] Last, the experts preferred a composite scoring for one environmental indicator (see Supplementary Table E).[4]

Workshop III was dedicated to the refinement of the tool via an online discussion. Experts were asked to validate the scoring assigned to each indicator, group the indicators into specific objectives, fill in the tool for a hypothetical situation, and finally report strengths and weaknesses of each indicator via a focus group discussion. Feedback was collected and used to finalize the tool design.

4. Composition and characteristics of the score-based assessment tool

The assessment tool is composed of 42 indicators across the three sustainability targets of which 28 are to be evaluated off-site and 14 to be inspected on-site (Table 6). 23 indicators are related to the nutritional target (*N1-N23*), 10 to the environmental (*E1-E10*) and 9 to the social one (*S1-S9*) (see Fig. 2). Indicators of the nutritional, environmental and social scores (*NS*, *ES*, *SS*) are belonging to three, three and four objectives (ON_i, OE_j, OS_k), respectively, as shown in equation (1). This imbalance in the numbers of objectives and indicators across targets reflects the relative importance that the professionals governing the school food environment agreed upon. The minimum and maximum scores of each indicator shown in Figs. 3–5 correspond to the measurement preferences of the stakeholders. The measurement scale of each indicator determines the weight of each indicator in the aggregation mechanism, that is, how much each contributes to the objectives, targets, and the total score.

Table 5
Affiliations and roles of the expert stakeholders involved.

No. of experts	Organisation	Role	Sector
1	Emilia-Romagna regional department of public health, and collective prevention	Member of the general direction	Policy and governance
20	Emilia-Romagna sanitary districts	Nutritionists and doctors responsible for the regional school meal design	Health
1	Emilia-Romagna regional service of innovation, quality, promotion and internationalization of the agri-food system	Management of school-related projects	Agriculture
3	University of Bologna – Department of Agricultural and Food Sciences	Scientific supervision on the intervention co-design	Academia

Source: Authors.

[3] We assign zero points to the least sustainable option and either 2 or 5 points to the most sustainable one.

[4] Zero points denote the least sustainable menu of largest negative environmental impact and ten points the most sustainable one.

Table 6
Summary of tool indicators and scores.

		Nutritional	Environmental	Social	Total
Number of indicators	Off-site evaluation	21	7	0	28
	On-site inspection	2	3	9	14
	Total	23	10	9	42
Maximum score	Off-site evaluation	21	26	0	47
	On-site inspection	2	14	12	28
	Total	23	40	12	75

The total sustainability score (*TS*) is the sum of the nutritional score (*NS*), the environmental score (*ES*) and the social sore (*SS*) which in turn result from the sums of the objectives as in equation (1):

$$\mathrm{TS} = NS + ES + SS = \sum_{i=1}^{3} ON_i + \sum_{j=1}^{3} OE_j + \sum_{k=1}^{4} OS_k. \quad (1)$$

Each objective comprises several indicators as specified in Figs. 3–5. *TS* can take any integer between 0 - if the characteristics quantified by all indicators are absent - and 75 if all indicators reach their maximum score. As a consequence, higher scores signal greater sustainability. As shown in Table 6 the maximum score for the nutritional target is 23, the one for the environmental target is 40, and the one for the social target is 12.

4.1. Nutritional sustainability

Sustainable food systems are first and foremost promoting nutritious and healthy diets, which result in human improved well-being and positive health outcomes (Biesbroek et al., 2023). Hence, 23 indicators – the 55 % of all indicators – monitor the quality and adequacy of school food from a nutritional perspective. The score for the nutritional target can take a value between 0 and 23 (Table 6). Fig. 3 shows how the nutritional indicators $N_l, l = 1, \ldots, 23$ are aggregated into the three objectives (ON_1 to ON_3) which compose the nutritional score (*NS*) via equations (2)–(4). *N1* to *N21* can be evaluated off-site.

$$ON_1 = \sum_{l=1}^{5} N_l \quad (2)$$

$$ON_2 = \sum_{l=1}^{16} N_{5+l} \quad (3)$$

$$ON_3 = \sum_{l=1}^{2} N_{21+l} \quad (4)$$

Achieving sustainable diets entails consuming diverse food, in which vegetables, fruits and pulses ensure adequate intakes of micro- and micronutrients (Verger et al., 2021). Hence, the tool measures the diversity of food offered in school canteens via indicators *N3* to *N5*. Indicators *N4* and *N5* signal adequate consumption of extra virgin olive oil and iodized salt by children as both have been unanimously associated with decreased illness and reduced disease progressions (Farhan et al., 2023; EFSA, 2014). In line with the Mediterranean diet (Willett et al., 1995) which has proven to yield multiple positive outcomes on children's health (Azzini et al., 2011) and with dietary reference values (Italian Society of Human Nutrition, 2014), the tool monitors the serving frequencies of recommended food categories by indicators *N6* to *N21*. Finally, making nutrient tables of the school menus and food quantities served available supports transparency of menu design. This is measured by indicators *N22* and *N23* because it can improve healthy eating knowledge among school children's families (Goggins and Rau, 2016).

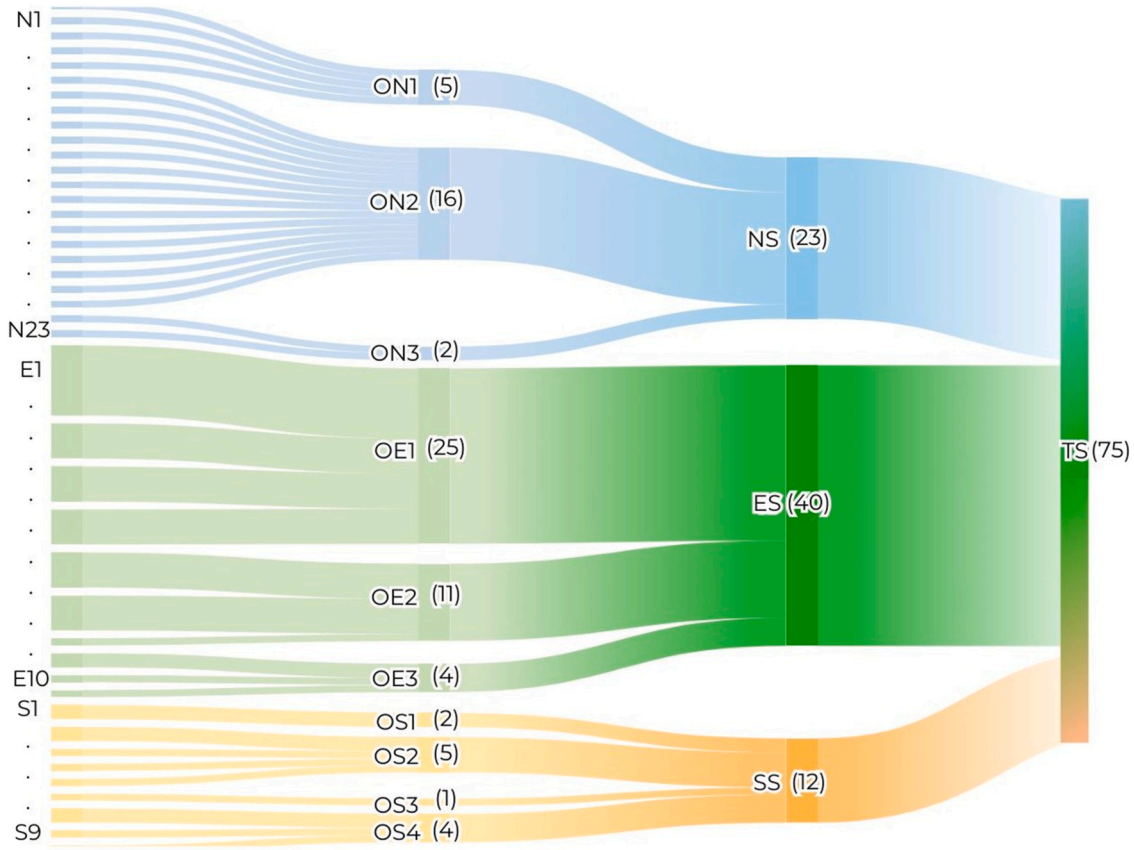

Fig. 2. Aggregation of indicators, objectives, targets scores into the total sustainability score.

4.2. Environmental sustainability

The second core characteristic of sustainable food systems is low environmental impact and nature protection (SAPEA, 2020). The tool measures that through 10 indicators grouped into 3 objectives (Fig. 4). The environmental indicators $E_m, m = 1, \ldots, 10$ are aggregated into objectives OE_1 to OE_3 which compose the environmental score (*ES*) as described in equations (5)–(7).

$$OE_1 = \sum_{m=1}^{4} E_m \tag{5}$$

$$OE_2 = \sum_{m=1}^{3} E_{4+m} \tag{6}$$

$$OE_3 = \sum_{m=1}^{3} E_{7+m} \tag{7}$$

7 indicators can be evaluated off-site (*E1-E7*). The environmental score can range from 0 to 40.

The second meal course can be composed either of animal-based, plant-based proteins, or a mix of them. Notably, the consumption of animal-based protein, particularly red meat, is associated with a more negative environmental impact (Simon et al., 2023). To evaluate environmental sustainability of the second menu course, *E1* builds on the eco-points strategy which reflect the life cycle impact with respect of 20 dimensions (Hartmann et al., 2022; Wassmann et al., 2023). It assigns the lowest sustainability score to red meat and the highest to pulses (Supplementary Table E presents the method for calculating the indicator *E1*). Indicators *E2* to *E4* relate to the seasonality of the served fruits and vegetables sourced locally, which is one of the core elements of the sustainability strategy of Emilia-Romagna. While debated by Foster et al. (2014), the lower environmental impact of local seasonal products has been acknowledged in different contexts (Röös and Karlsson, 2013; Xiong et al., 2023). Moreover, locally sourced fresh products have a lower carbon footprint than processed food, a phenomena captured by *E5*, *E6* and *E7*. Reduced transportation and storage needs as well as production inputs lead to regionally produced fresh vegetables being more environmentally friendly (Rasines et al., 2023). The types of tableware and strategies for effective food waste management used in the school canteen also have a significant impact on environmental performance (Genovesi et al., 2022). Finally, the use of reusable tableware (*E8*), waste segregation (*E9*) and serving only tap water (*E10*) instead of using plastic bottles (Fantin et al., 2014) have been considered to be desirable sustainability management approaches by the sector stakeholders.

4.3. Social sustainability

In line with the view of European Union (SAPEA, 2020) on sustainable food systems, the tool aims to promote just, inclusive, and socially acceptable food spaces. Therefore, the 9 indicators devoted to monitoring social sustainability in school food environments refer to 4 objectives so that the social score (*SS*) can range from 0 to 12 (Fig. 5). The social indicators $S_n, n = 1, \ldots, 9$ are aggregated into objectives OS_1 to OS_4 which compose the social score via equations (8)–(11). All social indicators need to be inspected on-site.

$$OS_1 = S_1 \tag{8}$$

$$OS_2 = \sum_{n=1}^{4} S_{1+n} \tag{9}$$

$$OS_3 = S_6 \tag{10}$$

$$OS_4 = \sum_{n=1}^{3} S_{6+n} \tag{11}$$

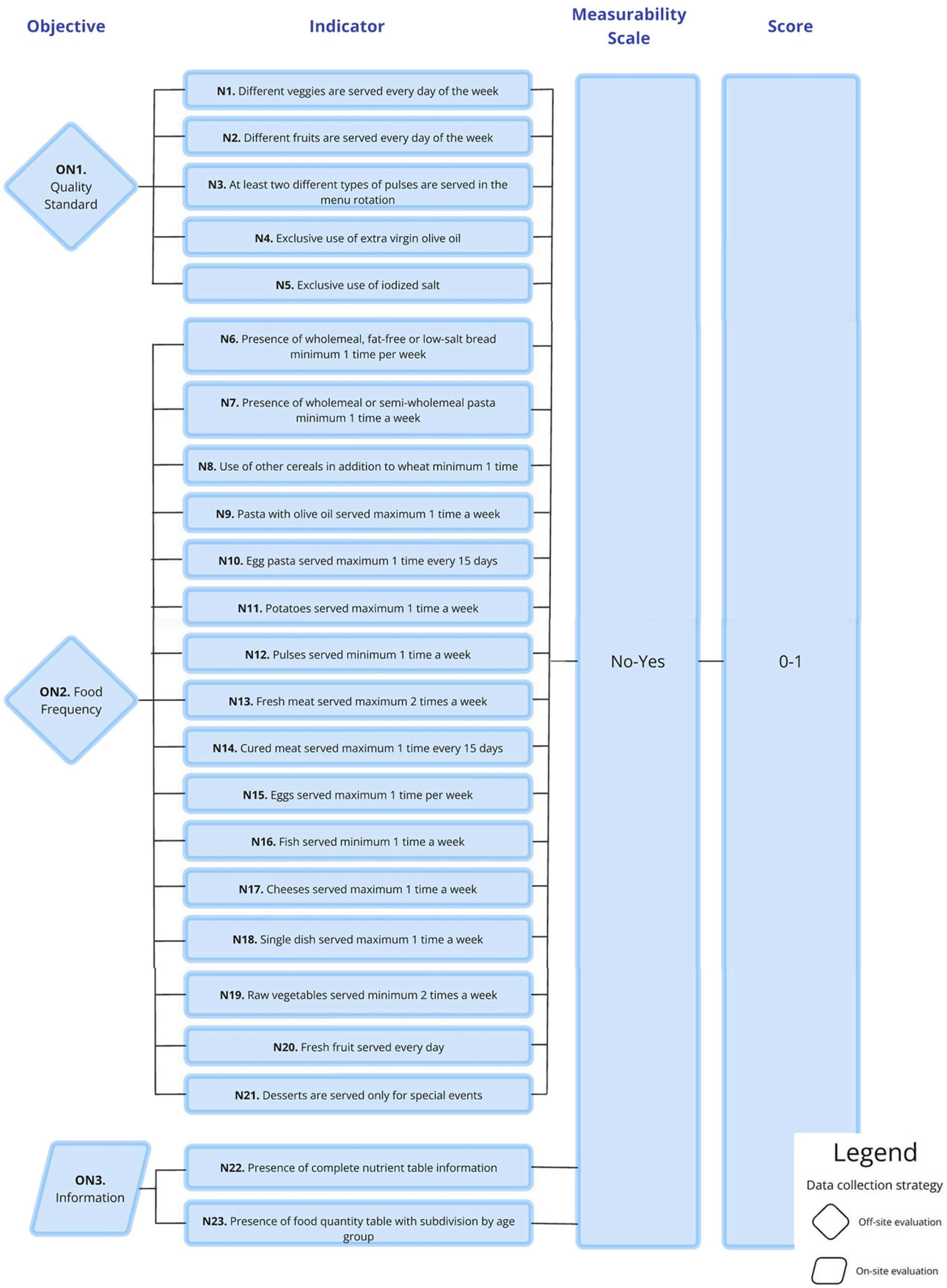

Fig. 3. Indicator characteristics for the nutritional score (NS).

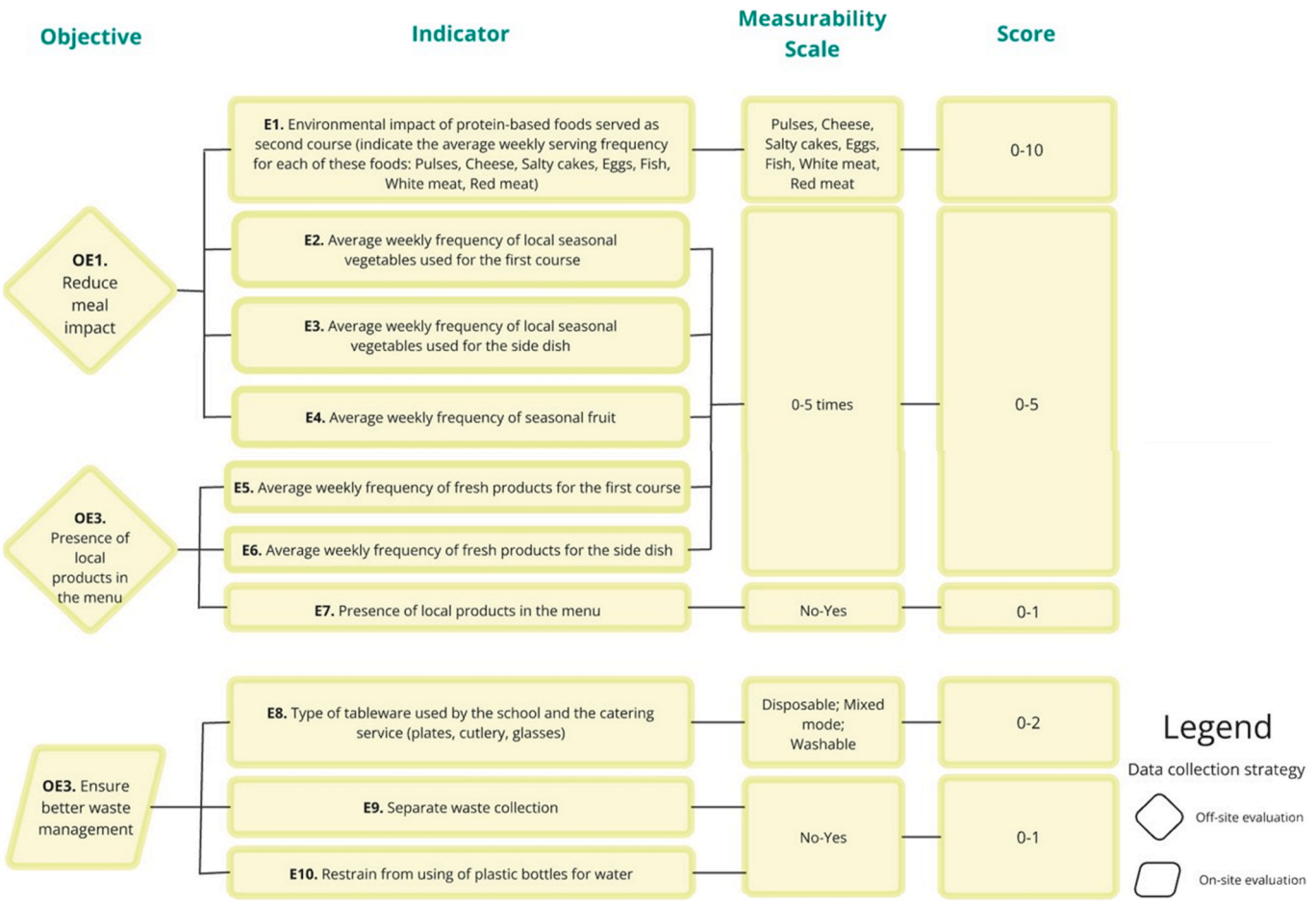

Fig. 4. Indicator characteristics for the environmental score (*ES*).

The educational aspect (Molin et al., 2021) is monitored by indicator *S1*. The quality of the eating environment is evaluated by 4 indicators. Namely, the presence of posters on adequate nutrition is evaluated by *S2* since discussing dietary knowledge with children is a mean for achieving conscious eating (Laitinen et al., 2022) and it affects their consumption attitudes (Gross et al., 2019). A calm ambience with reduced noise in school dining halls has been reported to reduce distractions and create opportunities for social learning (Steen et al., 2018) and is measured by *S3*. The number of children per table is considered via *S4*. 6–10 children per table is considered the best alternative from the consulted stakeholders since less children per table leads to reduced socialization opportunities during lunch, while more than 10 that would create excessive noise. Also, if teachers sit together with children, their reciprocal interaction is reinforced and can support the consolidation of correct food consumption practices (*S5*, Benn and Carlsson, 2014). Engaging with families via for example parents committees (*S6*) can improve children's food consumption attitudes (Chaudhary et al., 2020) and create trust between families and the school staff (Galli et al., 2014). Finally, Derqui et al. (2018) identified food waste amounts in school canteens as a critical social challenge. Via indicators *S7* to *S9* the tool monitors desirable food waste reduction practices.

4.4. Sensitivity analysis

Given that the participatory process adopted for the tool design was a bottom-up approach, the relative importance of each indicator reflects the consensus priorities of the group of stakeholders and the policy framework in which they operate. As an independent social planner might have preferences for differing overarching priorities to be reflected in the tool, we assess three scenarios of alternative tool designs to evaluate how different societal preferences would impact the final indicators measurement. Each scenario considers the same 23, 10, and 9 indicators for the nutritional, environmental, and social dimensions respectively, as in the present tool.

In scenario A we consider a top-down approach where all indicators are measured on a scale ranging from 0 to 10. Hence, each indicator has the same importance for the sustainability of the school food environments. In scenario B, we assume that each of the three sustainability dimensions is considered equally important for total sustainability. Scenario C supposes that the importance of one sustainability dimension differs from the others. Specifically, as nutritional targets are often prioritized by school authorities, this dimension is assigned the lion share for determining the final sustainability score (see Table 7).

Fig. 6 displays the contribution of each sustainability target to the total score, the maximum score per indicator within each target and the contribution of each indicator to the total score. The consensus understanding of the stakeholders involved in the present study reveals that in Emilia-Romagna, environmental aspects are considered to be most important for evaluating the sustainability as the 10 indicators of this dimension contribute 53.3 % to overall sustainability. The 23 indicators quantifying the nutritional dimension contribute 30.7 % and the 9 indicators of the social dimension 16.0 %. While all nutritional indicators are measured on the same binary scale, the revealed priority consensuses imply that stakeholders consider single environmental (social) indicators on average as four (1.3) times as important both for achieving the respective sustainability target as well as for overall sustainability.

As the maximum score for each indicator in scenario A is 10, the relative importance of the nutritional (social) target in the overall

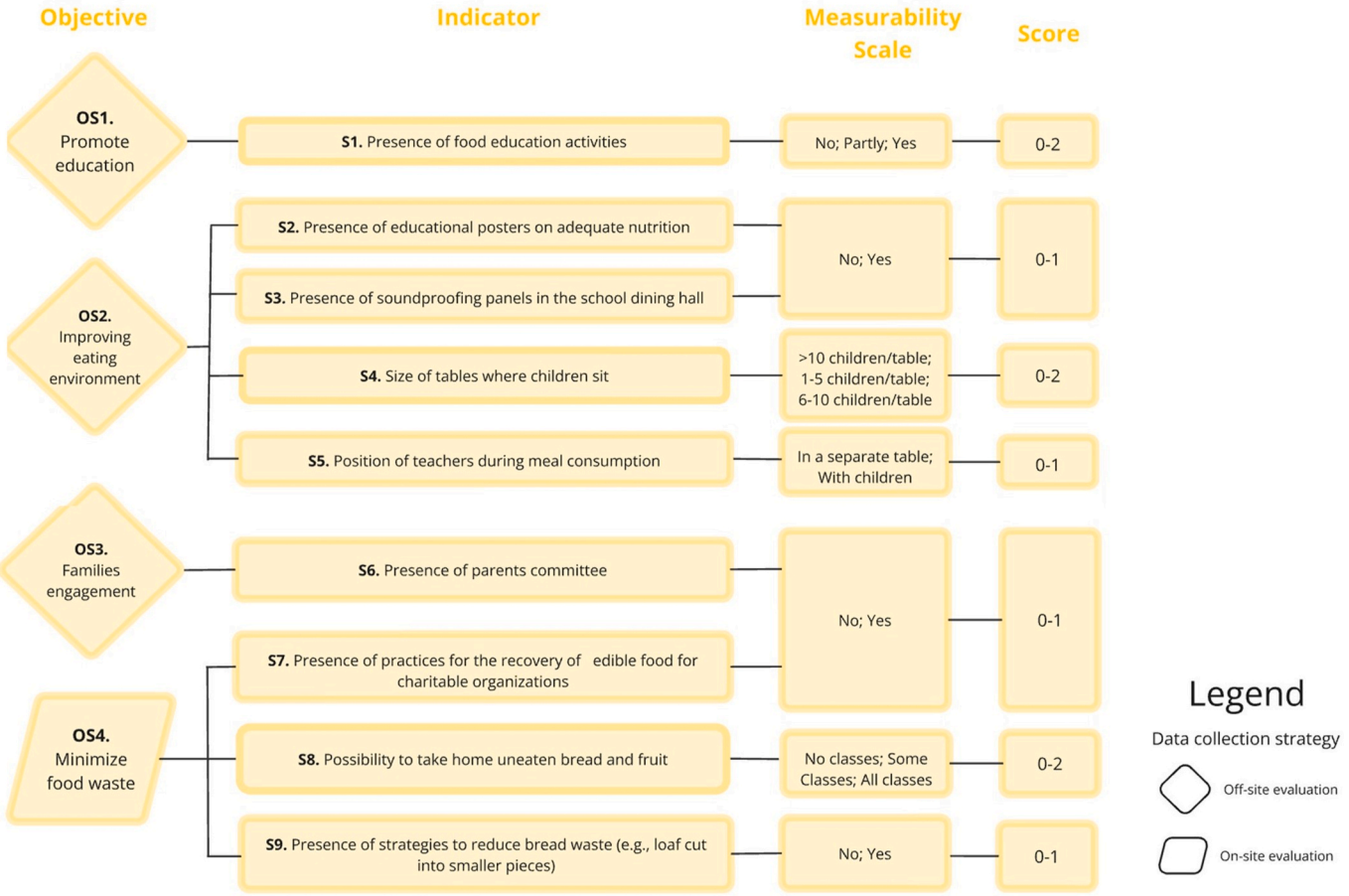

Fig. 5. Indicator characteristics for the social score (*SS*).

Table 7
Implications of alternative evaluation priorities for sustainability score aggregation.

			Maximum score		
Scenario	Characterization	Description	Nutritional	Environmental	Social
Baseline	Bottom-up: Revealed consensus of the priorities and preferences of the regional stakeholders	Indicators within dimensions as well as dimension maximum scores may have unequal weights	23	40	12
A	Top-down: Each of the 42 indicators equally important	Equal measurement scale, e.g., from 1 to 10* for each indicator	230	100	90
B	Top-down: Each of the 3 dimensions equally important	Equal maximum score of, e.g., 10* for each sustainability dimension	10	10	10
C	Top-down: Reflecting the existing relevant legal regulations	Dominating weight on the nutritional target	69	3	3

Note: The exact numerical choice for the maximum indicator or dimension weight (we chose 10 due to numerical convenience) does ceteris paribus not affect their implied weights within their dimension nor for composing the overall sustainability score.

sustainability score increases by 24pp (5pp) compared to the baseline, while the importance of environmental aspects decreases by 30pp. Each indicator contributes an equal share of 2.38 % (Fig. 6) to *TS* while these contributions vary in the baseline between 1.33 % and 13.33 %. Scenario B leads to an increased importance for the nutritional (+3pp) and the social (+17pp) targets, and to a decreased importance for the environmental dimension by 20pp so that each target has an equal weight in *TS*. Each individual environmental and social indicator is, hence, considered as more than two times as important for overall sustainability than each single nutritional indicator (3.70 %, 3.33 % and 1.45 % contribution, respectively see Fig. 6). In scenario C, the importance of both the environmental and the social targets decreases substantially (−49pp and −12pp, respectively) in relation to the baseline, while the role of the nutritional target almost triples (+61pp). This implies that the contribution of 4 % of each individual nutritional indicator to the overall school food sustainability is considered to be nine to ten times as important as the roles of indicators in the other two dimensions.

For getting an overview of what each scenario means for the distribution of importance across all 42 indicators, Fig. 7 visually summarizes the cumulative indicator impacts which result from the scenarios outlined in Table 7. The curve for the baseline design shows the varying contributions across environmental and social indicators being sorted both at the left- and the right-hand side. In contrast, the contributions of all indicators within each target equal each other in all three scenarios as the step functions have a constant slope within each dimension.

Supplementary Table F highlights the differing sources of the priority profiles which are below each of the scenarios shown in Table 7. Two classes of scoring mechanisms appear in Supplementary Table F. The first one consists of the baseline design and scenario C which are both

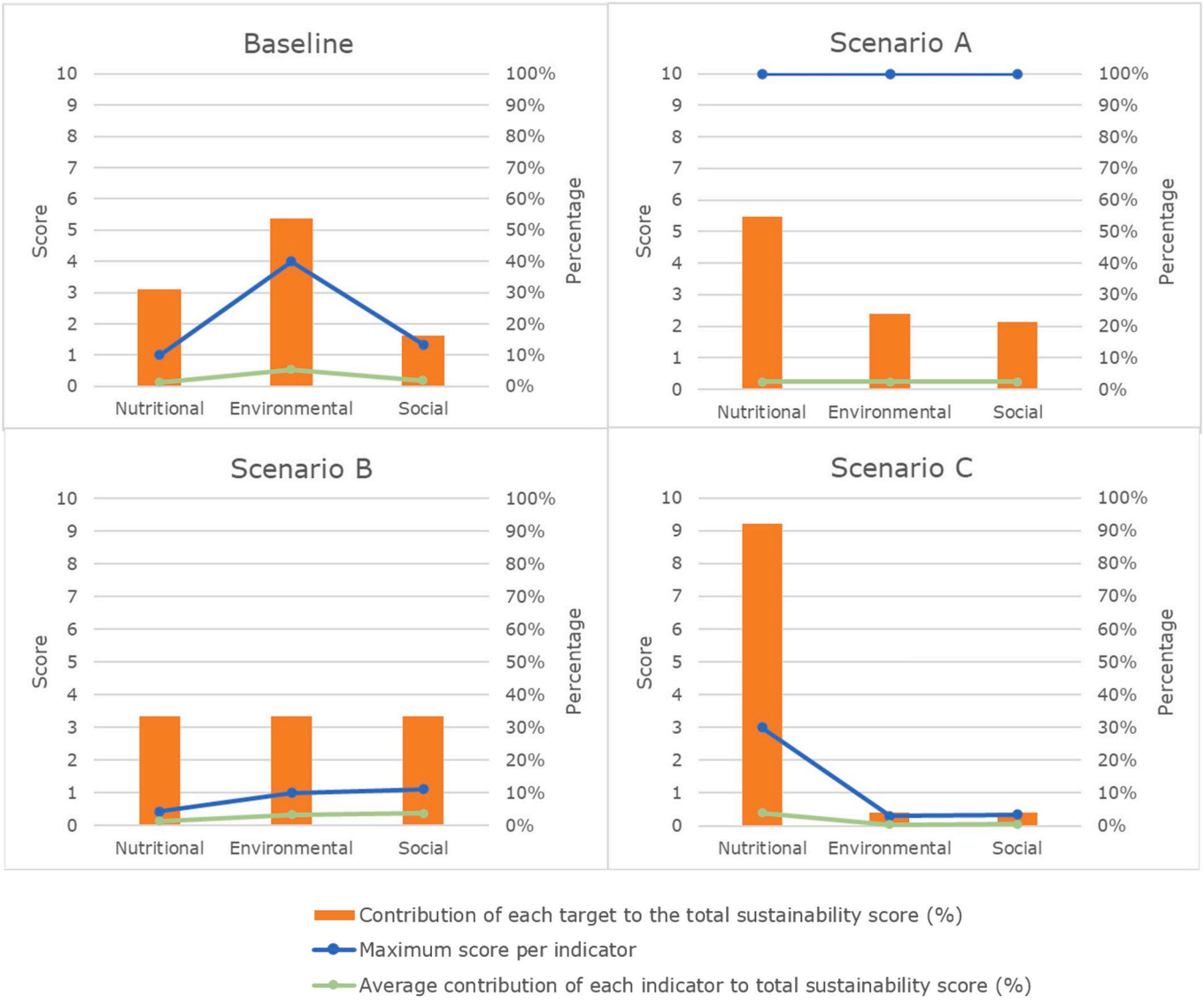

Fig. 6. Implications of the baseline and the three scenarios for the scoring mechanism.

highly relevant to the regional context, but due to that tailoring, they are also little transferable to other regions, other countries or other sustainability measurement contexts. If stakeholders wish to adapt any of the two mechanisms to their specific context, they should invest efforts as the priority profile needs to be re-tailored. The second class consisting of scoring designs A and B is straightforwardly adaptable to other contexts since they do not reflect context-based needs and priorities so that the same dimensions, indicators and measurement scales – potentially regarded as universal choices – may be used across contexts.

5. Discussion

5.1. Contributions to theoretical aspects of school food sustainability assessments

The developed tool offers several advancements beyond the limitations of state-of-the-art sustainability assessments for school food environments. Table 8 presents an exhaustive list of all currently existing approaches ordered by increasing framework complexity and number of sustainability dimensions covered. Two of the six tools exclusively cover health and nutrition reflecting national and international nutritional standards (Gregorič et al., 2015; Rocha et al., 2014). Fernandes et al. (2016) include a single economic indicator on the cost of food for healthy diets in Ghana. Black et al. (2015) evaluate both the nutritional and environmental sustainability of school food programs. At the Italian level, only Caputo et al. (2017) propose a food chain evaluation tool, which assesses nutritional contents, diet diversity, energy and land use as well as production costs of collective catering. Goggins and Rau (2016) combine the evaluation of more than thirty social, environmental and economic indicators.

Table 8 shows that there has been a predominance of nutritional indicators so far. This limitation appears, however, plausible as FAO (2019) stresses that nutritional monitoring is a natural first choice since the main function of school catering is to provide adequate nutrition and social indicators have so far been less mature in the literature (Desiderio et al., 2022).

Our approach helps closing the gap between the theoretical understanding of the multi-dimensional nature of sustainability transitions and their empirical quantification in school food contexts. It demonstrates the feasibility of a comprehensive, yet implementer-friendly measurement and suggests a set of indicators for quantifying also environmental and social dimensions. It has been designed to more comprehensively evaluate the sustainability of food systems not only regarding their primary role of promoting nutritional quality, but also in

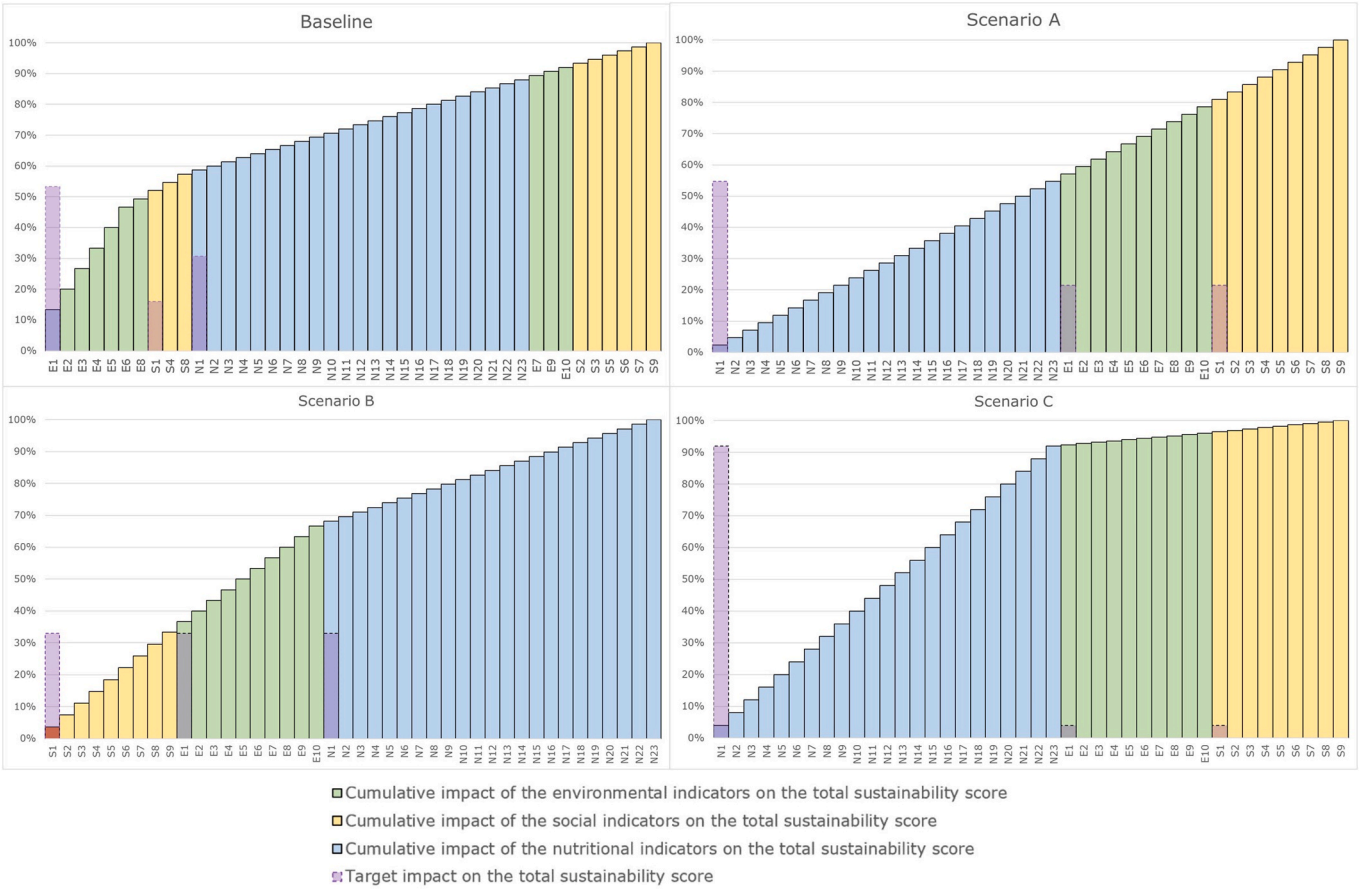

Fig. 7. Cumulative distribution of importance for the indicators in the scenarios.

Table 8
Comparison of sustainability assessment tools for the school food sector.

Article	Aim	Country	Indicators per sustainability dimension				Tailored exclusively to schools	Final sustainability score	Stakeholders' involvement in tool design
			Nutritional	Environmental	Social	Economic			
Gregorič et al. (2015)	Monitoring schools' dietary guidelines adherence	Slovenia (EU)	10	0	0	0	Yes	Yes	No
Rocha et al. (2014)	Software for planning and evaluating school meals according to food and nutrition standards	Portugal (EU)	27	0	0	0	Yes	Yes	No
Fernandes et al. (2016)	Package to promote healthy and sustainable diets for school meals	Ghana (AFR)	3	0	0	1	Yes	No	No
Black et al. (2015)	Scoring tool for food initiatives in schools	Canada (NA)	1	1	4	0	Yes	Yes	No
Caputo et al. (2017)	Tool for analyzing impacts and scenario design for institutional catering	Italy (EU)	3	2	0	1	No	No	No
Goggins and Rau (2016)	Tool for measuring the sustainability of food in public catering	Ireland (EU)	3	8	20	0	No	Yes	No
Our paper	Scoring tool for sustainability of school canteens	Italy (EU)	23	10	9	0	Yes	Yes	Yes

Notes: EU: Europe, NA: North America, AFR: Africa.
Source: Authors.

ways that protect natural resources and support socially desired pathways (Steenson and Buttriss, 2020).

None of the existing approaches has been designed via participatory research. We are the first to have demonstrated the feasibility, and value added of such an approach in the context of school food sustainability assessments. The tool we suggest has already been approved and

implemented by the Emilia-Romagna regional government. This stresses its societal value responding to the demand for integrating large and heterogenous groups of practitioner experts into scientific processes to profit from translating their daily work experiences and insights into joint consensuses forming the basis for scientific measurement. Our approach to monitoring design guarantees to reflect the needs and priorities of the experts and is, thus, tailored to the sustainability ambitions of the governmental authorities and straightforwardly applicable to the context in which the stakeholders are operating.

The application of the bottom-up paradigm has proven to have led to ownership, trust and willingness rendering the tool acceptable and implementable in real-world evaluation purposes at levels which have, to the best of our knowledge, barely been witnessed by comparable scientific research so far. As a next step, our contribution incentivizes to advance the analysis of strengths and weaknesses of top-down vs. bottom-up approaches compiled in Table 1. This is especially important in the context of research relating to sustainability transitions since the goals and the pathways of such transitions tend to be rooted in specific regional contexts. This conclusion coincides with Schneider et al. (2023) who call for consulting stakeholders at international and regional levels to identify and select the most appropriate indicators for capturing the sustainability transformation of global food systems.

5.2. Implications for policy agendas

The tool fosters science-society-policy integration by guaranteeing a monitoring design tailored to both the globally agreed sustainability goals as well as the region's food system context. It, hence, meets the quality criterion for sustainability assessments stressed by Sala et al. (2015): maximizing usability and effectiveness of the tool's practical implementation. Policymaking and governance can profit from this approach as it is suited to straightforwardly be implemented and guide authorities to incentivize management practices that improve the sustainability performance of school catering. It creates a transparent and reproducible mechanism through which schools are enabled to (self-) monitor achievements and identify needs for action to effectively govern the change needed for realizing the sustainability goals of the community they are embedded in. Furthermore, we show how participatory research which integrates and aligns the goals of policy makers to those of society and scientists can be a powerful principle to identify and operationalize the priorities of the relevant stakeholders.

The Italian region of Emilia-Romagna can reap several tangible benefits from this integration. First, thanks to the actionable indicators and intuitive scoring mechanism, the tool allows teachers, municipalities, authorities and governments at various levels to obtain insights into the extent to which schools are currently pursuing sustainable food system objectives at regional level. The resulting data will be used to quantify and effectively communicate in an easily understandable fashion the yearly sustainability performances of schools. Second, policy makers of Emilia-Romagna have succeeded in aligning their vision for the design of sustainability policies to concrete societal needs and priorities. Closing this gap contributes to raise awareness among citizens and stakeholders of the regional efforts to improve the food system sustainability, ultimately enhancing their trust in and the satisfaction with regional institutions.

5.3. Limitations and future research

The limitations of the tool we suggest imply several avenues for future research. The indicators included assess nutritional, environmental and social sustainability. The relative importance of each of these sub-goals in the total sustainability score is not equal as each of them is measured by a different number of indicators and partly differing scales. Therefore, additional investigation of how the suite of indicators could be best expanded into social, environmental and potentially further sustainability dimensions is an important next step.

Furthermore, the tool assigns weights to indicators depending on the measurability scales suggested by practitioner experts. However, the sensitivity analysis clarifies how stakeholder priorities concretely impact both the overall structure of any sustainability assessment tool and the resulting scores. Therefore, future research might explore the heterogeneity in stakeholders' priorities across regions and countries for indicator choice and adjust the associated weights accordingly, for example via analytic hierarchy processes or principal component analysis (Gan et al., 2017).

The tool should be comprehensively tested to allow identifying target ranges of acceptable and desirable sustainability performances across a representative sample of schools. We are currently providing the basis for further validation of the tool by implementing it to a sample of 153 schools in Italy's NUTS2 region of Emilia-Romagna. Results from the data collection will serve for optimizing usability, and actionability of tool indicators and the most intuitive presentation and summary of results.

Despite school meals services in Europe (Social Affairs et al., 2021) and beyond (Pastorino et al., 2023) need to address similar objectives, school catering in countries other than Italy[5] is likely to imply that different service infrastructure and menu organization and composition need to be considered. As a first step, we provide a comprehensive analysis of stylized options which guide the transferability, scalability, and adaptability of the tool to contexts outside Italy. Applications of the tool to differing school food environments will require additional research to detect indicators needing adaptations and additions.

6. Conclusions

The global efforts being made to attain the SDGs highlight the need to advance frameworks that monitor the sustainability of complementary segments of food systems pertaining to nutritional, environmental, social, and economic dimensions (Schneider et al., 2023). Recent research has suggested multiple tools for assessing the sustainability of food production and consumption, whereas monitoring frameworks for assessing the sustainability of collective catering settings, and particularly schools, have received less attention in a moment in which the School Meals Coalition hosted by the UN World Food Programme reaffirms the need to establish adequate school meal programs and to monitor sustainability progress globally (Pastorino et al., 2023).

We contribute to this unique global momentum by suggesting a novel sustainability assessment tool comprising 42 indicators which quantify nutritional, environmental as well as social dimensions of school food environments. The indicators offer an additive sustainability score ranging from 0 to 75 including the option to disaggregate it into complementary sub-scores. The indicator set has been selected via a participatory research process which advances science-society-policy integration by extracting and translating the consensus of participating school food stakeholders into precise numerical measurement. The resulting monitoring design reflects the needs and priorities of the practitioner experts and is, thus, tailored to the sustainability ambitions of the community and authorities. The methodological procedure used to design the tool, the indicators set, their measurements and their aggregation mechanism can serve as a reference and scientific basis for future sustainability assessments in the school food domain and beyond. Due to the tool's flexible modular structure, it can be easily scaled up as well as adapted to differing societal priorities by incorporating additional or different indicators as well as using alternative measurement scales or aggregation mechanisms.

[5] Petruzzelli et al. (2025) provide an overview of typical national primary school lunch environments in selected Western countries in Supplementary Material Table A.

CRediT authorship contribution statement

M. Petruzzelli: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **S. Amadori:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **R. Ihle:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Data curation. **M. Fridel:** Writing – review & editing, Project administration, Conceptualization. **M. Vittuari:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Conceptualization.

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Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2025.146015.

Data availability

Data will be made available on request.

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