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FROM FARM TO SCHOOL: INVESTIGATING THE POTENTIAL OF SCHOOL FOOD ENVIRONMENTS TO TRANSFORM THE FOOD SYSTEM

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From farm to school: investigating the potential of school food environments to transform the food system

Abstract

Sustainable transformations of the food system are today at the heart of the global debate. To comply with the widely agreed need for change, a large scientific interest has been dedicated to the potential of school food environments for transforming food production and consumption trajectories. Besides being responsible for the nutritional quality of children's diets, school meals also shape behaviours of the next generation consumers. Given that the relationships between the dietary patterns, consumption habits of children, the canteen setting, and the selection of food products for school consumption are complex and multifactorial, enlarging the body of analyses is essential for understanding patterns on how food is served and consumed. To this scope, this thesis adopts multiple approaches to understand sustainability dynamics behind school food environments and offers science-based implications derived from rigorous and reproducible social-science research. In particular, three studies are conducted: 1) a systematic literature review to explore the role of short food supply chains in supporting advancements towards global sustainability goals in view of sustainable public procurement practices in schools 2) an evaluation study with a randomized control trial design to assess if inverting the sequence of dishes served in school canteens is an effective intervention for reducing food waste in primary school 3) an indicator-based assessment tool to measure the sustainability of school food environments integrating nutritional, environmental and social implications via an easy-to-understand scoring system. Results of this thesis provide food professionals and policymakers with quantitative insights on areas of improvement of the sustainability status of school food environments. On this basis, effective tailor-made strategies can be designed in schools to foster food system transformations and tackle the fundamental goals of the 2030 Agenda for Sustainable Development.

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Introduction

Introduction

The need for a food system transformation via system thinking

Today a food system is defined as a system that "(..) *embraces the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption, and disposal (loss or waste) of food products that originate from agriculture (incl. livestock), forestry, fisheries, and food industries, and the broader economic, societal, and natural environments in which they are embedded"* (Von Braun et al., 2020). Despite the fact a univocal definition is not yet universally agreed upon worldwide and diverse conceptualizations have been advanced (Béné et al., 2019b), the food system is recognized to deliver multiple outcomes. Primarily, it guarantees the provision of sufficient, safe, and nutritious food for all (Schneider et al., 2023). By being the world's biggest employer, the food system also supports fair and equitable livelihoods for more than a billion people around the globe (Davis et al., 2023). Lastly, if appropriately managed, the food system protects ecosystems and restores natural resources (Herforth et al., 2022). Not surprisingly, the delivered positive contributions conceal significant failures (Béné et al., 2019a). More specifically, the food system is responsible for intensive use of land and water, while being among the largest greenhouse gas emissions contributors (Crippa et al., 2021). At the same time, it often falls short in delivering adequate dietary patterns: globally, around 738 million people cannot comply with sufficient dietary requirements (WHO et al., 2021). The resulting nutrient deficiencies represent a risk factor for increased deaths and non-communicable diseases (Afshin et al., 2019). These phenomena coexist with large amounts of food losses and waste (HLPE, 2014), resulting from the combination of structural factors (Canali et al., 2017) and behavioral patterns in the consumption of food (Vittuari et al., 2023).

Taken together, these elements highlight the importance of shifting from a siloed, linear interpretation of food consumption and production to a system thinking approach (Sonnino, 2023). System thinking implies conceptualizing food systems as a set of multi-dimensional factors that closely influence each other through continous feedback loops and trade-offs mechanisms in terms of natural components, social structures and economic resources (Béné et al., 2019a). Special attention is devoted in the literature to spatial and human relationships occurring across the different actors having stakes in the food system with their unique perspectives and priorities (Sonnino, 2023). System thinking also requires to place the food narrative within the interlinked dynamics between policies, people and the planet (Borman et al., 2022). For operationalising such approach a new governance archetype is needed, where professionals are asked to embed any micro-

level and local decision-making into macro-level food system knowledge. This multi-level and cross-sectorial governance arrangement stems to nurture the linkages across local, national and international policy structures (Santo and Moragues-Faus, 2019), maximising the capacity of individual decision makers in designing integrated solutions. That is, it calls for establishing cooperation across various stakeholder groups in order to unlock the potentials to learn and get inspired from each others' experiences and views. This will bring forward the citizen science approach currently advocated by the EU (European Commission, 2018) because will stimulate increased participation in policy-making. ....

Global policy initiatives for achieving food systems sustainability

Meeting the increasing global demand for adequate food while facing growing pressure on the economies, on the societies and on the environment is the current ambition. To encourage system thinking transformation of food systems, the debate around food system sustainability has gained common societal relevance (Gaupp et al., 2021). The United Nations define the vision of a sustainable global food system as *"one that contributes to food security and nutrition for all in such a way that the economic, social, cultural, and environmental bases to generate food security and nutrition for future generations are safeguarded"* (Von Braun et al., 2020).

Since the advancements of all 17 SDGs have been shown to depend on the policy decisions taken around the food system (FAO, 2023; Rockström et al., 2020; Petruzzelli et al., 2023), governments worldwide are questioned on how to design policies able to foster the benefits of the food system while addressing simultaneously the key barriers that hamper their transformation. To match the international overarching goals from a food system perspective, the Milan Urban Food Policy Pact (MUFPP, 2015) was signed in 2015 as a tool for action for cities. The pact sets out a large body of recommended actions and indicators organized in the six workstreams of governance, sustainable diets and nutrition, social and economic equity, food production, food supply and distribution, and food waste. This pact has been adopted to be the agenda of more than 270 cities around the globe and offers guidance to build healthy and resilient food systems at the local level (FAO, 2019a).

More recently, the United Nations Food System Summit (UNFSS) 2021 made a mark in advancing actionable food system interventions through system thinking. The summit served to set an agenda for closing the gap between the intents for food system transformation and strategic actions (von Braun et al., 2021). A large set of strategies emerged from the summit to support Member States through national

pathways for food systems transformations. One exemplary case is the creation of more than 20 coalitions assembled to advance systemic approaches on specific issues in food systems.

The role of school food environments' in the policy agenda

Within the political and civil society commitment towards food system transformations, a consistent focus has been put on the role of school food environments in shaping the production and consumption practices of future generations (FAO, 2019b). Recommended Action 15 of the MUFPP calls cities worldwide to reorient school feeding programs, setting a global priority on the topic (MUFPP, 2015). Other seven Recommended Actions of the MUFPP are linked to improving school feeding worldwide from both a nutritional and an educational perspective (MUFPP, 2024). On top of this call and in the wake of the UNFSS 2021, a group of about 80 countries launched the School Meals Coalition (SMC), recognizing the transformative potential of school feeding programs for SDGs attainment and setting common commitments to strengthen support for school canteens (School Meals Coalition, 2020). The SMC champions initiatives to support governments in establishing adequate school meal programs and monitoring progress. In line with the UNFSS, the approach of the Coalition is to systematically integrate school meals into educational plans for children (Pastorino et al., 2023). Consistently with its focus on education, also the OECD plays a supportive role for the Coalition, promoting a systemic thinking of school meals and looking at them as a constituent block for improving the learning environment of children.

Platforms such as the SMC tend to act at national or supranational levels, engaging national representatives and high-level organizations into the sector. However, while national governments are often responsible for regulatory aspects of school meals local governments are the ones practically operationalising school feeding programs and implementing them. Therefore, actionable efforts are in most of the cases in the hands of local rather than national governments.

Overarching theoretical framework: Understanding the potential of school food environments for transforming food systems

Compared with family meals, school meals are a more centralized activity since any decision taken in school canteens has the potential to influence the habits of many children at once (Oostindjer et al., 2017). Today, worldwide around 418 million children are yearly fed by school meals (WFP, 2022). This corresponds to US$48 billion spent annually on school meal programs and 1,377 jobs created for every 100,000 children eating at school (WFP, 2022).

First and foremost, school food environments have the potential to promote enhanced nutrition status and health of children via appropriately designed school meals positively contributing also to children mental development, and learning capabilities (WFP, 2017). Since for children in many countries the meal received at school represents up to half of the nutrients source of the day (Radcliffe et al., 2002), these benefits further multiply in the presence of social inequalities and poverty. School canteens are also settings able to influence the habits of children which have been found to transfer them to their families (Taylor et al., 2018). Children are particularly receptive to education activities that can avoid the proliferation of unhealthy consumption practices later (Sandell et al., 2016). Finally, by reaching large numbers of people, school meals constitute an ideal site to focus on reorienting procurement practices (Tregear et al., 2022). Taken together, these factors clarify the meaningful opportunity school canteens have to transform food systems both via establishing long-lasting dietary patterns and via influencing food markets.

Research gaps

In this dissertation, we explore three levers of change for school food environments. Levers of change are areas of work having the potential to realize positive changes in the field of interest and contribute to a sustainable transformation of the food system (Chan et al., 2020). Particularly these three levers of change relate to (1) procurement practices, (2) behavioural interventions and (3) sustainability monitoring. The three thesis chapters are articulated each on one of these three levers, which are described below in detail together with their relevance for the current debate.

Procurement practices in school canteens

The food procurement strategies of public institutions are instrumental in advancing global sustainability objectives, with specific reference to SDG 12.7 which aims to "*Promote public procurement practices that are sustainable in accordance with national policies and priorities*" (FAO et al., 2021). In Europe (EU-28), it is estimated that school canteens together with hospitals, industry and homecare canteens spend around €82 billion per year on food procurement. When breaking down the foodservice market of 15 European countries by segments, the school and education service is the second largest segment accounting for around 31% of the total food service market and serving 5 756 million meals per year (GIRA Foodservice, 2014). Therefore, decisions on which food products to use in school canteens can be entry points to increase demand for sustainable products and services (Neto et al., 2016). For this reason, the principle of Sustainable Public Procurement (SPP) - defined as "*the process of acquiring goods, services, and works in the public sector in a socially, economically, and environmentally responsible manner with the ultimate aim of achieving sustainable*

development outcomes" (Etse et al., 2021) - has become an issue of growing concern (Tregear et al., 2022). The schemes for food procurement in Europe have been impacted by the introduction of Green Public Procurement (GPP) practices, which guide public institutions on how to account for the environmental impact of their procurement (European Commission, 2008). The attention of the European Union has also been dedicated to broadening the sustainability perspective by including social indicators in the evaluation of food procurement schemes (Caimi and Sansonetti, 2023). By purchasing environmentally and socially preferable foods, schools can make a significant impact. In light of this debate, many researchers started to illustrate SPP practices across different sectors (Etse et al., 2021), to scrutinize the integration of innovative policies in public food procurement (Smith et al., 2016) and to analyze the main barriers challenging SPP (Leal Filho et al., 2019).

The recent statement of the World Food Programme "*to purchase more local food and match quality diets to local production*" (WFP, 2022) for school food, encouraged scientific assessments of how local and small producers can offer more sustainable forms of public procurement (Morley, 2021). A set of public procurement approaches to integrate local products in school menus already exists (Smith et al., 2016), but evidence on how these approaches affect sustainability outcomes is still limited. Therefore, it is crucial to enlarge the existing evidence on how local foods can promote environmental, social, and economic benefits for society, so as to understand what effects they could have if selected in procurement schemes for schools and beyond. Chapter 1 further explores the existing gaps in the investigation of benefits of local food chains and the contributions of this thesis.

Behavioral interventions in school canteens

Many eating behaviors that develop during childhood track into adulthood. These behaviors are rooted in multiple overlapping factors that concern the consumption norms of children as well as the food and eating environments they are exposed to at home and in school canteens (Wansink, 2004). On this background, choice-architecture interventions in schools give the impulse to shape the relationship children have with the food they eat and shift towards more sustainable patterns across their lifespan (Murphy et al., 2021). Choice-architecture interventions aim to direct individuals' behavior to desirable consumption choices by changing the way options and decision-making formats are arranged (Thaler and Sunstein, 2008). In schools they are often used to promote children's consumption of healthy food, in particular fruits and vegetables (Cohen et al., 2021), and the reduction of food waste (Reynolds et al., 2019). Examples of choice-architecture strategies targeting one or more of these issues are changes in portion size (Qi et al., 2022) and in the location of food

products (Mikkelsen et al., 2021), the introduction of canteen decorations (Hamdi et al., 2020), the delivery of nutrition education modules (Serebrennikov et al., 2020), the introduction of role modelling (Machado et al., 2020), changes in the order of food serving (Elsbernd et al., 2016), or a combination of them (Ang et al., 2019). The effectiveness of these interventions might have heterogeneous outcomes depending on the school canteen settings, the length of time for which the interventions are implemented, and the choices made on how to implement them (i.e., to inform recipients of the interventions or not) (Capper et al., 2022; Metcalfe et al., 2020).

The main limitation of the experiments implemented so far is the lack of rigorous methodological designs, such as randomized control trials, and transparent data collection protocols (Reynolds et al., 2019) which can provide internal validity of the analysis and establish external validity guaranteeing adequate results generalizability (Roe and Just, 2009). The adoption of larger sample sizes and representative random sampling when applying these interventions across different territories and dietary patterns is hence especially relevant and timely (Reynolds et al., 2019) to serve as the basis of policymaking to be implemented at the local and national level. Chapter 2 further details the research needs for behavioural interventions in school canteens and how this thesis uses them to create relevant food system transformation insights.

Sustainability monitoring in school canteens

Despite the existing unprecedented possibilities for data collection and storage due to technological advances, sustainability monitoring of school food systems is still under development (Chaudhary et al., 2018). Assessing the sustainability status of school food environments is critical to guide structural change towards school canteens that deliver affordable and healthy diets while promoting positive social interactions and respecting environmental boundaries (Goggins and Rau, 2016). Despite assessment tools being more often focused on the stages of the supply chains involved in food production (Cirone et al., 2023; Doernberg et al., 2022), the applications of these tools have also concerned the school environment (Caputo et al., 2017; Rocha et al., 2014). Yet, differences in the implementation of school food programmes across geographical and dietary patterns challenge a 'one fits all' solution. In addition, the complex networks of health, environmental and societal outcomes delivered from school canteens are strictly dependent on the territory where schools are located and operate (Bryant et al., 2023). Therefore, it is important to develop the design of school canteens' sustainability assessment tools at the local level, where the involved stakeholders are put at the center of the design process, in order to capture their needs and operative circumstances. Monitoring and reporting sustainability advancements of school canteens not only accelerate

progress towards food system sustainability but can also be insightful in terms of what to improve, offering reliable information for decision-making. Chapter 3 extends the elaboration of research gaps and clarifies the contributions of this thesis in helping to address them.

Research questions and thesis structure

For the investigation conducted in this PhD thesis, three research questions (RQs) have been deduced relatively to the three levers of change above described. RQ1 is dedicated to procurement practices, RQ2 focuses on behavioural interventions, and RQ3 refers to sustainability monitoring. The research questions are listed below and explored in Chapter 1, Chapter 2 and Chapter 3 respectively:

RQ1: *What is the potential of short food supply chains (SFSCs) for accelerating progress towards the international policy goals for food system sustainability transformations?*

RQ2: *Does the choice-architecture intervention of changing the sequence in which school canteens dishes are served promote sustainable diets by reducing vegetable food waste?*

RQ3: *How to measure the sustainability of school canteens by integrating their nutritional implications with their environmental and social effects?*

Chapter 1 presents the results of a systematic literature review creating an exhaustive global inventory of the benefits of SFSCs linking them with the global policy goals declared in the SDGs and MUFPP (**RQ1**). Chapter 2 analyses the effects of a choice-architecture intervention co-designed with stakeholders to assess whether inverting the sequence in which school dishes are served in the context of the Mediterranean diet effectively increases vegetable intake and reduces food waste. The intervention is conducted across 26 Italian schools to capture regional heterogeneity, maximize internal and external validity and offer concrete policy guidance (**RQ2**). Chapter 3 illustrates a scoring assessment tool for school canteens where multiple sustainability dimensions are analyzed at once and scored from 0 to 10, with a higher score corresponding to greater sustainability. The tool is developed together with stakeholders from school canteens via a participatory approach and offers an operational and ready-to-use application for direct planning and decision-making (**RQ3**). The thesis ends with conclusions that summarize the main research findings and suggest recommendations for policymaking and future research developments.

Methodology

For addressing the research gaps a methodology mix is used which includes a systematic literature review, a choice-architecture experiment and a stakeholder-based, i.e., bottom-up development of a sustainability assessment tool. A detailed description of the methods applied to address each research question, along with

the obtained results and discussions is provided in each chapter. The systematic literature review addresses RQ1 by collecting scientific and grey literature publications. It follows a well-establish rigorous protocol by adopting the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, Page et al., 2021a) to be able to guarantee replicability of the document search (Moher et al., 2015). The review is followed by bibliometric and content analyses extracting and systematizing the publications considered. Results are visualized in a set of multidimensional infographs to maximize their ease of understanding.

For RQ2 a randomized control trial combined with a participatory research design are adopted. Following the Consolidated Standards of Reporting Trials guidelines (CONSORT, Moher et al., 2001), the sampling design randomly select 26 schools. Thirteen of them are randomly allocated to the treatment group and the remaining 13 to the control group reaching the largest and the most diverse sample of fully randomized schools achieved so far in this context. The weighted the prepared food, serving waste and plate waste per meal course, a mass flow analysis. Finally, the impact of the inversion of the dish sequence on plate waste percentages is evaluated with a difference-in-difference regression model.

The develop the assessment tool for answering RQ3, the sustainability assessment procedure designed by Sala et al. (2015) is followed. According to this procedure, the sustainability approach adopted in the assessment tool is set, together with the sustainability targets addressed, the decision context for which the tool is destined to be used and the methodological design for the definition of indicators in the assessment tool. The indicators are identified through a Participatory Action Research design (Cornish et al., 2023) involving 25 core stakeholders of the provincial school lunch sector in five co-design phases.

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Chapter 1

The role of short food supply chains in advancing the global agenda for sustainable food systems transitions

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Chapter 1. The role of short food supply chains in advancing the global agenda for sustainable food systems transitions

Abstract

Food systems are experiencing a unique momentum of transformation guided by the Sustainable Development Goals (SDGs) and the Milan Urban Food Policy Pact (MUFPP). The potential of short food supply chains to contribute to this transition both in urban and rural environments has been broadly acknowledged by policymakers and scientists. Yet no exhaustive evidence exists on their capacity to meet the goals declared. This paper categorises the benefits these chains are reported to have in 69 publications selected via a PRISMA review. It develops an exhaustive inventory of which benefit is connected with which SDG target and recommended action of the Milan Pact. Multidimensional infographics illustrate the associations between these benefits and both sets of global sustainability goals. The 348 benefits collected show disparities in current research on the topic across benefit categories, chain structures and continents. Benefits have been reported for ten SDG targets and nine MUFPP recommended actions. Quantifying externalities of short food supply chains and establishing causal effects for their targeted usage worldwide are aspects barely addressed by scientific inquiry. The insights gained help urban policymakers to understand to what extent the promotion of short food chains can help cities to meet SDG and MUFPP goals.

Keywords: SDGs; public policy; systematic literature review; food system sustainability; food system transition; data visualisation.

1.1 Introduction

Given that the share of the urban population is predicted to rise worldwide from 39% in 2010 to approximately 60% in 2050 (Kii, 2021) an increasing number of cities around the globe are investing greater efforts into the design of sustainable urban food strategies (Filippini et al., 2019; Sonnino, 2023). Food and its multifaceted societal dimensions are considered essential to achieve the seventeen Sustainable Development Goals (SDGs) agreed by the international community (Sachs et al., 2019; Wilkinson et al., 2016). As a consequence a joint declaration of the largest cities and metropolitan areas, named the Milan Urban Food Policy Pact (MUFPP), has been agreed upon in 2015 to strengthen the implementation of SDGs in urban food systems (MUFPP, 2015). This alliance calls institutions to recognise the vital role of food systems in urban planning (Cohen, 2022) through six categories of interventions articulated in 37 recommended actions (RAs). These commitments represent today the backbone of the food policy agendas of more than 200 major urban conglomerations worldwide and drive food distribution and consumption patterns of their 400 million inhabitants (FAO, 2019a).

Within the global policy discourse about the required sustainability transition of food systems, the potential of short food supply chains (SFSCs) has been widely acknowledged (Augère-Granier, 2016; Belletti and Marescotti, 2020; USDA, 2022). The understanding of the comprehensive positive implications of SFSCs has been repeatedly advanced (Table 1.1, Forssell and Lankoski, 2018). SFSCs are promoted due to their potential to boost resilient urban-rural food economies (European Commission EIP-Agri, 2015), facilitate local cohesion (Kneafsey et al., 2013), and improve social relationships among food system stakeholders (Chiffoleau, 2009). They have been shown to territorialize food (Venn et al., 2006) and to provide increased access to fresh and healthy food products (Galli and Brunori, 2013). The evidence about their environmental impact is divergent (Kulak et al., 2015; Loiseau et al., 2020). However, major findings refer to their environmentally sound practices (Jarzebowski et al., 2020).

Various reviews about research on SFSCs have been published (see Table 1.1). They focus on their theoretical conceptualisation (Bazzani and Canavari, 2013; Fabbrizzi et al., 2014; Thomé et al., 2021), on their logistics (Liverpool-Tasie et al., 2020; Paciarotti and Torregiani, 2021), on their implementation (Bayir et al., 2022), or on the bibliometric impact of SFSC research (Luo et al., 2021). Although Liverpool-Tasie et al. (2020) link their analysis to SDGs, they do not explicitly consider them in their analysis. The investigation is restricted to the impact of market transactions without formal contracts on the welfare of small-scale producers in developing countries. Reviews specifically tackling the sustainability of SFSCs are either focused on a single continent (Evola et al., 2022), a single SFSC type (Michel-Villarreal et al., 2019) or the

consumer perspective only (Feldmann and Hamm, 2015). This comprehensive, though scattered, literature does not allow researchers to obtain a global overview of which SFSC types specific beneficial effects have been found for and which benefits have received more or less attention so far. The most comprehensive study of Chiffoleau and Dourian (2020) does not quantitatively analyse review results and does not decompose them by geographical scope or specific chain types. None of the existing analyses elaborates on the potential of SFSCs for achieving the policy goals of the SDGs and MUFPP.

Table 1.1. Existing review articles on short food supply chains (SFSCs) research.

Article	Geographical scope	No. of articles	Content scope	Temporal scope	Number of SFSC synonyms used for search	Focus on SDGs or other policy goals	Quantitative analysis
Bazzani and Canavari (2013)	Global	64	Evolution and description of SFSCs	Not specified	4	No	No
Fabbrizzi et al. (2014)	Not specified	Not specified	Classification and description of SFSCs	Not specified	Not specified	No	No
Thomé et al. (2021)	Global	51	Conceptual framework of the food supply chains and SFSCs	2015-2020	3	No	No
Liverpool-Tasie et al. (2020)	Developing countries	202	Market relationships of small-scale producers	2000-2019	7	No	Yes
Paciarotti and Torregiani (2021)	Global	66	Role of logistics in improving sustainability of SFSCs	2006-2019	3	No	No
Bayir et al. (2022)	Not specified	44	Understanding of challenges of SFSCs	2000-2020	2	No	Yes
Luo et al. (2021)	Global	684	Bibliometric mapping of research topics and future directions for SFSC research	2000-2020	4	No	Yes
Evola et al. (2022)	Europe	108	Overview of the SFSCs in Europe	2012-2021	2	No	No
Michel-Villarreal et al. (2019)	Global	61	Investigation of how sustainability has been studied in alternative food networks	2006-2017	1	No	Yes
Feldmann and Hamm (2015)	Global	73	Consumer perceptions and preferences for local food	2000-2014	2	No	No
Chiffoleau and Dourian (2020)	Global	157	Definition and characterisation of SFSCs and their sustainability	2000-2018	5	No	No
This paper	Global	69	Database of SFSC benefits and links to global sustainability goals	2000-2021	10	Yes	Yes

Source: Authors.

Our analysis extends the existing literature by structuring and categorizing research findings and by quantitatively analysing their links to the most prominent global sustainability goals. It creates the first exhaustive database of SFSC benefits reported globally in the literature, in which benefits are catalogued by continent and by SFSC organisational structure. The search of the documents reviewed is designed to capture SFSC diversity across organisational structures and geographical scopes by considering a broad set of keywords referred to SFSCs. This analysis complements the predominantly narrative accounts on the merits of SFSCs and unifies them into a single structured framework that can be decomposed based on categories relevant to policymakers or scientists. Building on this database, this paper establishes the first inventory of the links between SFSC benefits reported and the most prominent policy goals for achieving the global sustainability transition as declared in the SDGs and MUFPP. Multidimensional infographics visually summarise these links. Last, we examine publication patterns in the bibliometric characteristics of the identified documents. This analysis provides thus timely science-based evidence suitable to establish coherent policy design (Collste et al., 2017) for aligning urban transformations with the agreed-upon sustainability goals (Grainger-Brown et al., 2022).

Our analysis does not consider costs or negative effects these chains might potentially cause (Forssell and Lankoski, 2015). We focus on inventorying and synthesising their positive effects as these are the aspects which are referred to in policy discourses (European Commission, 2017; FAO et al., 2021). Quantitative cost–benefit analyses of SFSCs, causal analyses of their effects on sustainability via randomised controlled trials or similar approaches or quantifications of their effectiveness, costs and disadvantages (Aubry and Kebir, 2013) are beyond the scope of this paper and, thus, left for future research.

This article is organized as follows. Section 1.2 details the methodology used for the search strategy, the data analysis, and the visualisations. Section 1.3 summarizes SFSC benefits and maps them to specific SDGs and MUFPP recommended actions. Section 1.4 discusses the results and limitations of the analysis and concludes by pointing out future research options and policy implications.

1.1.1 Conceptual background

SFSCs are very heterogeneously defined throughout the literature. First categorised by Marsden et al. (2000) into face-to-face, spatially proximate and spatially extended channels, these chains are understood as local or regional food production and distribution networks characterised by the closeness of producers and consumers (Goodman et al., 2011). Hence, important dimensions for their definition are geographic distance (Aubry and Kebir, 2013), the number of intermediaries (Poças Ribeiro et al., 2021) and economic

relationships between participants (Sellitto et al., 2018). Connections among actors are particularly essential for the success of SFSCs (Galli and Brunori, 2013) and are mostly built on trust and reciprocity (Taylor, 2005; Torquati et al., 2016).

The term SFSCs refers currently to a wide range of organisational structures, for example, to alternative food networks (AFNs), community-supported agriculture (CSA), farmers markets (FM), box schemes (BS), home delivery or pick-your-own approaches (Bazzani and Canavari, 2013; Bertazzoli et al., 2010). Martinez et al. (2010) considers them as local networks where food is sold less than 400 miles away from its production origins. In contrast, the European Union (2013) in Article 2 regulation 1305/2013 defines an SFSC as a "*chain involving a limited number of economic operators, committed to cooperation, local economic development, and close geographical and social relations between producers, processors and consumers*".

To distil the commonalities among SFSCs terminologies and to embrace a global perspective, this analysis adopts the SFSCs categorisation of the UN industrial development organisation (Belletti and Marescotti, 2020).[1] We, therefore, consider short supply chains (SSCs), local food systems (LFSs), AFNs, on-farm selling, FMs, farmers' shops, CSA, BSs, solidarity purchasing groups (SPGs) and consumer managed shops as SFSCs.

1.2 Methods

1.2.1 Data collection

To identify the relevant publications reporting SFSC benefits in a transparent and reproducible way, we conducted a systematic literature review implementing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021a). Our review follows this rigorous protocol that guarantees objectivity and replicability in document selection and summary of results (Moher et al., 2015). Supplementary Figure A shows the structure of the search strategy designed according to the PRISMA flow diagram (Page et al., 2021a). The review considers English-language documents from 2000[2] until the end of 2021. Our analysis takes the global perspective of the SDGs and MUFPP.

Scientific publications were searched for in Scopus.[3] The Scopus search query was deduced from the above-mentioned UN categorisation of SFSCs (Belletti and Marescotti, 2020) in combination with the keyword *benefit* and its synonyms. The search query documented in Supplementary Table A yielded 327 results. We

[1] Public procurement or HoReCa are not considered since Belletti and Marescotti (2020) explicitly treat them as opportunities of supporting SFSCs.

[2] In this year, the term SFSC was firstly used by Marsden et al. (2000) and the scientific debate took off (Luo et al., 2021).

[3] Visser et al. (2021) as well as Singh et al. (2021) emphasize that Scopus is one of the largest databases globally of peer-reviewed publications in social sciences. It includes more than three times the journal entries and covers 99% of the journals indexed in Web of Science (Singh et al., 2021).

manually eliminated duplicates and ineligible documents. Then the titles, abstracts, and keywords of the remaining 323 articles were read by the authors and the ones not focusing on SFSC benefits were manually excluded from the database if not compatible with the research objective (see Supplementary Figure A).

We follow Garousi et al. (2019) and Paez (2017) by complementing scientific journal publications with grey literature to improve the comprehensiveness of the review. As in Bazzani and Canavari (2013) and Wood et al. (2021), we opt for targeted websites which are relevant for our research objective because there is no universal consensus on the databases to be used for identifying grey literature. Hence, we conducted a targeted search on the websites of the most relevant intergovernmental and non-governmental organisations which are working with an international scope and have a key role in the food system debate: the FAO, the MUFPP, the International Panel of Experts on Sustainable Food Systems, Slow Food, and the International Food Policy Research Institute. The website search was conducted in January 2022 for collecting documents reporting the benefits of SFSCs in line with the research objective. The websites were screened and the identified documents double-checked to guarantee validity of the search (Page et al., 2021b). This resulted in twenty-eight English-language organisation reports published between 2000 and 2021.

We accessed and read the full texts of both scientific articles and grey literature reports and only documents meeting the inclusion criteria (see Supplementary Figure A) were manually selected. Hence, we included documents which (a) had their full text available, (b) explicitly focused on the assessment of SFSC benefits, (c) presented novel evidence which did not summarise or review previous studies, and (d) produced quantitative or qualitative results. After this rigorous and structured selection process was completed in February 2022, 64 scientific and 5 documents published by organisations were included (see Supplementary Table B).

1.2.2 Data analysis

Based on the final set of 69 publications, the database of reported benefits of SFSCs was established and connected to the global sustainability goals. The analysis followed the four steps outlined in Figure 1.1.[4]

Step 1. Benefit extraction. Following Neuendorf (2002), each document was examined through content analysis. Given the heterogeneity of studies, this analysis was conducted manually to guarantee an adequate critical perspective and continuous reflection throughout the process (Anastasiei and Georgescu, 2020).[5]

[4] Supplementary Table C shows examples of the data analysis process.

[5] The first author led the process which was supervised and double-checked by co-authors.

The identified benefits were extracted as individual text lines. The methodology used, the geographical scope and the organisational structure of the SFSCs assessed were recorded in the terminology used in the document. Additionally, to assess the claim that SFSCs are more often qualitatively analysed (Kneafsey et al., 2013), the analysis used in the document for the evaluation of the SFSC benefits was categorized into qualitative or quantitative. The data were organised in an Excel file that served as a basis for the following steps.

Figure 1.1. Data analysis process.

Source: Authors.

Step 2. Benefit coding. To make benefits suitable and comparable for further analysis, a set of keywords was extracted from each benefit contained in the database. The extraction was performed using the RAKE algorithm (Rose et al., 2010) which guarantees reproducibility. The algorithm results were interpreted by the authors to define a final set of essential keywords describing each benefit.[6]

Step 3. Benefit categorisation. Once the benefits had been coded, each benefit was categorised through deductive reasoning to systematise and unify the database. A major advantage of this process is that categories are defined prior to the analysis (Moretti et al., 2011) which increased the objectivity of the approach. To overcome the often used three-pillar sustainability construct (Luo et al., 2021), we adapted the conceptual framework of Hoang (2021) and created six thematic categories that refer to the sustainability dimensions and the related subcategories. The final categories and subcategories adopted in the analysis are summarised in Table 1.2 and described in detail in Supplementary Table D. For each category, a subcategory named "Others" was considered to include benefits whose characterisation did not fall in any other subcategory. The coded benefits were uniquely assigned to one category and subcategory.

Table 1.2. Thematic categories and subcategories of SFSC benefits.

Categories	Product quality	Space and Time	Information	Economy	Environment	Society

[6] As for step 1, the first author led the process which was double-checked by co-authors to obtain the final set of keywords.

Subcategories	•Freshness •Safety •Taste •Certification •Speciality •Nutritional profile •Appearance •Others	•Short distance and time •No preservation •Others	•Label •Traceability and transparency •Communication •Others	•Price •Profitability •Job •Income •Local development •Others	•Production pollution •Water usage •Energy usage •Food waste •Biodiversity •Animal welfare •Others	•Health •Relationship •Fairness •Trust •Culture •Others

Source: Authors.

To objectively quantify the uniformity of the existing knowledge, i.e., the attention of the literature on SFSC benefits across and within benefits categories, we follow Gomez et al. (2021) - who measure the diversity of a city's food inflow supply chains - and calculate the normalised Shannon entropy index S (Shannon, 1948). It has been applied to measure the concentration of bibliometric parameters (Merediz-Solá and Bariviera, 2019; Polyakov et al., 2017). Given that p_i denotes the frequency of observing each item $i = 1, \ldots, N$ within the set of interest, the entropy S is defined as:

$$S = \frac{-\sum_{i=1}^{N} p_i \ln(p_i)}{\ln N}.$$

The closer the index is to zero, the higher the concentration of attention for a few benefits within a category and, hence, the more uneven the distribution of benefits across and within categories.

Step 4. Policy matching. Based on the coding, we connected each benefit to the SDGs and MUFPP policy objectives it contributes to. For both the MUFPP and SDGs, we considered the match to the highest level of detail possible. Hence, we link each benefit to one of the 37 RAs rather than to the six outcome areas of MUFPP and to one of the 169 targets of the SDGs. We did not consider SDG indicators since they provide quantitative goal attainment measurements that are not informative for our analysis. RA and SDG target went through manual concept extraction to have each of them identified with a univocal scope. Then, based on the benefit coding, we qualitatively matched each coded benefit based on deductive reasoning with the single RA and the single SDG target it appeared to be associated with most strongly.

1.2.3 Data visualization

For facilitating the intuitive understanding of the results, various multidimensional infographics were created following the data visualisation design suggested by Chen et al. (2008). Such data visualisations are helpful for translating scientific knowledge into intuitive visual summaries, rendering quantitative information more communicable to non-academic audiences such as stakeholders of policy-making processes (Khoury et al., 2019; Masud et al., 2010). The most informative design was selected based on the relevant levels of information to be communicated (Schwabish, 2021). The graphical draft of the infographics was created

using Flourish (2022) and finalized with vector graphics application Adobe Illustrator CC 2021 (Adobe, 2007).

1.3 Results

1.3.1 Bibliometric analysis

Figure 1.2 indicates the annual distribution of documents on SFSC benefits published as well as the annual growth rates of scientific output and of the impact of that specific literature on general research. Until 2013, no more than two documents were published per year. Eighty percent of the scientific publications were published after 2013 and all publications by organisations after 2011. The growth of the cumulated number of scientific documents (citations) represents a measure of the increase (of the impact) of knowledge on the benefits of SFSCs (on the scientific debate). The growth rates of the impact tend to exceed the growth rates of knowledge generation. Until 2006, the scientific output on SFSC benefits doubled in two years and showed a stable growth of approximately 20% per year after 2006. Citations show high annual growth rates of more than 50% from 2005 to 2010. Since 2011, annual citation growth has smoothly declined from approximately 40% to also about 20%.

The methodologies adopted in the studies assessing the SFSC benefits vary greatly – often several

Figure 1.2. Annual publications and growth rates of documents on short food supply chain benefits and their citations.

Source: Authors

approaches are used in combination (Supplementary Table E). Qualitative approaches appear to dominate

the publications on SFSC benefits. Most methods collect primary data from various SFSC stakeholders through surveys, interviews or focus group discussions. Participant observations, mathematical modelling and other quantitative approaches have rarely been applied. Sample sizes vary between more than 2000 (Maestripieri, 2017) and 5 (Pato, 2020). Most of the documents using SFSCs as the unit of analysis consider fewer than five chains, and the remaining nine studies consider up to 24 chains. Four documents use country data and five do not explicitly specify their sample size (Supplementary Table E).

Taxonomy of short food supply chain benefits

The 69 documents considered report 348 SFSC benefits in total, of which 250 are from scientific papers and

Figure 1.3. Frequencies of categorised benefits.

Source: Authors.

98 are from organisational reports. Figure 1.3 provides a packed circle chart of the collected benefits, classified into the six predefined categories and their subcategories. Each line and colour indicate a separate benefit category. The size of each circle is proportional to the frequency count of the benefits in each (sub) category. Figure 1.3 reveals the disparities in the attention of scientific analysis to certain benefits subcategories. The Shannon entropies in Supplementary Table F show that benefits are quite evenly

distributed across the six categories. Within categories, benefits relating to society, space and time and information have been addressed until 2021 most unevenly by this literature each having only one predominant subcategory.

Figure 1.4 links each benefit category with the most prominent organisational structures of SFSCs[7] and the continent for which the benefits have been reported. On the left-hand side, benefits are presented based on the different categories and related organisational structure to which they belong (see Supplementary Table H). The widths of the connections are proportional to the number of benefits they represent. The heights of the bars in the middle of the graph are proportional to the numbers of benefits reported for each organisational structure. On the right-hand side of Figure 1.4, the benefits reported per organisational structure are disaggregated by continent (see Supplementary Table I). Only very few benefits (6 out of 348) have been assessed by quantitative methods while the overwhelming majority has been reported based on qualitative research.

Each fourth benefit has been reported by scholars for CSA, which is the most extensively investigated organisational SFSC structure globally. Approximately every tenth benefit has been reported for FM and AFN. Less than every twentieth benefit has been found for LFS, BS and SPG. Figure 1.4 is complemented by Supplementary Table F containing the Shannon entropies which suggests that benefits related to economy, product quality and society have been evaluated most uniformly across all organisational structures. The three organisational structures for which the highest numbers of

[7] We thank an anonymous referee for pointing out that these categories are not on the same level. Creating a unifying framework of the internationally very diverse forms of SFSCs clarifying these hierarchies would be a core task of future research. As the aim of our review is to reflect terminology diversity and avoid misinterpretation of data, the organisational structure to which the benefits are attached to, is the one referred to in the document of origin (i.e., benefits classified as AFN are extracted from documents that reported to analyse AFN). A short explanation of each organisational structure is provided in Supplementary Table G.

Figure 1.4. Short food supply chains benefits per category, chain structure and continent.

benefits have been reported (CSA, others and SSC) are also the ones whose six benefit categories have received the most balanced attention in the literature.

Figure 1.4 shows pronounced differences in the distribution of the number of benefits reported per continent. Forty-four percent of the benefits have been reported for Europe and 24% for North America, which highlights the geographical disparities in SFSC research. CSA and FM have primarily been assessed for North America and Europe. SSC forms are predominant in Europe and Asia, with no records in North America. The SFSC benefits reported for the remaining five organisational structures have been reported for only one or two continents. BS is the only category whose majority of records come from the African continent. SPG has reported benefits in Europe only.

1.3.2 Contributions of short food supply chains to SDGs

The radial tree diagram in Figure 1.5 categorises the SFSC benefits collected in the database and links each of them to the specific SDG target it contributes to reach. The diagram consists of three circles. The innermost circle consists of two sub-circles and shows the reported SFSC benefits for each of the six benefit categories which are marked with the same colour scheme as in the two preceding graphs. A taller bar indicates that more benefits to that SDG target have been reported for that category. The two sub-circles denote whether rich[8] or poor evidence has been reported for the benefits which contribute to a certain SDG target and belong to a certain benefit category.

The middle circle - containing the numbered targets - connects these benefit categories to the SDG target which they contribute to. A thicker (longer) circle segment indicates that a higher number of SFSC benefits (distinct benefit categories) has been reported for that target. The outermost circle names the SDGs which the targets shown in the middle circle belong to. A longer outermost circle segment indicates that more benefit categories relating to more targets have been reported for this SDG, i.e., the knowledge on SFSC benefits per benefit category and target of this SDG is more encompassing and more diverse.

[8] Rich evidence refers to those targets for which 90% of the total benefits have been reported as outlined in Supplementary Table J. For the SDG targets for which the benefit numbers are mentioned in the outer innermost circle, rich evidence of the contribution of SFSCs to reaching the SDG targets has been reported in the literature. For the SDG targets for which the number of benefits is mentioned inside the inner circle, poor evidence of the contribution of SFSCs to reaching the SDG targets has been reported in the literature. Supplementary Table K briefly describes each SDG target.

The outermost circle shows that the richest evidence exists for SFSC benefits relevant for SDG 2 “zero hunger” (50% of all); 174 benefits are relevant for five targets of this SDG. SDG 11 “sustainable cities and

Figure 1.5. Associations between SFSC benefits and SDGs.

Source: Authors.

communities” is the sustainability goal for which the second most diverse evidence (82 benefits) has been reported. SDG 12 “responsible consumption and production”, generally linked to food systems through food losses and waste (Munir, 2022), is connected to 29 benefits mostly through SDG 12.8, which aims to create awareness for sustainable development. SDG 10 “reduced inequalities” appears to be linked to 23 positive effects of SFSCs, particularly via target 10.2 (promoting social, economic and political inclusion).

The middle and innermost circles of Figure 1.5 show that SFSCs have been reported to help achieve 26 SDG targets, for 10 of which rich evidence exists.[9] Most benefits have been reported for the potential of SFSCs to facilitate links between urban, peri-urban and rural areas (SDG 11.a), to provide nutritious, seasonal, and sustainable food that is accessible to consumers and that can improve the provision of adequate food to all (SDG 2.1) and to foster environmentally and socially related sustainable agricultural practices to improve the sustainability of food production systems (SDG 2.4). Rich evidence on the role of SFSCs has also been reported for topics that play important roles in national agricultural and food system policymaking, such as farm income (SDG 2.3), awareness of food sustainability (SDG 12.8), safeguarding cultural and natural heritage (SDG 11.4) and the proper functioning of food supply chains (SDG 2.c). For most of these 26 targets, only one or two benefit categories have been reported in the literature. For ten targets, only scattered evidence has been reported in the literature thus far. More than 3 different categories are associated with targets 2.1, 2.4 and 11.4.

1.3.3 Contributions of short food supply chains to MUFPP goals

The radial tree diagram in Figure 1.6 categorises - in a similar way as Figure 1.5 does - the SFSC benefits reported and links each of them with the specific MUFPP RAs it contributes to reach. The figure has the same structure as Figure 1.5. The outermost circle shows that the richest evidence exists for SFSC benefits contribute to MUFPP category "food production" (30% of the total), as 105 benefits are associated with 5 RAs of this category. "Social and economic equity" is the MUFPP category for which the second most comprehensive evidence (104 benefits) has been reported. "Sustainable diets and nutrition" relates to 101 benefits across four RAs, mostly via RA 7 on "sustainable diets". For these three categories, the benefits associated with them are also most diverse. Benefits linked with the "food supply and distribution", "governance" and "food waste" categories appear to be less connected to SFSCs.

[9] Supplementary Table I gives a complete inventory of which SDG target each benefit is associated with.

The middle and innermost circles of Figure 1.6 reveal that SFSCs have been reported to help achieve 18 of the 37 RAs, for 9 of which rich evidence exists.[10] Most comprehensive evidence has been reported for promoting sustainable diets (RA 7), developing opportunities for improved land management and ecosystem services (RA 22) and providing food producer services such as safe market and resource access, training, and

Figure 1.6. Associations between SFSC benefits and MUFPP Recommended Actions.

Source: Authors.

assistance to create economic solidity (RA 24). The evidence on the merits of SFSCs is most diverse for RA 7, as this action is associated with benefits belonging to all six categories. There is also rather diverse evidence for the central role of SFSCs in encouraging networks for participation and social inclusion in food systems

[10] Rich evidence refers to those targets for which 90% of the total benefits have been reported, as outlined in Supplementary Table L. Supplementary Table M briefly describes each RA. Supplementary Table I gives a complete inventory of which MUFPP RA each benefit is associated with.

(RA 18), stimulating participatory education, knowledge sharing, awareness building and cultural contamination (RA 19), promoting decent employment (RA 16) and improved infrastructure for food market systems (RA 32). Finally, rich evidence exists on the capacity of SFSCs to address food-related diseases (RA 8) by pushing consumers to have healthier diets and to strengthen solidarity economic activities (RA 17). For the 9 remaining RAs, 5 RAs are linked with a maximum of 3 benefits each, and 4 RAs are linked with between 6 and 10 benefits.

1.4 Discussion and conclusions

1.4.1 Summary of the evidence on short food supply chains benefits

The current knowledge on the benefits of SFSCs reported in 69 documents connects to 12 of the 17 SDGs. However, approximately 92% of these connect to only five SDGs. SDG 2 (zero hunger) dominates, as 50% of the reported benefits are linked to it. The insights on SFSC benefits gained and reported so far connect to only 15% of all 169 SDG targets, and for only 6% of them is the existing evidence comprehensive. For 16 more targets the current evidence on the contributions of SFSCs to them is scattered, while no benefits have been reported for the remaining 143 targets. Although current knowledge on the benefits of SFSCs links to all six categories of MUFPP interventions, 90% of them connect to "food production", "social and economic equity" and "sustainable diets". The benefits assessed in the literature link to 18 of the 37 RAs. Among these 18, rich evidence exists for only 50% of them.

Most of the benefits reported focus on the positive effects of SFSCs on society in general as well as on their beneficial economic implications and reduced environmental impacts. These focuses coincide with the three sustainability dimensions that are most commonly investigated in food systems (Alves and de Oliveira, 2022; Doernberg et al., 2022). The statistical evaluation via the Shannon index shows that the existing scientific publications have not given equal attention to SFSC benefits across sustainability dimensions. Benefits relating to the society, space and time and information categories have been addressed unevenly.

Reproducible evaluations of causal links between SFSCs and their benefits as well as comparisons of positive effects in terms of some generally applicable metrics that quantify benefits' quality and quantity are missing in this literature. Only six of the 348 benefits reported are deduced from quantitative analyses implying a substantial need for quantification. Such quantifications would create transparent evidence for determining which of the six sustainability dimensions and their subcategories provide most benefits to societies. Such insights would also create value added for policy-makers when it comes to taking decisions in favour of or against short food supply chains.

Across almost all organisational types of SFSCs, benefits to society have been assessed most frequently. For alternative food networks and box schemes the economic benefits and product quality benefits are most often assessed, respectively. In line with Chiffoleau and Dourian (2020), we confirm that most benefits have been reported for community-supported agriculture while very few benefits have been reported for box schemes and solidarity purchasing groups.

Geographically, the assessment of the positive effects of SFSCs is concentrated to industrialized countries in Europe and North America (68% of reported benefits). For four of the six continents, barely any evidence on the positive effects of SFSCs has been reported. Especially for Africa, the topic of SFSCs has barely been assessed so far – at least not using the terminology which is being used for this research in Europe and North America. Most of the focus has been placed on the effects of establishing modern marketing channels which mirror the large-scale food retailing structures of industrialized countries (Maertens et al., 2012; Rao and Qaim, 2011). This lack of evidence contrasts with the supposedly frequent incidence of SFSCs around the globe, many of which are traditional chains in the Global South (FEWS NET, 2022) which are often short, local and informal and dominate food provision (Nickanor et al., 2019). However, literature on comprehensive measurements of the length and structure of supply chains by food category or country, such as King et al. (2010) or Low and Vogel (2011), appears to be scarce.

The systematic review of documents suggests that the overwhelming majority of the benefits of SFSCs have been evaluated by qualitative analyses, of which surveys and interviews have been the most widely adopted methods as found by Michel-Villarreal et al. (2019). The scientific output on the topic has been growing on average by 23% per year reaching 69 documents at the end of 2021. The impact of this literature on the scientific debate has been growing each year by 40% on average reaching 265 citations at the end of 2021. This strong increase in the attention of research as well as in scientific impact developed in parallel with an intensifying societal debate about SFSCs in Europe and North America.

1.4.2 Limitations and future research

Any analysis of such an heterogenous topic can only be carried out subject to limitations which also bring new research opportunities. Not considering important keywords used might have caused the exclusion of relevant documents. The restriction to English-language documents might have ignored core organisational reports in national languages. Moreover, the quality of each literature review depends on the limitations in the analysis or transparency of communication of the included documents. For example, some of the articles included in our database do not explicitly mention the procedure used for data collection and analysis.

Nevertheless, due to the aim of conducting an exhaustive review of the existing documents, they were included despite potential weaknesses in the rigour of their analyses.

As most of the current literature is based on qualitative analyses, the association between benefits and specific policy goals can also only be qualitative. Hence, we stress that methodologically solid research that quantifies effects and clarifies causal linkages, for example, via randomised controlled trials or similar approaches for the assessment of the causal impacts of SFSCs, needs to be added to the current literature to ensure the quantification of effects and to guarantee the comparability of results across commodities and countries.

1.4.3 Implications for the science-policy research agenda and policymaking

Knowledge on the links between SFSCs, SDGs and the MUFPP supports policymakers in increasing their science-based capacity for making use of SFSCs toward more sustainable food systems as requested by the UN Food Systems Summit (UN, 2021). Our results have implications both for local and national policymakers. Municipal policy makers willing to develop an urban food policy, can use the results of this analysis to know that investing in SFSCs will help the city in meeting certain SDGs and MUFPP goals. In turn, when they plan to prioritize advancement of some of these sustainability goals, they can use our results to know to which extent SFSCs can be an opportunity to do so.

Furthermore, our findings highlight a set of future research directions to be explored. First, the objective of this study is to exhaustively revise and inventory existing knowledge on the positive impacts of SFSCs, as these benefits dominate the discourse in industrialized countries' societies and policymaking. A complementary analysis addressing the negative effects and costs of SFSCs and how they challenge progress towards reaching sustainability goals is needed to complement the picture. This would allow policy makers and other stakeholders to understand trade-offs and opportunities across countries and SFSCs structures. Such an analysis should ideally be accompanied by creating a unifying framework of the internationally very diverse forms of SFSCs which will ideally be used as the global reference system for analyses and narratives about SFSCs.

Second, for fostering the science-policy research agenda future research should focus on analysing the frequency and scope of the various types of organisational SFSC structures across countries and continents. Such an overview could estimate the size of agricultural land operated under each type or the number of employees involved to obtain measurements of the current scope of each SFSC type. This would allow to assess to what extent the distribution of scientific interest corresponds to the distribution of land or human

capital involved in each type. Most importantly, it would also form a basis for estimating the aggregated benefits resulting from each organisational type and thus pave the way for establishing a powerful concrete measurement of the sustainability contribution and future sustainability potential created by each.

Third, targeted policy making would profit from quantifying positive and negative implications of SFSC and a clarification of causal pathways for being able to conduct evidence-based comparisons of their effects with those of global supply chains as the latter are being increasingly innovated to comply with sustainability standards (Meemken et al., 2021). Qualitative analyses do not, for example, allow to precisely evaluate by how much and in which sustainability dimensions SFSCs are superior or inferior to global supply chains. Any objective assessment and ranking of the effects of competing food marketing channels in terms of CO_2 or the water footprint, for example, or the social benefits created must be based on quantification. The development of such measurements would also facilitate the quantification of the contributions of SFSCs to achieving specific policy goals of the SDGs and MUFPP so that their attainment can be more precisely operationalised than currently.

Finally, research on the characteristics of SFSCs should move beyond industrialized countries to analyse the characteristics of this specific food marketing approach - embedded in a country's economic system - in the Global South, where the preservation of traditional knowledge and farming techniques might be lost during the ongoing food retail transition (e.g., Rischke et al., 2015) if not documented. Thus, comparative analyses of SFSCs for similar commodities in dissimilar economic systems and political contexts may constitute a major step ahead for understanding how the characteristics of economic and political systems condition the types and magnitudes of the benefits and costs of SFSCs as, for example, assessed by Schipmann and Qaim (2010) or Short et al. (2021). The above-mentioned inventory of the geographical distribution and size of organisational SFSC types may also lay the foundation for analysis of the facilitating and impeding institutional and socio-cultural factors for the existence of certain organisational types in certain countries. The identification of such general institutional factors would provide substantial value added for policymakers, as it would open practical ways to aid food policy design (González-Azcárate et al., 2023).

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Chapter 2

Does the dishes order in school canteens reduce vegetable waste? A Cluster Randomized Control Trial

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Chapter 2. How changing the meal sequence in school canteens can reduce vegetable food waste? A cluster randomized control trial

Abstract

School canteens are crucial for stimulating sustainable eating habits of children for achieving global sustainability. Using a participatory approach, we co-design a choice-architecture intervention to assess whether inverting the sequence of Mediterranean lunch dishes served in school canteens is effective in reducing food waste. We implement a randomized control trial using 26 Italian schools, creating one of the largest and the most diverse experiment samples achieved so far. Hence, our analysis yields evidence of internal and external validity far beyond existing interventions which consider only a few education institutions without random selection. A food mass flow analysis of the weighed prepared food, serving waste and plate waste per meal course suggests that in primary school canteens 29% of the lunch prepared gets wasted, i.e., 22,000 tons per year in Italy. Big catering providers are found to produce 23% more food waste. Prioritizing the vegetable side dish as first course has heterogeneous effects across school clusters changing the share of plate waste in total vegetable servings between -26pp to +32pp. Also, the side dish plate waste depends on the type of vegetables served. Differences in lunch implementation and food and eating environments across schools appear to dominate the effectiveness of the intervention, hence, no treatment effect is found for the full sample. Upscaling of the dish reordering as a binding policy strategy for the entire regional territory is therefore not recommended. We conclude that policymakers and researchers should more often use citizen science to maximize benefits for society.

Keywords: intervention; food waste; Mediterranean diet; school meal; SDG 2; sustainability transition.

2.1 Introduction

Schools are recognized as key intervention options for developing pupils' healthy eating behaviors in line with the Sustainable Development Goals of the United Nations Agenda 2030 (WFP, 2017). They can contribute to achieving food security and improved nutrition (SDG2) and reduce food losses and waste (SDG12). The food consumption patterns children adopt at an early age can critically influence their lifestyle into adolescence and adulthood (Bonomo and Schanzenbach, 2024). As school canteens host children of various socio-economic backgrounds, they have the potential to play a central role in sustainable food system transitions (Maietta and Gorgitano, 2016).

Recent research has underlined two prominent challenges to be addressed by food policies in school environments, namely the large amount of food wasted and the insufficient consumption of vegetables. Boschini et al. (2018) reports that around 41% of the food which is prepared for school consumption is wasted. This does not only undermine an adequate nutritional intake of children (Chen et al., 2020) but has also proven to create adverse environmental (Zhu et al., 2023) and economic impacts of school catering (García-Herrero et al., 2019).

For example, in Italy only 9% of children consume adequate amounts of fruits and vegetables (Nardone et al., 2019). Most of the food thrown away belongs to these two categories (Boschini et al., 2018). In this context, the government of Emilia-Romagna, a region in the northeast of Italy accounting for about 8% of the country's population, planned to design school food policies to reduce food waste of vegetables and increase their consumption. Thus, the government aimed to obtain evidence-based insights on the effectiveness of interventions tackling vegetable food waste in primary schools (Emilia-Romagna region, 2023). To this scope a living lab was activated by involving stakeholders from the school food sector of Emilia-Romagna with a citizen science approach (Emilia-Romagna region, 2023).

Kovacs et al. (2020) point out that many researchers and policymakers are working to design strategies for boosting sustainable consumption patterns in schools. Several information-based interventions such as educational programs (Boulet et al., 2022; Mariam et al., 2022; Piras et al., 2023), cooking shows (Neyens and Smits, 2017) or cartoon exposition (Binder et al., 2019) have been studied.

In parallel, choice-architecture interventions have been increasingly set up as they are often low-cost and easy to implement (Szaszi et al., 2018). The choice-architecture indicates the physical or social setting in which decisions are made at the status quo. This can include the characteristics of the default setting, the number of options, the attributes, or the description of these options (Thaler & Sunstein, 2008). Considering that individuals make nonoptimal decisions due to bounded rationality and uncomplete information, the

approach is based on the principle that a change in the status quo of a situation can lead to change in individual choices fostering a more favorable outcome (Thaler and Sunstein, 2008). When identifying a specific behavioral problem, choice-architecture interventions can target that behavior by changing the way options and decision-making formats are arranged, e.g., in the eating environment (Münscher et al., 2016).

Not surprisingly, a set of interventions modifying the choice-architecture (i.e., the status-quo setting) of school meals have been found effective to incentivize vegetable intake and reduce food waste (Appleton et al., 2016; Cohen et al., 2021; Graça et al., 2023). Strategies include rewards for eating vegetables (Mazzeo et al., 2017), role modelling from adults (Machado et al., 2020), introduction of motivational stickers (Gwozdz et al., 2020; Thapa and Lyford, 2018) and plate size change (Qi et al., 2022; Spill et al., 2010). It has been reported that effects of these interventions are reinforced in public canteens since children are exposed to greater peer pressure towards desired behaviors (Landwehr and Hartmann, 2024; Zhang et al., 2023). On top of that, various analyses modified the placement order of vegetables and fruits in the meal order as a strategy to raise acceptance and intake (see Table 2.1).

Despite the popularity of this latter type of choice-architecture interventions, their scalability into policy recommendations remains limited. Interventions that assess how changes in the placement of vegetables impacts food waste amounts are rare and often limited to few schools or kindergartens (see Table 2.1). Although the randomization of samples is considered the gold standard for evaluating the effectiveness of behavioral interventions (Szaszi et al., 2018), all existing studies on dish reordering interventions selected participant schools via convenience sampling. Only one among the seven most recent publications on the change of the dish sequence (Adams et al., 2015) used limited randomization, but only for selecting participants within schools. Only Cohen et al. (2015) implemented a randomized control trial (RCT) in which randomization regarded only the assignment to the treatment and control group.

Such methodological choices not considering experimental approaches not only weaken the internal validity of the analyses conducted, but also limit their potential to deduce policy conclusions at regional or national level as the external validity of the results obtained is not robust (Roe & Just, 2009). Two out of the seven most recent articles listed in Table 2.1 implement several choice-architectures simultaneously which limits the internal validity of the experiments as effects of each single intervention can hardly be isolated. While five of the existing studies target more than 300 children, these pupil numbers are spread across no more than 8 schools (Cohen et al., 2015) which reduces the potential to capture heterogeneities across school canteen eating environments and providers. The often-small sample sizes of schools considered so far, hence,

limit the potential of extracting generalizable patterns which could serve for inferring robust policy conclusions (Peters et al., 2017).

Although direct measurement via weighting is the most common method to assess food waste quantities, three out of seven studies rely partially or exclusively on the counting of food items. Cohen et al. (2015), and Spill et al. (2010; 2011) provide results either in cups or portions of vegetables which are hardly comparable internationally, since these measurements have differing metric equivalents depending on their geographical context. The measurements used and treatment effects of the interventions reported are quite diverse, but results are always supported by significance tests. As all of the existing studies focus on North America their international generalizability is limited as the country has fairly specific eating culture so that the practical implementation of school meal catering, and the associated eating environments differ from most other countries and diet patterns.

Given this background, we have been commissioned from the regional government of Emilia-Romagna to assess whether prioritizing the vegetables side dish as first course does avoid food waste and raise vegetable consumption and, hence, can represent a scalable policy strategy. For three consecutive weeks (i.e., 15 consecutive school days) pupils in the schools randomly assigned to the treatment group have been served a lunch menu in which the side dish made of vegetables was served as first course before the rest of the meal. As public authorities should design effective policy strategies ideally based on context-based and robust scientific evidence (Filippini et al., 2018), our contribution extends the present literature by adding an impact evaluation of a choice-architecture intervention on vegetable food waste. We, hence, provide the first analysis which extends the evaluation of school lunch dish order interventions beyond North American food consumption habits, namely to the Mediterranean region with its distinct dietary pattern (Alexandratos, 2006; González Turmo, 2012; Romagnolo and Selmin, 2017).

Secondly, we adopt a participatory approach for the co-design of the intervention which guarantees direct access to personnel involved in school canteens with up-to-date information providing an accurate applicability of the intervention to the local context through a tailored implementation strategy. Third, we conduct a cluster Randomized Control Trial (cluster RCT) of so far unequaled comprehensiveness which randomly selects schools and randomizes them across control and treatment groups. This approach enables us to establish robust internal and external validity of our results allowing for robust causality and generalizability claims. The cluster setup is necessary as the intervention of interest to the involved authorities was to be implemented at school level while the statistical analysis needed to be conducted at individual class level. By opting for a stratified random selection of schools to control for unobservable factors

of pupils' food choices (Custodio et al., 2021) related to different characteristics of school canteen services in the different strata we guarantee internal validity. This results in the second largest sample of pupils (760) and covers the by far largest heterogeneity across schools achieved so far (26 schools). Data on food waste are objectively collected through weighting expressed in kilograms to minimize errors and maximize international comparability (Reynolds et al., 2019) providing a chomprensive and accurate measurement of food consumed and wasted.

Table 2.1. Existing articles on choice-architecture interventions focused on the placement of dishes in schools to improve children's vegetable consumption.

Article	Intervention	Experimental design	Random selection of the sample	Random assignment to treatment/control group	Sample	More interventions combined	Food waste measurement methods	Measures	Effect	Country
Adams et al. (2015)	Differing salad placement: inside or outside of the serving line	Cross-sectional study	No for schools, yes for children	No	533 students attending 6 middle schools	No	Weighting	Amount of fresh F/V taken, consumed, and wasted	Students with salad bar outside the line wasted significantly less F/V than those with salad bars inside the line (30% vs 48%)	Arizona (USA)
Cohen et al. (2015)	Strategies include offering vegetables at the beginning of the lunch line	Randomized clinical trial	No for schools, no for children	Yes	2638 students in 8 elementary and middle schools	Yes	Weighting	Weight of plate waste	Vegetable consumption significantly increased on average of max 0.16 (95% CI, 0.09-0.22) cups per week	Massachusetts (USA)
Thompson et al. (2017)	Strategies include placement of fruit and vegetables at the beginning of the lunch line	A pre-post prospective evaluation	No for schools, no for children	No	2 elementary schools, 373 students	Yes	Weighting	Weight of plate waste and number of students consuming a portion	Average vegetable consumption increased by 1.1 g (p = .27), not significantly. Number of students taking vegetables increased, but not significantly (p = .28). The number of students	Minnesota (USA)

									consuming an entire serving of vegetables (p = .45) increased but not significantly	
Elsbernd et al. (2016)	Serving raw vegetables while children wait to receive the rest of their lunch meal	Within-subjects experimental design	No for schools, no for children	No	1 kindergarten, 532 students*	No	Weighting and counting food items	Number of pieces left in a given cup from the starting number of pieces in a full portion	The total vegetable intake significantly increased from 4.0 to 5.4 g per child	Minnesota (USA)
Redden et al. (2015)	Vegetables provided as a first item of the menu in isolation	Observational field study	No for schools, no for children	No	800 students in 1 elementary school	No	Weighting and counting food items	Number of uneaten vegetable and number of students taking vegetables	Significant increase in vegetables consumption of over 430%	Minnesota (USA)
Spill et al. (2010)	Serving different portion size of vegetables at the start of a meal	Within-subject crossover design	No for schools, no for children	No	51 children aged 3–5 years in one school	No	Weighting	Weight and energy intake of carrots and all other foods as well as total vegetable intake and total food and energy intake at the meal	Vegetable intake increased significantly of 1 portion per child	Pennsylvania (USA)

Spill et al. (2011)	Serving different portion of tomato soup at the start of the meal	Within subject cross-over design	No for schools, no for children	No	72 children aged 3-5 years in one school	No	Counting food items	Soup intake, vegetable intake, and meal energy intake	Significantly increased vegetable intakes up to 1 additional portion	Pennsylvania (USA)
Our paper	Serving vegetables as a first dish	Cluster Randomized Controlled Trial	Yes for schools, no for children	Yes	760 third grade students in 39 classes of 26 elementary schools	No	Weighting	Weight of prepared food, plate waste and serving waste	On the full sample no statistically significant changes are detected in the plate waste share of vegetables, but significant heterogeneous effects are observed across school clusters.	Italy (EU)

*Since different numbers of participating students are provided, we included the number of students present at the first day of data collection (control).

Source: authors.

2.2 Theoretical background

Choice-architecture interventions start from the premise that people are bound in their ability to make rational decisions (Thaler and Sunstein, 2008). They hypothesize that individuals' choices are not always driven by rationality, but often result from interactions of contextual factors on which it is possible to intervene to change people's behaviors. Using the Motivation-Opportunity-Ability framework, they are often categorized in the literature as motivation factors (i.e., the willingness of individuals to perform actions), opportunity factors (i.e., availability and accessibility of materials and resources required to take actions) and ability factors (i.e., person's proficiency of taking an action) (MacInnis et al., 1991).

Figure 2.1. Overview of the factors influencing food consumption quantities.

Source: Authors based on Wansink (2004).

In the context of personal choices regarding food consumption, the motivations, opportunities and abilities of individuals relate to consumption norms as well as characteristics of the eating and the food environments

(Figure 2.1). Hence, people's consumption quantities and the corresponding food waste amounts can be influenced by the atmosphere in which individuals eat (e.g., light, noise), by the effort they need to put into consumption (e.g., easy access to certain foods), by the social context (e.g., peers influence), and by external distractions (e.g., watching TV). Additionally, they make their choices based on how the food is presented in terms of salience, variety, size of portions, stockpiling and size of containers. Figure 2.1 shows that also consumption norms such as dietary habits (e.g., food preferences), educational or cultural frames (knowledge and meanings of food), and social and biological needs (e.g., hunger, age, gender) play a role (Story et al., 2002).

In school canteens, those factors have complex interrelationships, which makes it hard to find univocal consensus on why children eat or discard foods. Steen et al. (2018) Steen et al. (2018) report that noisy and stressful school canteens tend to increase the amount of food discarded by children, while the presence of teachers during lunch time increases consumption (Liz Martins et al., 2020) since children are less distracted. Consumption norms have mostly to do with the quantities children are used to eat which ultimately results in individual hunger levels (Zhao et al., 2019), or the type of food they are most exposed to at home, which often results in disliking certain foods. The awareness of and education about healthy and sustainable diets, for example on adequate fruits and vegetables intakes, are also affecting consumption levels (Haß and Hartmann, 2018; Myers et al., 2018). Moreover, the location of schools in either urban or rural municipalities showed a relation with children's food consumption (Boschini et al., 2020). The menu composition including the order of courses, the meal presentation and plate size are some of the environmental factors more often mentioned to affect school children's consumption quantities (Falasconi et al., 2015; Boschini et al., 2020; Qi et al., 2022). The literature also reports several operative circumstances that are associated with children's food consumption and waste. For instance, the more time children have for consuming their lunch, the less they waste (Cohen et al., 2016). The recess organization (whether the break is pre or post lunch) as well as the catering providers' management have been found to contribute directly to children's food consumption volumes (Boschini et al., 2020; Price and Just, 2015).

2.2.1 Literature review on dish order and vegetable waste

To target the bottleneck of inadequate vegetable consumption and waste, research agrees that changing the default sequence in which foods are served (i.e., the structure of food assortments) matters since people tend to accept the default option (Münscher et al., 2016; Carlsson et al., 2021). One of the main reasons reported for school children to leave vegetables on their plate is that they are too full to eat (Ilić et al., 2022). Therefore,

if those vegetables will be served first, they might require less eating effort to be consumed (i.e., students have easier access to them – see Figure 2.1), or children eat larger quantities of them due to their sense of hunger (Wansink, 2004) and to the absence of competing foods (Spill et al., 2011). Both spatial and temporal anticipation have been found to increase vegetable consumption and reduce waste (see Table 2.1). Spatial anticipation relates to the fact that increased visibility of food leads people to eat more of it (Wansink, 2004). Examples in school cafeterias are the placement of salad bars inside vs. outside the serving line, which resulted in increases of salad consumption of 35%, but also an additional 18% of salad waste because students took a lot more fruits and vegetables (Adams et al., 2015).

Temporal anticipation is based on the notion that children will spontaneously eat the first food placed in front of them to fulfil hunger (Roe et al., 2012). Serving vegetables as a first course, in combination with other strategies (like long-term exposure to intervention), has been shown to increase vegetable consumption by one sixth of a cup per week on average (Cohen et al., 2015). Thompson et al. (2017) find that serving vegetables at the beginning of the lunch line together with other choice-architecture strategies increases – although not significantly – average vegetable consumption by 1.1 grams per person and day. The supply of raw vegetables to children while they wait for other foods was observed to quadruple the number of children at least trying those vegetables (Elsbernd et al., 2016). Redden et al. (2015) showcased that serving either carrots, broccoli or cauliflower to children at the start of the meal without other more preferred foods always had the effect of increasing intakes both in the short and in the long run. By investigating interactions between plate size and anticipation, Spill et al. (2010, 2011) find that the bigger the portions of vegetables offered as a first course of the school lunch the larger the intake.

2.2.2 School canteens in Italy

In Italy, the functioning of school canteens needs to follow the guidelines of the Italian Ministry of Health (2010). The dietary pattern, the suggested frequency of the preparation of different food categories, as well as the envisaged nutritional intakes are based on the Nutritional Recommended Intake Level for the Italian population (LARN) (Italian Society of Human Nutrition, 2014). Emilia-Romagna, as all Italian regions, translated the national guidelines into a regional operational framework, which is applicable to all its provinces and guarantees the same food procurement practices and sanitary standards across its territory (Regional Sanitary Service ER, 2023).

Every region of Italy is split into sanitary districts called *Aziende Unità Sanitaria Locale* (AUSL), 8 in Emilia-Romagna, which have the role of approving the menu, supervising the menu implementation, monitoring the

food quality, and developing educational food activities within their districts. This implies a certain degree of heterogeneity in the way schools deliver their meals across different AUSL. School lunch provision becomes more heterogenous within an AUSL as school canteens are served by different catering companies.

The guidelines require that a school meal in Italy consist of a first dish (FD), a second dish (SeD), a side dish of vegetables (SiD), bread (B) and fruits (F). This structure is culturally embedded in the Mediterranean diet (MD) characterized as a nutrition pattern rich in fruits, vegetables, breads and other non-refined cereals, beans and nuts. Local and seasonal products are predominantly used, while dairy products, fish, milk and meat are only moderately consumed (Alexandratos, 2006; González Turmo, 2012). Olive oil is the primary source of fat (Willett et al., 1995).

Pupils are accustomed to first eating the carb-based FD alone. Then, after a fixed period of time that changes from school to school, they receive the protein-based SeD together with the plant-based SiD. FD, SeD and SiD are served in this order in virtually all schools. Only in rare situations these lunch components are served at once in a single tray with the recommendation of eating them in that order. On an occasional basis, the guidelines allow schools to serve a single dish that takes the place of FD and SeD together, accompanied by the SiD only.

Menus are predetermined and usually rotate on a weekly basis to guarantee a varied diet. Menu rotation can last from 4 up to 8 weeks depending on the catering provider. In contrast to North American settings where most of the existing studies have been conducted (see Table 2.1), Italian school children have no choice on which food to select but are exposed to the type and sequence of foods the way they are served to them which is predetermined by the menus approved by the AUSL.

Therefore, we expect that in Emilia-Romagna school canteens if vegetables are served first and children have no other foods to choose from, they consume the SiD in higher quantities compared to the normal setting where vegetables arrive as third course only. As we directly measure both served food and food waste of school children (see section 2.3.2), we assess the intervention results based on the share of plate waste in the amount of food children have received. This approach provides us not only with a precise measurement of school canteen waste but also with an indirect measurement of pupils' consumption. Hence, we empirically assess the following hypotheses:

H1. Serving the side dish of vegetables (SiD) first leads to a lower share of its served amounts wasted.

Current research also questions whether offering vegetables first has an influence on consumption levels of other meal components (Elsbernd et al., 2016; Redden et al., 2015). Satiety from vegetables can induce individuals to consume less of the following courses. To evaluate the secondary effect of the intervention

investigating on the consumption of FD and SeD is hence of particular interest[11]. Therefore, we also investigate:

H2. Serving the SiD first increases plate waste share of the first dish (FD) as well as the second dish (SeD).

Finally, Redden et al. (2015) state that the effectiveness of the serve-first strategy is not dependent on the type of vegetables. Knowing whether choice-architecture interventions work only for specific vegetables is key for real-life settings so that we also test:

H3. The shares of side dish of vegetables not eaten by pupils does not depend on the type of vegetable.

Considering that the existing studies listed in Table 2.1 assess intervention impacts for an average sample of 3 schools, and that each stratum of our sample also includes on average 3 schools, we test these three hypotheses first at the strata level (i.e., for all schools per AUSL) and afterwards for the full sample of 26 schools. The results disaggregated by AUSL provide insight on regional heterogeneity of effects, while results at the level of the entire sample allow robust conclusions about the external validity and scalability of results.

2.3 Methods

We implemented a choice-architecture intervention in randomly selected primary schools in the Italian region of Emilia-Romagna between October 2022 and March 2023. The schools have been randomized across control and treatment groups. The intervention consisted in changing the lunch component order from the standard FD – SeD – SiD to SiD – FD – SeD, that is, serving the vegetable side dish first for children in 3rd grade attending the canteen all 5 days of the school week. The intervention has been co-designed with a participatory approach based on Citizen Science and Responsible Research & Innovation principles (Robinson et al., 2018). We follow the internationally recognized spectrum of public participation (IAP2 International, 2018) to define and develop the participation process reflecting the five principles of (1) information, (2) consultation, (3) involvement, (4) collaboration, and (5) empowerment. About 25 stakeholders from the school food sector of Emilia-Romagna (documented in Supplementary Table A) have been involved in three different online workshops between June and July 2022[12].

[11] Bread and fruits were excluded from the analysis considering that their serving order is more likely to differs from school to school and the heterogeneity of modalities make these elements not suitable for a standard choice experiment setting. Bread can be served either with the FD, or with the SeD. Fruits are either served as a last menu item or are offered as a mid-morning snack, depending on the AUSL decision. Bread and fruits are sometimes even brought home as afternoon snacks.

[12] Supplementary Table B and Supplementary Figure A detail the full stakeholder participation process. The data gathering protocol was approved by the University of Bologna Ethics Committee on 25 October 2022 (Approval N. 0299280).

2.3.1 Sampling design

As lunch catering for pupils is organized at school level in Italy, the intervention had to be implemented at school level so that schools are the sampling units. We consider the largest number of schools used achieved so far in comparison to previous studies (Table 1). This helps us to account for institutional heterogeneity due to differences in regulations defined by each AUSL and across practical lunch implementation practices. Following the Consolidated Standards of Reporting Trials (CONSORT; Moher et al., 2001), this study uses a cluster RCT with schools being the units of randomization (clusters) and all third-grade classes of a given school the units of analysis. Compared with individual RCTs, cluster RCTs require more participants to obtain equivalent statistical power as individuals in the same cluster tend to be correlated (Campbell et al., 2004), hence, also offer the advantage to obtain robust external validity of the analysis about the generalizability of intervention impacts.

The region of Emilia-Romagna has 946 eligible primary schools. The intervention design excludes those schools which have no canteen or whose third-grade classes are composed of pupils of different ages. Both exclusion criteria were essential to guarantee the applicability of the intervention. The sample size of 26 schools among the eligible ones has been calculated following Ahn et al. (2015) and Campbell & Walters (2014). Based on previous studies we expect the generated food waste per capita between 130 and 150 gr/day and a minimum detectable effect of food waste reduction between 15 to 25 g (Boschini et al., 2018; Antón-Peset et al., 2021). We follow Iaia et al. (2017) and assume an intraclass correlation coefficient between 0.01 and 0.05. The sampled schools were stratified with respect to the eight AUSL districts of Emilia-Romagna as these authorities govern the school food catering at local level. From the 8 strata (each of them having different territory and population) sampling units were selected proportionally to the size of the population in each stratum. In the first round of sampling, 3 schools refused to participate and were resampled to reach the intended sample size. The selected schools were then randomly assigned to the treatment or the control group without masking. To guarantee the applicability of the intervention, for each school only third-grade classes eating at school from Monday to Friday were included. Hence, 10 third-grade classes in the 26 sampled schools were excluded. In the treatment (control) group 20 (19) eligible third-grade classes in 13 (13) schools participated in the experiment (see Supplementary Figure B for the locations of the schools within Emilia-Romagna).

Schools of the treatment and control groups are balanced in terms of number of students per school, class size, location of the school (urban vs. rural, costal vs. inland) as well as catering providers (Supplementary Table C). The treatment group experienced the intervention SiD – FD – SeD of serving the SiD as first

component of the meal for three consecutive weeks. The control group did not experience any change in the menu serving order FD – SeD – SiD during that period. Each phase of the experimental design is displayed in Figure 2.2.

Figure 2.2. Sampling design based on the CONSORT guidelines (Moher et al., 2001).

Source: Authors.

2.3.2 Intervention co-design and data collection

The co-design process led to several crucial decisions for intervention design. First, the consensus emerged that 3rd graders are the best choice for the target population as they have sufficient autonomous capacities in eating skills with respect to 1st and 2nd graders, while, at the same time, they are not old enough to experience pre-teen transformations and growth. Moreover, the two more years of primary school they attend allow for possible follow-up studies. Second, compromising between stakeholders' priorities and implementation challenges led to the choice of the reprioritization of the dish order by serving the side dish first as the most relevant and feasible intervention design from several options which would address vegetable intake or food waste. Third, the duration of the intervention was chosen for meeting two competing goals, namely allowing children to have sufficient time to adjust to the intervention menu before

evaluating its impact on food waste and proposing an approach feasible for school canteen providers. Due to these reasons the consensus among the 25 stakeholders involved in the co-design process was to implement the intervention for 3 weeks.

Measurement of food waste quantities was carried out at baseline (T0) in which the normal menu was served to all 26 schools, and during the third week of the intervention (T1) which only 13 schools received. At T0 as well as T1, measurements lasted for five consecutive school days from Monday to Friday for both the treated and the control group. The stakeholders also indicated that entire classes should be defined as units of analysis in order to make precise weighing feasible as space and time limitations would usually not allow for individual measurements per pupil. Although school staff was informed about the intervention, pupils were not made aware of the background of the experiment to avoid changes in their consumption behavior prior to the menu re-ordering in order to achieve highest possible internal validity.

To minimize biases in food waste measurements prior to and during the intervention due to different palatability of recipes, it was important to have the same menu at T0 and T1. As described in section 2.2.2, the menu in each school rotates on a weekly basis for a minimum of 4 weeks repeating during the school year. Hence, T0 and T1 were set for the identical weeks of two consecutive rounds of menu rotation in order to have pupils exposed to the same menu in both measurement weeks. Once T0 and T1 were selected for each school, the menu intervention was implemented starting two weeks prior to T1 in the treatment group. Following this structure, the normal menu was served to children in the control and treatment groups in the week following T0. The structure of the intervention design and the measurement steps are shown in Figure 2.3 for a standard school with a 4-weeks menu[13].

Schools were asked to separate the prepared food for each 3rd grade class. Before lunch got served, we weighed the food prepared (*PF*) intended to be served to an entire class defined as the amount of food prepared to be consumed (García-Herrero et al., 2021). Hence, the *PF* was separately measured for each of the 39 3rd grade classes. After lunch, we weighed food waste - being the food appropriate for human consumption being discarded (FAO, 2019b) - split into the plate waste (*PW*) defined as the amount of edible

[13] For schools having menu rotations of more than 4 weeks, one or more standard menu weeks were implemented before the 3 weeks of intervention menu to respect the same intervention structure.

Figure 2.3. Overview of the data collection process.

Source: Authors.

food served and left uneaten in the plates (Chapman et al., 2019) and the serving waste[14] (*SW*) referred as the amount of food that has not been served and remains in the serving tray (García-Herrero et al., 2021). As children were asked to put the individual plate waste into a single basket for the class, a single plate waste measurement for each third-grade class was obtained for a given day. Similarly, the serving trays containing the serving waste were separated for each third-grade class so that we weighed the serving waste aggregated at class level for each third-grade class in each school.

Following Boschini et al. (2018) *PF*, *PW*, *SW* were separately weighed for the FD, SeD, SiD, using commercial digital scales for treatment and control groups alike. The weights of consumed food $w_{c,CF}^{u,d}$ and served food $w_{c,SF}^{u,d}$ at class level have not been measured but can be derived from *PF*, *PW* and *SW* via equations (1) and (2) and illustrated in Figure 2.4:

Eq. 1 $$w_{c,PF}^{u,d} = w_{c,SF}^{u,d} + w_{c,SW}^{u,d}$$

Eq. 2 $$w_{c,SF}^{u,d} = w_{c,CF}^{u,d} + w_{c,PW}^{u,d}$$

where w denotes the total weight in grams per course $c = \{FD, SeD, SiD\}$ and each measured food waste step $s_m = \{PF, PW, SW\}$ (see Figure 2.4). For each of the analysis units (classes) $u = \{1,2, \dots ,39\}$ for days $d = \{1,2, \dots , 10\}$ – resulting in 373 observations[15] – all 9 measurements (PF, PW, SW) x (FD, SeD, SiD)

[14] In the Italian context, the food that is not served to pupils is thrown away and not reused due to sanitary rules at national and local level.

[15] 17 of the intended 390 observations are missing due to unplanned local strikes of school staff that caused the unanticipated closure of schools.

were repeated. Hence, a total of 3,357 weight measurements $w_{c,s_m}^{u,d}$ – 1,701 for the treatment and 1,656 for the control group – have been gathered.

Figure 2.4 also highlights the link between lunch sustainability and nutritious diets because the prepared food $w_{c,PF}^{u,d}$ represents the adequate intake quantities of various food types as recommended by nutritionists. This implies, the higher the amount either lost during serving (*SW*) or not eaten by children and discarded at the end of the meals (*PW*), the farer away will be the nutritional quality of the lunches from the ideal recommendations. This in turn means that reducing food waste implies more sustainable and healthier diets. Researchers were appointed in each school to conduct the experiment while catering provider employees and teachers were assigned to supporting roles. Researchers were responsible for the location of food waste bins, for the weighting procedure and data collection. Kitchen employees oversaw the weighting of the *PF*. Teachers supervised the pupils for emptying each course leftovers in a separate basket and guided connected logistical issues providing instructions when needed. Each of these experiment staff received a tailored handbook including all needed instructions.

Figure 2.4. Food mass flows considered in this study for all classes and all days.

Note: The size of the boxes does not represent food quantity of food for each box. Colored boxes indicate measured quantities, while white boxes indicate quantities that have not been measured but are calculated as derivatives. The sizes of the boxes approximately represent the shares of the median food quantities at T0 for all 26 schools in the column total. Note that the weights of FD, SeD and SiD do not exactly add up to the column totals as all values are measured/ calculated medians.
Source: Authors

To account for other factors potentially influencing pupils' food consumption, we selected as many determinants of Figure 2.1 as possible which were measurable at class level. Social distraction and canteen crowding, presence of teachers, education and awareness and school location were quantified by five variables at class level by researchers present during classes mealtime (see Supplementary Table D). All weight data were collected using a digital form accessible via QR code as well as on paper being later added to the digital form by researchers.

2.3.3 Outcome measures

Data has been collected for three complementary groups of variables: food and waste weights following principles established in the literature, a qualitative classification of each of the three dishes as well as qualitative factors potentially influencing consumption volumes as specified in Figure 2.1. For each class the food follows the flow described in Figure 2.4 and equations (1) and (2). Hence, the first variable group consists of the 9 weights (*PR*, *PW*, *SW*) x (FD, SeD, SiD) for each of the 39 sampled classes for each of the 10 considered days. These three weights per class and day for each of the three courses are measured at aggregated class level. Knowing the number of children per class, average quantities of *PF, SF, SW, CF, PW* in gr/pupil within a class have been calculated and used for the analysis.

The second group of measurements categorizes all observed FD, SeD and SiD into the food categories defined by the Emilia-Romagna regional government (Regional Sanitary Service ER, 2023). This categorization of dishes is included to control for the qualitative differences in sensory attributes and plate taste from a children's perspective which connects to the literature as Williams et al. (2005) has shown that children tend to be highly selective in this respect. The categorization allows to assess hypothesis H3 stating that SiD waste does not depend on qualitative differences in sensory attributes and plate taste. Hence for each course category *Ca*, dummy variables $Ca_c^{u,d} = \{1; 0\}$ which take the value 1 if the dish served on day *d* to class *u* belonged to category *Ca* or zero otherwise resulting in 373 indicator variables.

Table 2 presents some descriptive analysis of the resulting 10 FD, 15 SeD and 12 SiD categories focusing on their frequencies observed in our sample. Pasta with veggies, the most popular FD, is served almost 8 eight times the least served one (i.e., pizza). White fresh meat is the most frequently served SeD, and together with cakes (i.e., pies and salty cakes) and fresh fish accounts for 45% of all SeDs served. Raw veggies and salads are by far the SiD most often chosen by schools (see Table 2.2).

Table 2.2. Incidences of food categories across courses.

FD category	#	%	SeD category	#	%	SiD category	#	%
Pasta with veggies	92	25%	Meat (white, fresh)	69	18%	Raw salads	112	30%
Rice	63	17%	Cakes (pies, salty cakes etc.)	51	14%	Carrots (cooked)	53	14%
Soups	61	16%	Fish (fresh)	50	13%	Others	38	10%
Fresh Pasta	52	14%	Cheese (fresh)	29	8%	Fennel (cooked)	32	9%
Pasta with oil	37	10%	Pulses (processed)	28	8%	Cabbage (cooked)	30	8%
Pasta with pulses	21	6%	Meat (beef, fresh)	27	7%	Potatoes (cooked)	30	8%
Pasta with fish	16	4%	Eggs	25	7%	Green peas (cooked)	29	8%
Pasta with meat	13	3%	Cheese (matured)	22	6%	Peas (cooked)	17	5%
Pizza	12	3%	No SeD*	19	5%	Spinach (cooked)	12	3%
Others	6	2%	Fish (processed)	17	5%	Cauliflower (cooked)	10	3%
			Meat (pig, fresh)	12	3%	Zucchini (cooked)	6	2%
			Pulses (natural)	12	3%	No SiD**	4	1%
			Meat (preserved)	10	3%			
			Others	2	1%			
Total	373	100%	Total	373	100%	Total	373	100%

Source: authors.

Notes: Categorization for first dishes (FD), second dishes (SeD) and side dishes (SiD), respectively. Incidences measured via observation counts ("number of" #) and frequencies (percentages %).

*In these cases, schools served the single dish (see Section 2.2.2) which we categorized as FD.

**In these cases, schools did not serve SiD contrarily to what suggested in the regional guidelines.

The third group of variables also contains 373 observations of qualitative covariates X^{ud} class u was exposed to on day d that are hypothesized by the literature to influence food consumption of children (see Supplementary Table D for the full list). They are derived from Fig. 1 and relate to the eating environment and operative circumstances of the lunches.

To assess our three hypotheses, we define three outcome variables calculated as the share of plate waste in the total amount of food served to children ${PW\%_c}^{u,d}$ for each of the three courses $c = \{FD, SeD, SiD\}$ as:

Eq. 3
$$ {PW\%_c}^{u,d} = \frac{w_{c\,PW}^{u,d}}{w_{c\,PF}^{u,d} - w_{c\,SW}^{u,d}} \cdot 100. $$

In contrast to most similar studies that adopt absolute weights or frequencies of plate waste as outcome measures (Cohen et al., 2015; Redden et al., 2015; Thompson et al., 2017), ${PW\%_c}^{u,d}$ allows to standardize food waste measurements relatively to the amount of food that a class actually received. This approach is necessary when covering a wide set of schools many of which differ from each other in the actual institutional implementation of the lunch serving and, hence, also portion sizes. We cover a sample of schools governed by 8 different sanitary units (i.e., having slightly different practices for menu implementation) and supplied

by 6 different catering providers, ultimately resulting in a high degree of heterogeneity. Thus we are able to control for differing service styles of the canteen providers as some canteen providers or school staff might systematically serve more/less food than specified in guidelines. Moreover, this enables us to compare foods that are very different in mass as wasting 30 grams of salad is hardly comparable with wasting 30 grams of potatoes, since the recommended portion for Italian schools for potatoes is 150 g/pupil while the one for salads is 50 g/pupil.

Using *PW* in gr/pupil as outcome measure might not be accurate since it does not account for the differing weights resulting from the different menus in schools and it does not control for the amount of food that children of one class receive. Hence, we choose the share of plate waste in the weight of food children have received ($PW\%_c{}^{u,d}$) as this appears to be the most accurate measurement of food waste produced. We observe a significant difference in the SiD quantities served to children in the two groups despite of randomization resulting from a Wilcoxon signed-rank test on median[16] weights of *PF, SF, SW, CF, PW* (g/pupil) at T0 between the control and treatment groups (see Supplementary Table E). Supplementary Figure C depicts the distributions of the deviations of *PF, SF, SW, CF, PW* (gr/pupil) from their median weights for the control and treatment groups at T0 and T1. Their skewed shapes appear plausible due to the fact that food categories are very different in weight (i.e., see previous example confronting salad and potatoes), and register only right-coded outliers since no negative values are possible. At T0 there are 121 different menu combinations of FD, SeD and SiD (see Supplementary Tables F and G).

2.3.4 Empirical approach

First, to show the internal validity of our study, we describe the core characteristics of our randomized sample at baseline[17]. We investigate the dietary patterns of children in order to provide a general assessment of their relations to the MD and characterize typical menus of FD, SeD and SiD served to the third graders.

Second, we use flow diagrams – following García-Herrero et al. (2021) or Pancino et al. (2021) – to visualize the typical food flow and food waste structures across all sampled school canteens before the intervention

[16] Considering the skewed distribution of *PF, SF, SW, CF, PW* in gr/pupil (see Supplementary figure C) we use the median as preferred measured of central tendency.

[17] In order to deliver a transparent analysis, we report all weights in gram per average pupil unless differently stated.

based on median weights[18] and their 95% confidence intervals (CIs) of each of the five preparation steps *PF, SF, SW, CF,* and *PW*.

Third, we investigate whether company sizes of the catering providers *P* cause heterogeneity in food waste structure. For that aim, we consider three types of catering providers: small ones serving one school, medium ones serving two to four schools, and big ones serving between nine to ten schools. We focus the analysis on contrasting largest vs. the smallest caterers. For that, we aggregate the food waste measurements of the two largest and the two smallest catering companies. With the help of a tree map we visually compare the food waste structures in the classes they serve relative to the weights of their prepared food at T0. Wilcoxon signed-rank tests are conducted on the medians of *PF*, *SF*, *SW*, *PW*, *CF* between the two groups in order to detect significant differences.

Fourth, we characterize the observed patterns in the changes in average plate waste shares per pupil before and during the intervention in order to assess its causal impact. As the existing literature reported in Table 2.1 assesses intervention impacts for an average sample of 3 schools[19] and each of the eight AUSL strata of our sample of 26 schools also includes on average 3 schools, we first take a disaggregated perspective and re-interpret our experiment as eight simultaneously performed small interventions. Hence, we analyze in a first step the plate waste shares *PW%* disaggregated by AUSL. This perspective guarantees comparability with the typical sample sizes used so far and, most importantly, allows to assess the homogeneity of the effects found across all eight AUSLs which will – in contrast to the existing literature – for the first time provide evidence on the external validity of the results obtained. To describe how *PW%* differs for the FD, SeD and SiD across the AUSLs, we compare the means[20] of *PW%* for the treatment and control groups at T0 and T1 by AUSL. We then present summary statistics of *PW%* for the entire sample and test for statistically significant differences of the changes in *PW%* from T0 to T1 for the treatment and the control group accompanied by boxplots of *PW%* by AUSL.

To assess the treatment effect of the inversion of the dish sequence on plate waste percentages we apply a difference-in-differences regression in the fifth and last step of the analysis.[21] We assume that the average

[18] We choose medians due to the skewness of the distributions of these variables as shown in Supplementary Figure C.

[19] We calculated the means of schools sampled in similar previous studies (see Table 1).

[20] Considering the normal distribution of *PW%* (see Supplementary Figure D) we use the mean as the preferred measured of central tendency.

[21] Since we found no statistically significant correlation between the class composition[21] and the *PW%* for FD, SeD and SiD (see Supplementary Table H), we consider each observation as repeated cross-sections in which only two time periods are available (i.e., the treated schools that receive the treatment during the second period, and the schools of the control group that do not receive the treatment in either period).

outcome among the treated and non-treated would have followed "parallel trends" in the absence of treatment because without the intervention they would have been exposed to the same menus and stimuli. Since children were not informed about the intervention, we also can plausibly assume that the treatment has no anticipation effect (i.e., a causal impact before its actual implementation). Together these assumptions allow us to identify the average treatment effect on the treated (ATT) defined in eq. 4 using a two-way fixed effects (TWFE) regression. To account for the institutional heterogeneity of catering services due to the different AUSL regulations and service implementation, we consider a difference-in-difference specification that allows for multiple groups, one treatment (*i=1*) and one control (*i=0*) for each AUSL.

Eq. 4 $$PW\%_c{}^{u,d,a} = \alpha_{i,a} + \phi_{t,a} + \sum \delta_{post,a}\, D_{i,t,a}^{u,d} + \sum \beta_{ca} Ca_c^{u,d} + \sum \beta_X\, X^{u,d} + \varepsilon_{i,t,a}\,.$$

The outcome variable $PW\%_c{}^{u,d,a}$ denotes the share of plate waste in the total food served to the average pupil in class u on day d for meal course $c = \{FD, SeD, SiD\}$ in AUSL $a = \{1,2,..,8\}$; $D_{i,t,a}^{u,d}$ is a dummy variable that takes value 1 for the treatment groups in the second time period for each AUSL. It represents the interaction of a treatment variable that takes value 1 for the treatment group during the intervention with 8 dummies taking value 1 for each AUSL. The parameters $\alpha_{i,a}$ and $\phi_{t,a}$ are the corresponding group and time fixed effects at AUSL level and $\sum \delta_{post,a}$ represent the ATT for each AUSL. $Ca_c^{u,d}$are dummy variables for the food categories (see Table 2.2 for the full list) and $X^{u,d}$ is a vector of class-level covariates described in Supplementary Table D; $\varepsilon_{i,t,a}$ is a mean-zero error term. As suggested by Roth et al. (2023) we estimate standard errors clustered at the school level at which treatment is independently assigned.

We then estimate eq. 5 for the overall sample, i.e., considering only one treatment and one control group to assess whether the effect of the intervention is homogeneous across the eight AUSLs:

Eq. 5 $$PW\%_c{}^{u,d} = \alpha_i + \phi_t + \delta_{post}\, D_{i,t}^{u,d} + \sum \beta_{ca} Ca_c^{u,d} + \sum \beta_X\, X^{u,d} + \varepsilon_{i,t}.$$

In eq. 5, $D_{i,t}^{u,d}$ simplifies to a dummy variable that takes value 1 for the treatment group in T1 and α_i and ϕ_t are again group and time fixed effects. δ_{post} is the ATT at the level of the full sample.

We assess robustness of these estimations in two ways. Considering the repeated measures over time for each class (5 consecutive school-days for T0 and T1) we test the model whether our results are robust to time correlations between observations. As Boschini et al. (2020) reports that differences in catering

providers are the most important food waste driver in Italian schools, we estimate eq. 5 also for each of the three caterer company sizes.

2.4 Results and discussion

2.4.1 Dietary pattern of sampled school

Table 2.3 displays the characteristics of the 13 schools randomly assigned to the control group and the 13 of the treatment group. Characteristics are similar across the intervention and control group.

Table 2.3. Descriptive statistics.

Characteristics	Schools in treatment group (n=13)	Schools in control group (n=13)
# AUSL	8	8
# schools	13	13
# classes	20	19
# children	357	403
Min # children/class	8	6
Max # children/class	26	22
# average children/class	20.2	18.8
#catering providers	3	3

Source: Authors.
Notes: # means "number of".

Schools serve a vast range of dishes (10 FD categories, 15 SeD categories and 12 SiD categories across the full sample – see Table 2.2) and diverse menus. In the control and treatment groups in both periods 127 unique dish combinations of FD, SeD, and SiD are served (Supplementary Materials Tables F and G)[22]. The combination across both groups most frequently served is pasta with veggies (FD) followed by fresh fish (SeD) and raw veggies (SiD). Among the ten most served unique combinations, pasta with veggies is the most frequent FD, while meat (both beef and white) is the most frequent SeD. The only reoccurring SiD across the ten most served unique combinations were raw veggies and salads.

Although we do not aim to evaluate school children's adherence to the MD as done by Aresi et al. (2023), Roccaldo et al (2014) and Tognon et al. (2014), our results allow several conclusions. In line with the MD, the most frequently served FD are made of cereals topped with vegetables, or extra virgin olive oil (Table 2). While only rare amounts of red meat and moderate amounts of fish, dairy and poultry are suggested in the MD in favor of larger quantities of plant-based proteins (Benhammou et al., 2016), the investigated lunch menus do not strictly reflect this dietary pattern. The most frequently served SiD are animal-based proteins

[22] The observed differences in the numbers of unique menus at T0 (121) and T1 (110) was caused by the 17 missing observations due to unplanned strikes (see section 2.3.2) and the few exceptional cases when catering services implemented small menu changes due to procurement shortages. Menu counts in the control and treatment groups at T0 are similar.

in the form of meat and fish. A variety of vegetables is served on a daily basis, both raw and cooked indeed reflecting MD patterns (Bach-Faig et al., 2011).

2.4.2 Food mass flows in school canteen lunch

Figure 2.5 displays the median weights and their 95% CIs of each step of the food mass flow in the canteens of all 26 schools before the intervention (see Supplementary Table J for the list of variables used in the analysis). In the full sample, one pupil receives for lunch 361 grams of food ($w_{c,SF}^{tot}$) of which 207 g are FD, 79 SeD, and 70 SiD. From those amounts, children typically discard as plate waste 56 g of FD, 26 g of SeD, and 30 g of SiD resulting in a total of 117 grams of plate waste generated by each child on every school day. This amount is almost one third lower than the 160 grams waste per pupil and meal observed by Pancino et al. (2021) across 76 Italian schools. Nonetheless, Boschini et al. (2020) indicate a fairly high variability of food waste in schools as a consequence of factors such as types of foodservice providers, kitchen locations or existing mid-morning snacks. Similar patterns of very high variations of food waste in schools due to different menus and structural conditions were also found by Eriksson et al. (2017) or Derqui et al. (2018) in European school contexts. Our results confirm this heterogeneity, since in our sample of 26 schools located in a single region, the 95% CIs of plate waste medians tend to be large. This confirms the rather nonuniform structure

of this food waste generation presumably due to highly heterogeneous food and eating environments (Figure 2.1) which exist across school canteens and affect pupils' food intake.

We confirm findings from previous studies in Italian school canteens (García-Herrero et al., 2019; Falasconi et al., 2015), which unanimously detect the presence of significant waste amounts in the serving of food and the inadequate intake of vegetables by children. Food consumption per pupil amounts typically to 137 g of FD, 49 g of SeD and 27 g of SiD. Compared with the regional recommendation for primary schools (Regional Sanitary Service ER, 2023) we observe a certain deviation. Children typically consume 61% more of the recommended FD quantity and insufficient amounts of SeD and SiD which fall short the recommended portions by -20% and -76%, respectively. The large CIs hint to a certain variability of intake across children, classes, and schools.

Based on the data provided in Supplementary Table K, we estimate total food and waste amounts circulating

Figure 2.5. Median food mass flows across all control and treatment groups at T0.

Note: The size of the boxes represents food quantity of food for each box at T0 in the control and treatment group.
Source: Authors

in public primary school canteens at the country level of Italy. Food amounts are estimated by multiplying the

number of total meals served in Italian primary schools by the median food mass weights of Figure 2.5. The quantity of food prepared for all primary school canteens in Italy amounts to ca. 77,000 tons per year of which 45,000 tons of FD, 17,000 tons of SeD, and 15,000 tons of SiD.[23] Over one school year, the plate waste generated in public primary Italian school canteens amounts to ca. 22,000 tons, of which 11,000 tons of FD, 5,000 tons of SeD and 6,000 tons of SiD. Our estimation enriches the results of Pancino et al. (2021) which provide aggregated quantities for plate waste plus serving waste. They estimate that all Italian primary school generate about 30,000 tons of non-consumed food per school year.

2.4.3 Food waste structure and caterer size

In order to provide some insight about the relation between institutional implementation of school lunches and food waste, we now analyze to what extent the structure of various food waste aspects depend on the size of the catering provider – measured as the number of schools supplied by a certain company – at T0. For that aim, we contrast big to small caterers.

Figure 2.6 shows that although served portions of the first three courses of small caterers amount to 420 g, 86 g get typically discarded by pupils without any serving waste, while for large operators 358 g are served of which typically 108 g get wasted and 4 g per student are lost in the serving process[24]. SiD portions served by small operators are structurally 38% smaller than those served by large firms and significantly less serving waste is generated. Plate waste and pupil's SiD intakes do not structurally differ by catering company size (Supplementary Table M).

In schools served by small companies, children consume 50% significantly more of the first three courses FD, SeD and SiD so that total *PW* is 20% significantly lower (see Supplementary Table M). Therefore, we observe a significant relationship between the size of catering companies and the total plate waste of children. The sustainability performance of small catering providers is much better than big catering providers. The median pupil wastes 20% (30%) of *SF* in schools supplied by small (big) providers of the total of the three courses served. The largest share of *PW/SF* occurs for SiD (47% for small and 42% for big caterers), while only 11% (26%) of the FD is discarded for small/big caterers.

[23] Such evidence supports a better understanding of the relevance of this sector in driving procurement practices. The exact values are 77,097 tons servings per year of which 44,493 tons of FD, 17,662 tons of SeD, and 14,943 tons of SiD of which 22,012 tons is total plate waste consisting of 11,069 tons of FD, 5,076 tons of SeD and 5,867 tons of SiD. When using/referring to these point estimates the large CIs of our results should be considered which suggest some heterogeneity of food mass quantities across school canteen settings.

[24] Precise median weights for the sum of FD, SeD and SiD are indicated in Supplementary Material Table L. In the text the total median weights are indicated as sums of the median weights for FD, SeD and SiD visible in Figure 2.6.

Significantly larger FD quantities (+49%) are served in schools supplied by small operators, children consume significantly more FD (+93%), and waste less of it (-34%). No significant differences appear between small and big catering providers for SeD intake and plate waste.

Figure 2.6. Median weights (gr/pupil) of lunch components for small and big catering providers at T0.

Note: SW is shown only for the SiD of big caterers since for small providers it has a median of zero for all three courses.
Source: Authors.

2.4.4 Descriptive statistics of the outcome variable

Figure 2.7 shows the distributions of plate waste shares *PW%* for each of the three courses FD, SeD and SiD as well as the total *PW%* for control and treatment at T0 as well as T1 for all eight school clusters (AUSLs) and the entire sample. The heterogeneity both in changes of *PW%* averages and Cis from pre- to during intervention point to a high variability in practical implementation of the school catering services which are governed and defined by each AUSL for all schools located in its area. In particular, average plate waste shares of SiD during the intervention significantly lowered only in AUSL4, significantly increased in AUSL2, but did not significantly change for six of the eight strata (Supplementary Table N). Plate waste shares of FD during the intervention did not significantly change in any of the treated classes, while plate waste shares of SeD significantly increased in treated classes in AUSL2 and significantly lowered in AUSL3 (Supplementary Table N). This evidence, hence, stresses the importance to consider a more diverse sample of schools for guaranteeing the external validity of the effects of such interventions in comparison to sample sizes of three schools or less which are predominantly used in the literature.

Statistical characteristics of the plate waste shares for the full sample are presented in Table 2.4 and illustrated in the bottom right panel of Figure 2.7 and in Supplementary Figure E. Supplementary Table O details the same characteristics for the treatment and control groups separately at T0 and T1. Across the treatment and control groups before and during the intervention 36% of the food served is wasted by the average pupil. Both for the treatment and control, SiD accounts with 53% for the largest shares of the servings not consumed while waste of the second dish (around 36%) and of first dish (around 32%) are on average lower. In both groups, the variability of FD and SeD plate waste indicated by the coefficient of variation (CV) is higher than for SiD. This can be interpreted as a broader convergence of likes and dislikes on the SiD across children, which in turn drives the lower variability of the total plate waste (i.e., they waste similar amounts across different SiD types). Differently the high variability of FD and SeD suggests that children are more sensitive to the type of FD and SeD served (i.e., they waste very different amounts depending on what is served on that day). However, the Cis for the control and the treatment groups have similar widths (see Figure 2.7). For the entire sample no significant changes in plate waste shares of FD, SeD and SiD appear between T0 and T1 (see Supplementary Table N).

Figure 2.7. Means and 95% CIs of plate waste shares *PW%* by course, period and school cluster.

Notes: The frame highlights changes in PW% for the vegetable intake via SiD. The asterisk denotes significant changes observed in treatment schools during T1, that is, the third week of the intervention.
Source: Authors.

Table 2.4. Descriptive statistics of the full sample of plate waste percentages *PW%*.

Variable	Mean	95% CI		CV	p50	IQR	IQR/p50
PW% FD	32%	30%	34%	65%	28%	25%	92%
PW% SeD	36%	34%	38%	60%	32%	33%	102%
PW% SiD	53%	51%	56%	47%	54%	42%	78%
*PW%*_tot	36%	34%	37%	47%	33%	23%	69%

Note: FD = first dish, SeD = second dish, SiD = vegetable side dish (target of the intervention), tot= FD+ SeD+SiD.
Source: Authors

2.4.5 Average treatment effects of the intervention

Table 2.5 and Table 2.6 report estimations for the difference-in-difference regression models providing insights for the hypothesis guiding this study (H1 to H3).

Table 2.5 reports the ATT for each of the 8 AUSLs estimated with eq.4 on the SiD (H1), FD and SeD (H2) respectively. Concerning hypothesis H1, we find that in all but one AUSL (AUSL8) SiD plate waste shares change significantly due to the intervention. We observe significant decreases in PW% of SiD in AUSL 3 (-26 percentage points (pp) change in plate waste share), and AUSL 4 (-13pp change in plate waste share), while in the other six the intervention led to a significant increase in SiD plate waste shares (+19pp, +32pp, +10pp, +10pp, +18pp in AUSL1, AUSL2, AUSL5, AUSL6, and AUSL7, respectively). This pattern at individual school cluster level per AUSL results in no significant ATT for the SiD plate waste share across all 13 treated schools as estimated with eq. 5 (Table 2.6, first line).

When assessing hypothesis H2, Table 2.5 shows a significant increase of the intervention on the FD plate waste share in AUSL2 (+13pp), AUSL4 (+13pp), and AUSL5 (+6pp). Concerning the induced changes in the shares of served SeD discarded by students, Table 2.5 reports heterogenous effects: a significant increase of SeD plate waste share is registered in AUSL2 (+39pp) and AUSL5 (+9pp), while a significant decrease is found for AUSL3 (-16pp) and AUSL6 (-18pp). Across all treated schools, serving the SiD first has no significant effect in changing plate waste shares of either FD or SeD (Table 2.6).

Thus, if we interpret our experiment as eight simultaneously performed small interventions, they exhibit a considerable heterogeneity of effects with respect to H1 and H2. Due to that lack of comparable effect sizes and effect directions, no significant change for any of the three plate waste shares due to the intervention is found across all 13 schools with 357 pupils which have been exposed to the intervention of serving the vegetable side dish first. Our results are robust to time correlations (Supplementary Material Table P presents the robustness check) and to catering service provider company sizes supplying the sampled schools (see Supplementary Table Q). Therefore, we infer that differences in the intervention effects across

the eight AUSL described in Table 2.5 are not driven by differences across provider sizes. We also conclude that the heterogeneity in practical lunch implementation described in the literature as food and eating environments (Figure 1) across schools and classes appears to dominate the effects of the intervention on the shares of the served food for each of the three courses discarded.

This suggests that previous studies assessing intervention impacts from small samples of about 3 schools on average, which were not randomly selected (Table 1) are likely to have mainly picked up school-specific institutional or socio-cultural factors instead of robust and generalizable effects of the intervention. They, therefore, possess not only very limited internal validity – because they are not conducted as RCT, but also very limited external validity so that any generalizations of their findings have to be made with great care.

Table 2.5. Average treatment effects of the intervention by AUSL (percentage points).

	***PW%* SiD**	***PW%* FD**	***PW%* SeD**
Treatment AUSL1	19**	-4	-7
	(-7)	(-9)	(-7)
Treatment AUSL2	32**	13*	39***
	(-12)	(-8)	(-4)
Treatment AUSL3	-26***	-10	-16**
	(-5)	(-8)	(-7)
Treatment AUSL4	-13**	13***	-5
	(-6)	(-4)	(-4)
Treatment AUSL5	10**	6***	9***
	(-4)	(-2)	(-2)
Treatment AUSL6	10***	-1	-18***
	(-3)	(-3)	(-3)
Treatment AUSL7	18*	3	-3
	(-9)	(-7)	(-4)
Treatment AUSL8	1	10	-3
	(-6)	(-10)	(-8)
Food categories	Yes	Yes	Yes
Covariates	Yes	Yes	Yes
Observations	369	373	354
R-squared	0.912	0.852	0.862

Source: Authors.

Notes: Standard errors in brackets. The asterisks mean: * p < 0.1 ** p < 0.05 *** p < 0.01. FD = First Dish, SeD = Second Dish, SiD = Side Dish. Covariates are part of the model, but coefficients are omitted.

For answering H3, average effects across the eight small-scale subsamples are presented in Table 2.6. Results suggest that – in contrary to the literature - the shares of the side dish which does not get eaten by pupils indeed depend on the type of vegetables served. Table 2.6 shows that among the vegetables served as SiD children waste on average significantly more zucchini (+48pp plate waste share), cauliflower (+11pp plate waste share), and cabbage (+8pp plate waste share), with respect to the benchmark category 'other vegetables'. Potatoes' plate waste share is significantly lower (-20pp) than the benchmark. Plate waste shares of carrots, green beans, fennels, raw veggies, peas and spinach do not significantly differ from the benchmark

category. Hence, contradicting the conclusion by Redden et al. (2015), some of the vegetables which an experiment might be using in a school lunch setting constitute a relevant influence factor on the intervention effect itself.

Table 2.6. Average treatment effect of the intervention estimated in eq. 5 for the full sample.

	PW% SiD	*PW%* FD	*PW%* SeD
Treatment	1	1	-5
	(-6)	(-4)	(-4)
SiD vegetable categories:		Yes	Yes
		(omitted)	(omitted)
Zucchini as SiD	48***		
	(-8)		
Spinach as SiD	11		
	(-7)		
Cauliflower as SiD	11*		
	(-6)		
Cabbage as SiD	8**		
	(-4)		
Fennel as SiD	6		
	(-7)		
Raw veggies as SiD	2		
	(-4)		
Green beans as SiD	1		
	(-7)		
Carrots as SiD	0		
	(-6)		
Peas as SiD	-4		
	(-8)		
Potatoes as SiD	-20***		
	(-5)		
SiD categories	Yes	Yes	Yes
Covariates	Yes	Yes	Yes
Observations	369	373	354
R-squared	0.328	0.322	0.291

Source: Authors.
Notes: standard errors in brackets. * p < 0.1 ** p < 0.05 *** p < 0.01. FD = First Dish, SeD =Second Dish. SiD = Side Dish. Covariates are part of the model, but coefficients are omitted.

2.4.6 Limitations and future research

Compared with existing comparable studies outlined in Table 1 our paper substantially extends the internal as well as the external validity of the literature on the topic, moving from a US-focused analysis to a RCT in the context of Mediterranean food culture. Since different dietary patterns also reflect different nutritional public priorities (Miller et al., 2022), we recommend for upcoming research to create repeated evidence of this choice-architecture intervention across countries and dietary contexts to isolate general effect patterns across national and regional nutrition habits.

As described in Table 1, the majority of studies on vegetable dish reordering suggest that the results of such an intervention can have either very small or null effects on the consumption of vegetables. Others indicate

an increase in vegetable intakes of a maximum of 430%. Spill et al. (2011) also found that when serving vegetable soups first, the lunch vegetable intake (in particular of broccoli) is reduced by more than 10%. Taken together previous results are in line with the heterogeneity of effects that we observe in our large sample. The increase of *PW%* of SiD in 5 out of the 8 AUSLs where we implement the intervention is against our expectations. The reason can be attached to a set of social norms which are often powerful in influencing eating behaviors (Salmivaara et al., 2021) and might have mediated the effectiveness of the vegetable anticipation. It might be that children being used to a typical meal sequence as for the Mediterranean dietary pattern, reject the consumption of vegetables first because it's beyond their consumption habits and shared identity. For future research, we suggest unveiling the potential association between social norms and the sequence in which food is served which is an underexplored field. Future interventions would also benefit from investigating the role of such social norms in influencing the intervention's effectiveness.

The intervention of prioritizing the side dish in the course order has been implemented for only three consecutive weeks. It is possible that exposing children to such a stimulus for longer periods could amplify the effects on vegetable food intake and waste reduction. In addition, to isolate the effect of the intervention, we did not combine the change in dish order with any educational activities for children that could raise acceptance. As our participatory approach for the design of the intervention did not include children although they are the recipients of the experiment, intervention effectiveness might be improved by considering their views. This, however, will require a broad cross-disciplinary approach in order to effectively communicate with them to successfully bring across the main ideas. Finally, we did not evaluate the temporal stability of the intervention effect. For achieving this, it would be desirable to replicate the same experimental setup after a couple of months or 1 to 2 years targeting the same classes and schools.

We find that selected aspects of plate as well as serving waste significantly vary between large and small catering companies. Small companies serving only single randomly sampled schools turn out to have a superior sustainability and nutritional quality performance as pupils' average vegetable intakes are structurally larger and some plate waste aspects are significantly smaller. Also, for some school clusters we find sizable treatment effects of the intervention while no or unexpected effect directions for others. Therefore, disentangling the role of dish order versus taste and qualitative food and eating environments as well as operative lunch circumstances would be help understanding the reasons of such considerable heterogeneity. Such insights would facilitate developing effective incentive designs to support improving the sustainability performance of school and other public canteens.

Although greater attention in the literature is dedicated to plate waste, complementary analyses on serving waste are needed to pave the way for improving the sustainability of food supply chains. Starting from existing knowledge on country-based drivers of serving waste (Ofei et al., 2015), future research might focus on identifying the most influential causes generating serving waste so that sustainability strategies can be tailored to avoid it.

We also provide a detailed characterization of the food mass flow in school canteens which might serve as the starting point for comparative analyses with food mass flows of other types of canteens. Such a comparison would allow to precisely evaluate the role of school canteens in comparison to, e.g., catering in hospitals, universities, or companies. Thus, similarly solid quantification of the food prepared, served, and wasted in combination with an extended quantification of qualitative food and eating environment characteristics should be provided for other contexts too based on sufficiently large sample sizes which will allow for the generalization of results. Lastly, advanced automatic measurement approaches such as picture-recognition in combination with artificial intelligence analyses might represent interesting options for future real-time food waste quantifications and would allow to assess their methodological strengths and weaknesses in comparison to direct weighting (Mikkelsen, 2019).

2.5 Conclusions and policy implications

Socio-economic research aims at informing evidence-based policymaking. Hence, we analyze to what extent does changing the dish order in school canteens by prioritizing vegetables yield a scalable policy strategy for shifting food intake towards a healthier and more sustainable trajectory.

Our study covers the widest institutional heterogeneity of school catering analyses conducted so far. We use not only the largest and most diverse sample of schools so far achieved for this type of choice-architecture intervention, but our analysis is also the first implementing a randomized selection of schools. The design of our experiment substantially extends internal and external validity of similar studies and has, thus, an unprecedented potential for offering policy implications for international, national and local stakeholders.

Firstly, we broaden the existing knowledge on how much food is wasted in each food system segment (Caldeira et al., 2019) which will facilitate the design of effective policies for reducing food waste helping to reach SDG target 12.3 asking *to halve per capita global food waste*. Extrapolating our estimates informs national policymakers that all pupils eating at primary school canteens in Italy waste about 22,000 tons of food per year, which represents 29% of the food prepared for them. Bigger catering providers are found to generate more service waste and 23% more plate waste than smaller ones. This emphasizes the potential for

food service companies and authorities to tailor waste reduction strategies. This could be substantially accelerated if policymakers or international institutions like the Milan Urban Food Policy Pact will create inventories of best practices, recommended actions as well as disincentivized actions for supporting the practical design and optimization of canteen food and eating environments which incentivize sustainable consumption patterns. Having provided evidence of the systematic presence of substantial food waste across lunch meal courses in schools, we conclude that actual food intake amounts rather strongly differ from nutritionally desired intakes. Hence, we encourage policymakers and nutritionists to scrutinize whether reducing the portion sizes of FD, SeD and SiD served to children would offer an option to cut food waste and resource use without jeopardizing nutritional goals – at least in the short and medium term until effective stimuli for raising vegetable intake have been identified.

Furthermore, our study contributes to the current debate on optimizing school menu structure for speeding up progress towards reaching core global sustainability goals for food systems transition (OECD, 2023). We enlarge the evidence on the effectiveness of a dish reprioritizing intervention in a school canteen environment with the aim of reducing waste to make more food available for children and achieve improved nutrition for reaching SDG2 of *zero hunger*.

From our experimental design and results researchers and international policymakers can understand the role of a sufficiently large sample size and heterogeneity for achieving generalizability of the measured effects. The treatment effects we derive from a sample of 26 randomly selected schools across an entire region of a country, in which around 4.5 million people live, appear to be fairly heterogeneous and not always consistent with each other. Hence, the heterogeneity in practical lunch implementation and food and eating environments across schools and classes seems to dominate the effects of the intervention and challenges drawing a single conclusion about the general effectiveness of the intervention. Implementing food policies without considering this heterogeneity may result in undesired effects on food waste amounts generated by children.

Regional and municipal policymakers who took part in the participatory co-design were interested in understanding whether the intervention was effective enough to be translated into a binding policy recommendation to be applied across the entire regional territory. Based on our results, in school clusters where positive effects of the intervention were found (i.e., food waste amounts of vegetable are reduced), shares of plate waste in vegetable servings were reduced from 42% to 16% (i.e., only 12 grams of vegetable servings would be discarded per child). Hence, our results also show the potential of the intervention. Put differently, if one assumes that this best-case scenario of reducing vegetable plate waste by 26 pp through

prioritizing the vegetable side dish would be feasible in all Italian primary schools, about 1000 kg of vegetable plate waste per year would be avoided.

Comparing results across the school sub-samples show that the intervention significantly reduces food waste for some school clusters but increases it for others and therefore one type of intervention does not fit all. Since different vegetables are found to be associated with different shares of plate waste reduction, sustainability and diet improvements can only be expected for specific vegetable types. As a consequence, authorities of Emilia-Romagna have concluded that they will not upscale the dish reordering as a policy strategy applicable to the entire region. We expect such a condition holds even more at national and international levels since we hypothesize that interventions covering various dietary patterns and school settings – which are likely to change across regions of one country and even more so across countries – is very likely to face even larger effect variability.

The participatory approach we adopted created positive spillovers in terms of engagement, trust, and sense of belonging. The authorities of Emilia-Romagna benefitted from initiating an exemplary effort for participating in intervention design and data collection in schools as well as from being an active stakeholder in creating robust science-based knowledge for optimizing the use of limited public funds for the best benefit of society. Such a citizen science approach in which stakeholders are involved via a living lab, entitles them to define questions and to find solutions jointly with science. As they are core agents of change, this experience increased their trust in the relevance, usability, and credibility of scientific results which they actively have influenced. As this process was perceived as a very positive and inspiring experience by all participants, we conclude that policymakers should strive to implement those living labs more often in order to involve stakeholders from different fields of knowledge and disciplines. By doing so scientists can in turn optimize the relevance, recognition, and societal impact of their research.

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Chapter 3

Monitoring sustainability of the school food environment: a scoring assessment tool

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Chapter 3. Monitoring sustainability of the school food environment: a scoring assessment tool

Abstract

Within the transition towards sustainable food systems, school canteens play a vital role both due to their dietary and educational outcomes. Providing school personnel with tools which enable them to monitor the sustainability of the school food environment accounting for nutritional, environmental, and social aspects is needed, as it can provide information on tailor-made strategies to spark positive change. We develop an innovative, ready-to-use indicator-based scoring assessment tool that simultaneously investigates the nutritional, environmental, and social dimensions of the school food environment in the Italian context. The design of the scoring tool is guided by a detailed methodological framework through which the sustainability approach adopted, the sustainability targets to be reached and decision contexts where the tool is applied are explored and presented. Indicators are defined through a participatory process with 25 stakeholders. 42 indicators are proposed and articulated in ten objectives across the three sustainability dimensions. All indicators are composed of scores summed up to produce both a single sustainability score ranging from 0 to of 75 sustainability points and a score for each sustainability dimension. Other than being the until now most comprehensive architecture of indicators across similar tools for assessing sustainability in school food environments, its structure is also flexible to easily adapt indicators for replications in differing school settings. By defining actionable indicators, the tool results serve policymakers to highlight areas of improvement in each school, and easily compare sustainability performances across schools in Italy and beyond.

Keywords: monitoring; school food environment; food system; SDG; food policy; sustainability.

3.1 Introduction

The Sustainable Development Goals (SDGs) and the Milan Urban Food Policy Pact set ambitious standards for food systems through a series of interconnected goals and measurable indicators (FAO, 2019a). Achieving these sustainability objectives requires adequate monitoring tools able to support stakeholders in evaluating the sustainability progress of the food system components (Fanzo et al., 2021). Monitoring tools, defined as applications supporting analysis to measure specific phenomena (Sala et al., 2015), are crucial to compare and quantify performance, track improvements, and identify trade-offs. They are needed throughout all steps of the food chain and across the full spectrum of economic, social and environmental outcomes (Béné et al., 2020)[25].

School canteens are pivotal spaces for achieving sustainable food systems in line with the SDGs (Oostindjer et al., 2017) since they affect the attitudes, knowledge, and behaviours of future generations (FAO, 2022). Providing healthy meals and adequate consumption environments at school can help lower the risk of diseases connected to dietary inadequacies (Sabinsky et al., 2019) and address diet inequalities (Bryant et al., 2023). School meals can also be important moments for children to socialise and gain knowledge (Stone and Murakami, 2021). The promotion of education during school meals has also been shown to increase awareness of environmental concerns (Black et al., 2015) and educate against food waste (Piras et al., 2023) from a very young age.

Researchers approached the theme of sustainability in school food environments adopting a variety of methodologies, ranging from top-down evaluations (Chiaverina et al., 2023; Hill et al., 2023; Jones et al., 2012; Sundin et al., 2023) to more participatory ones (Bryant et al., 2023; Eustachio Colombo et al., 2021; Nguyen et al., 2023). Most of the approaches focus on the impact assessment of case-specific school menus or programs in terms of food quality and nutrition (Foo and Tan, 2021; Reilly et al., 2021), affordability (Hill et al., 2023) and food waste (García-Herrero et al., 2021, 2019). Barnard et al. (2020) and Eustachio Colombo et al. (2021) integrate the nutritional assessment with the perception analysis of families and school personnel on the menu of selected school canteens. Adopting a more overarching approach, Chiaverina et al. (2023) extended the scope of the menu analysis by coupling nutritional considerations with the carbon footprint quantification of the meal.

[25] European Commission Joint Research Centre (2019) for example, gives an overview of existing monitoring tools for food prices and food affordability in the EU. Further examples for such monitoring tools are European Commission (2023) or FAO (2023).

In the food system domain, scholars developed a plethora of frameworks succeeding in moving from a case-specific sustainability evaluation to the development of sustainability monitoring tools, which are more broadly applicable and scalable. Still, limited evidence exists of an assessment tool that ensure replicability, comparability, and self-monitoring of school food environments. Large attention has been dedicated to sustainability tools developed at the farm-gate level (de Olde et al., 2016). A recent example refers to the operational rapid tool to assess sustainability in short food supply chains (Doernberg et al., 2022). Broader applications are offered by the decision support tool developed for food systems at the city-region level by Arciniegas et al. (2022), or the set of indicators co-developed with local experts to evaluate the impacts of the water–energy–food nexus by Moreira et al. (2022). Moreover, Cirone et al. (2023) delivered a simplified scoring framework, to get insights on the social, economic, and environmental impacts of food initiatives. Relatively to the out-of-home food sector, Maynard et al. (2021) are the first to propose a tool for evaluating restaurants' sustainability through a scoring system based on 76 indicators.

Only a few indicator-based tools to evaluate the sustainability of school food programmes exist. Table 3.1 presents an exhaustive list of all developed tools in the field from the less to the most articulated one in terms of number of indicators and sustainability dimensions covered. Two out of six tools exclusively cover aspects of health and nutrition by a list ranging from 10 to 27 indicators. These tools are developed to support the evaluation of school meals according to the main national and international nutritional standards in Slovenia (Gregorič et al., 2015) and in Portugal (Rocha et al., 2014). Fernandes et al. (2016) test a school planner to improve healthy diet decision-making in Ghana, by also including an economic indicator on the cost of food products in the menus. Black et al. (2015) enlarge the comprehensiveness of previous approaches and propose a tool to evaluate both the nutritional and environmental sustainability of food programs for schools in Vancouver, where the social aspects of educational activities is also associated to multiple indicators. An easy-to-understand score is provided for interpreting results of each indicator. On top of it, Caputo et al. (2017) implement a food chain evaluator for the Italian context, which assesses the nutritional content and diets diversity, the energy and land use, and production cost of different institutional caterings. However, the high level of complexity of the method used and the absence of a final score understandable to non-practitioners limit its practical applicability. A tool that combines the evaluation of social, environmental and economic factors with a user friendly approach has been suggested by Goggins and Rau (2016) for the understanding of Irish public catering. The tool is based on 36 indicators, with scores for each indicator ranging from 1 to 6. Nonetheless, the focus is not on schools, but more generally on public caterings. Such a feature limits its applicability in school food environments, where production and consumptions dynamics

are very different from university or industry canteens. None of the existing tools evaluate nutritional, social and environmental dimensions at once for the school food environment.

1 **Table 3.1**. Existing articles on assessment tools for the school food sector.
2

Article	Aim	Country	Number of indicators per sustainability dimension				Designed for schools only	Numerical score delivered
			Nutritional	Environmental	Social	Economic		
Gregorič et al. (2015)	Monitoring systems of dietary guidelines adherence in schools	Slovenia (EU)	10	-	-	-	Yes	Yes
Rocha et al. (2014)	Software for planning and evaluating school meals according to foods and nutrition standards	Portugal (EU)	27	-	-	-	Yes	Yes
Fernandes et al. (2016)	School meals planner package to the programmatic and environmental reality	Ghana (AFR)	3	-	-	1	Yes	No
Black et al. (2015)	Tool and scoring system for food initiatives in schools	Canada (NA)	1	1	4	-	Yes	Yes
Caputo et al. (2016)	Tool for analysing the impacts and designing scenarios for the institutional catering	Italy (EU)	3	2	-	1	No	No
Goggins and Rau (2015)	Tool for measuring the sustainability of food in public caterings	Republic of Ireland (EU)	3	8	20	-	No	Yes
Our paper	Monitoring tool to investigate sustainability of school canteens using a scoring system.	Italy (EU)	23	10	9	-	Yes	Yes

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

To address the need of designing tools that can measure progress towards various dimensions of food systems sustainability, the literature highlights an attention gap towards analysis on the school food environment. On the specific request of the government of Italia's NUTS2 region of Emilia-Romagna, we develop a scoring assessment tool for school food environments where multiple sustainability dimensions are analysed via a monitoring architecture of indicators scored from 1 to 10. This analysis adopts the definition of FAO (2019b) that describes 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*". The tool is developed for Microsoft Excel and contains a set of innovative elements. First, it embraces a system perspective where school canteens are not only evaluated on the diet quality they deliver, but also on the broader environmental and social aspects. Second, the tool is developed via a participatory approach through which we involve stakeholders that have direct experience in school canteens. As a result, the indicators included closely mirror the functioning of the school canteen system in the Italian region of analysis guaranteeing adequate usability and higher effectiveness of the tool (Sala et al., 2015). Third, it integrates the performance of school food environments related to the universally acknowledged nutritional, environmental and social dimensions of the food system (Fanzo et al., 2021) into a single sustainability score. The economic dimension is excluded from the analysis since budgetary considerations on the school food environments are a prerequisite for the functioning of schools in Italy. Lastly, it offers an operational and ready-to-use application for direct planning and decision making for academic and non-academic actors. Attention is placed on keeping the tool simple and flexible so that it can be easily adapted to other environments. The tool is currently included in the Regional Sanitary Service ER (2023) and is adopted as a binding commitment across the entire territory of NUTS2 region of Emilia-Romagna. The article is organized as follows. Section 3.2 describes the school food functioning in Italy. Section 3.3 details the methodology used, including the sustainability approach and targets, the decision context and the participatory process. The results and discussions are presented in Section 3.4. Finally, Section 3.5 comprises the major conclusions and policy implications.

3.2 Italian school food functioning

Italian school canteens are governed by the guidelines of the Italian Ministry of Health (2010) based on the Nutritional Recommended Intake Level for the Italian population (LARN) updated by the Italian Society of Human Nutrition (2014). The guidelines indicate the suggested consumption frequency of different foods, as well as the nutritional intakes. Italian regions, including the Emilia-Romagna region, translate the national guidelines into local guidelines, which are applicable to the entire regional territory

and guarantee homogeneous characteristics for the food procurement practices, and dietary standards (Regional Sanitary Service ER, 2023).

The Emilia-Romagna region is split into eight sanitary districts called *Aziende Unità Sanitaria Locale* (AUSL) which have the role of validating the menus of the school catering services, supervising menu implementation, monitoring food quality, and developing educational food activities at local level. Professionals from the AUSL are asked to evaluate the school food environment of the schools in their territories twice a year, i.e., for the winter and the summer menu. Evaluations consist of two layers: (1) an off-site evaluation of the menu to examine its compliance with national and regional guidelines and (2) an on-site evaluation of the school canteen via school inspection. To date, these two layers of evaluations are conducted separately, via qualitative approaches so that evaluation results are not comparable across schools.

The Emilia-Romagna region activated a working group to provide AUSL professionals with a tool able to combine the two layers of school food environments evaluations into a single format. This tool has several requirements, namely it should (a) deliver scorable results that can be compared across schools, (b) be directly usable for AUSL professionals, (c) combine the nutritional evaluation, with environmental and social evaluations of the school food environment (Laboratorio di Ristorazione Sostenibile, 2021).

3.3 Methods

The assessment tool aims to provide local practitioners with an easy-to-use mechanism to evaluate the sustainability of the school food environment intended as the sum of spaces and conditions where school food is consumed and the composition of this food (FAO, 2019b). The tool is composed of a suite of comprehensive indicators divided into three sustainability targets that provide quantitative and comparable data across schools.

To define the assessment tool, we follow the sustainability assessment procedure designed by Sala et al. (2015). The procedure is structured across four steps. Firstly, we set the sustainability approach, which is characterised by a set of sustainability values and principles to define the vision of the food system adopted in the assessment tool. Secondly, we illustrate the sustainability targets addressed, which identify the areas of actions monitored by the tool. Thirdly, the decision context for which the tool is destined to be used is explored. The decision context determines what are the local specificities that the assessment tool must take in consideration and is crucial to correctly adapt the assessment tool to these specificities and guarantee its practicality and usefulness. Finally, we detail the methodological design used for the definition of indicators in the assessment tool which describes how indicators have been

selected. A full representation of these steps and how they are adapted to the tool is shown in Figure 3.1 and detailed in the following sections.

Figure 3.1. Methodological framework for the development of the sustainability assessment tool.

Source: Authors.

3.3.1 Sustainability approach

3.3.1.1 Sustainability values

The starting point for any sustainability assessment is to define the value judgements to which the tool adheres (Sala et al., 2015). Considering our tool is designed to promote the transition of the EU's food systems towards improved sustainability, it 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*" (European Commission, 2019). On this background, the tool is guided by the following key overarching values for sustainable food systems suggested by Termeer et al. (2018) which we adapt to the school food environment. Table 3.2 presents the full list of values together with their implications for the design of the assessment tool.

Table 3.2. Sustainable food system values adapted from Termeer et al. (2018) and their implications for the tool design.

Sustainable food systems values	Implications for the tool design
System-based problem framing and boundary-spanning structure	The tool is design by adopting a system lens, where multiple sustainability targets are considered.
Adaptability	The tool is designed with a certain degree of flexibility, to respond to different school food environments.
Inclusiveness	We involve in the tool definition those actors who daily face the analysed context.
Transformative capacity	The tool serves to foster the positive transformation of the school canteen sector in the direction for sustainable food system stated by the European Commission (2019).

Source: Authors.

3.1.1.2 Sustainability principles

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, we distinguish three principles. Namely the principle of food system thinking (FAO, 2018), the one of One Health (Mettenleiter et al., 2023) and the one of participatory science (Cornwall and Jewkes, 2010). By endorsing the sustainable food system definition of the European Commission (2019), we support the multicriteria acceptance of the complexity that considers food systems as a result of competing goals and diverse functions (FAO, 2018). Therefore, we acknowledge 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 this food systems thinking principle by defining multiple sustainability targets for our tool (see Section 3.3.2). The One Health principle is based on the idea for which human, environmental, and animal welfare should be tackled in a holistic way (Gu et al., 2023) and is spreading both in the sustainability assessment discourse and in policy making (Council of the European Union, 2023). The complexity of health issues calls for integrated prevention strategies focusing on enhancing nutrition, reducing emissions and pollution and the associated health risks, but also for a sustainable management of animal production to tackle the emergence of zoonoses and microbial resistance (Lefrançois et al., 2023). This approach has to be implemented at every stage of the food chain, and as such it should be at the core of the strategies to spark positive change in school canteen sustainability (Eustachio Colombo et al., 2021). This principle further confirms the choice of including multiple sustainability targets in our tool (See Section 3.3.2). Finally, we postulate that social sciences and its scientific outputs can largely benefit from participatory science. Initially defined by

Cornwall and Jewkes (2010), the concept of participatory science states that linking researchers with society enables the co-production of more comprehensive forms of knowledge, with an increased capacity to answer global challenges. To this scope, the tool indicators have been co-designed via a participatory approach with the interested stakeholders as described in Section 3.3.4.

3.3.2 Sustainability targets

Based on the confrontation with stakeholders described in section 3.3.4, three main sustainability targets are set for our tool, namely the nutritional, environmental, and social one. These three dimensions, along with the economic one, are acknowledged as the base of food system sustainability (Béné et al., 2019b) and also able to capture school canteens functioning (Sundin et al., 2023). We exclude the economic target from our evaluation tool because budgetary considerations on the menu and school canteen functioning are in Italy a pre-requisite of the tenders for assigning catering services to schools (Salvatore et al., 2021). Once the menus and canteens infrastructures of each school are in place, the monitoring of the economic dimension is not of interest for the professionals evaluating it.

3.3.3 Decision context

Transparently documenting the specificities of the context for which any sustainability assessment is destined to be used for is crucial to clarify what the assessment takes into consideration (Sala et al., 2015). Exploring these specificities also guarantees that stakeholders wishing to replicate the tool in different contexts have a full understanding of what aspects of the tool might need adaptations. Following the categorization proposed by Sala et al. (2015), we explore the aspects of the context for which our assessment tool is developed. We detail the object of the assessment, the actors that will use the assessment tool, the scale of the assessment (i.e., the unit of analysis for the tool), the complexity and the uncertainty governing that context which need to be known, the time horizon in which the assessed impacts are foreseen, the activities monitored by the assessment tool and the impacts of interest (see Table 3.3 for a complete summary). The object of the scoring tool is the school food environment. The tool is developed for the sanitary districts (AUSL) professionals who are in charge of evaluating the food programmes of schools. In parallel, the results of the assessment also support teachers, municipalities, and regional governments in understanding the sustainability status of their schools and identify areas of improvements. The tool is applied at the scale of a single school, so that each school receives its own scores. The most relevant complexity with which our tool deals, relates to the many actors that oversee the school food environment and take decisions on it. School deans organise the canteen environment (e.g., setting of tables, presence of posters). Catering companies oversee the procurement and food transformation, service, and waste. Teachers supervise children's food consumption daily. AUSL

professionals monitor the school food environment evaluating adherence to the regional guidelines (see Figure 3.2). We also identify the main factor of uncertainty that can affect the interpretation of our tool results. Namely the large variability in the regional school canteens' organization that hamper a homogeneous interpretation of the score achieved. This is why our tool does not aim to set thresholds for judging a school as sustainable or unsustainable. It is rather designated for the identifications of areas of improvements and relative evaluations between schools. The tool is meant to be used twice per school year, for each seasonal menu (i.e., summer and winter) as described in section 3.3.2. The school food environment activities assessed by the scoring tool include the canteen setting, the food procurement, transformation, service, and waste, plus the educative environment which is provided to pupils. The

Figure 3.2. Responsibilities of different actors on the school food environment.

Source: Authors.

performance dimensions (i.e., impacts) of interest are detailed in section 3.3.2 and refer to the nutritional, environmental and social dimensions of sustainability.

Table 3.3. Fundamental aspects for the assessment tool as defined by Sala et al. (2015).

Fundamental aspects	Description of the aspects in the assessment tool developed in this paper
Assessment object	School food environments
The actors	Primary users: AUSL professionals
	Secondary beneficiaries: teachers, public bodies
Assessment scale	The school
Decision complexity	Multiple responsibilities over a single school canteen
Uncertainty of the decision	Large heterogeneity of school organisation
Time horizon for assessment	Seasonal menus
Activities assessed by the tool	Canteen setting, food procurement, transformation, service, and waste, educative environment
Performance dimensions of interest for the tool	Nutritional, environmental, and social

Source: Authors.

3.3.4 Methodological choices and participatory approach

Based on the sustainability approach defined and the participatory science principle we adhere to, the tool is developed through Participatory Action Research (PAR). The PAR is a research design that supports the experiential knowledge for solving global problems (Cornish et al., 2023). The experiential knowledge is intended as the one acquired by lived experience of people in a specific food system setting (Born, 2019). Instead of building knowledge only based in science, the PAR values the generation of knowledge both via systematic research methodologies and direct experience of stakeholders involved in a specific problem (Cornish et al., 2023). Therefore for developing the tool via a participatory action research design we follow and adapt the steps suggested by Cornish et al. (2023). Table 3.4 details the PAR steps we follow, their goal and their application for the tool development.

Table 3.4. Application of PAR building blocks (based on Cornish et al., 2023) to the tool development.

Steps for the design of PAR	Goal	Application
S1. Building relationships	Select the community setting	Setting up the '*Laboratory for sustainable caterings*'
S2. Establishing working practices	Agree on working and communication practices	Defining principles and working methods of the '*Laboratory for sustainable caterings*'
S3. Establishing a common understanding of the challenge	Define tool aim and principles	Workshop I
S4. Gathering and generating materials (i.e., software setting)	Reflect on how to collect data and store them in the tool	Workshop I
S5. Planning and taking action	Develop the tool	Workshops II and III

Source: Authors.

S1. Building relationships. A participatory living laboratory has been established with a formal agreement (Emilia-Romagna Region, 2022). The laboratory (Laboratorio di Ristorazione Sostenibile, 2023) in which around 25 stakeholders are participating is coordinated by the Emilia-Romagna region and the University of Bologna. As Cornish et al. (2023) recommend to put those individuals involved in a specific system as leaders of change, these stakeholders are directly involved in the regional school food sector (see Supplementary Table A for a complete list). Most of them are professionals working for the sanitary districts (AUSL) who conduct seasonal evaluations of the school food environment and are intended to be the main users of the evaluation tool. The other stakeholders belong to the regional government, regional agricultural sector, and academia.

S2. Establishing working practices. To formally guide the functioning of the laboratory a workplan has been agreed upon and published (Laboratorio di Ristorazione Sostenibile, 2021). The workplan includes

details on the laboratory objectives, governance and methods used as well as the deliverables. The development of a tool for the evaluation of sustainability of school food environments is the objective of the laboratory and is explored in the following paragraphs.

PAR steps S3, S4 and S5 (Cornish et al., 2023) have been developed via three workshops between April and July 2023.

S3, S4. Establishing a common understanding of the challenge as well as gathering, and generating materials. Workshop I set the tool scope including the sustainability targets important to reach and chose the software for data collection. During the workshop, the moderator illustrated the challenge of sustainability monitoring in school food environments. The assessment tool developed was then proposed as a solution to address this challenge. The scope of the tool was discussed with the stakeholders and formulated as follows: an easy-to-use indicator-based evaluation tool to monitor the sustainability performance of the school food environment via a quantitative scoring mechanism that allows comparisons between schools and continuous improvements. After, the four most adopted sustainability targets in food system assessments (i.e., economic, environmental, social, and nutritional, Fanzo et al., 2021) had been illustrated. A discussion was developed with the stakeholders for selecting the sustainability targets to be included in the tool. As a result, the economic dimension was excluded considering that budgetary monitoring of school food environment functioning is not an issue since budgets considerations are a pre-requisite of the tenders for assigning catering services to schools. Finally, an open discussion was conducted on the best software to implement the tool in. All participants unanimously proposed to use Microsoft Excel due to its user-friendliness and broad working experience.

S5. Planning and taking action. Workshop II aimed to co-create the set of tool indicators. Three groups of stakeholders were formed one for each of the three selected sustainability targets. Each group was provided with a list of candidate indicators. For the nutritional dimension the reference for indicator design were the official guidelines on the adequacy of school meals (Regional Sanitary Service ER, 2023), which detail frequency and composition of school meal ingredients in accordance with the dietary recommendations of the Italian Society of Human Nutrition (2014). For the social and environmental indicators, a list of potential indicators for public catering assessment based on Goggins and Rau (2016) was provided (see Supplementary Table B)[26]. Each group was asked to select the indicators among the candidates and adapt them to the school food environment reflecting the criteria of coverage, relevance, interpretability, and usefulness (Schneider et al., 2023, Table 3.5) for monitoring food system

[26] The decision to provide this list as a base is due to the fact that across the sustainability assessments of public canteens (see Table 3.1), Goggins and Rau (2016) provide the most comprehensive set of indicators (i.e., larger number) and the most fitting one in terms of sustainability dimensions included due to our sustainability targets (i.e., nutrition, environment, society).

sustainability[27]. Considering that no specific indication was given on the minimum or maximum number of indicators for each target, the final suite of indicators reflects the relative importance that stakeholders attached to each target (i.e., more indicators for a target means stakeholders, and the regional school system they represent, attach larger importance to that target).

Table 3.5. Criteria for indicator selections adapted from Schneider et al. (2023).

Criterion	Description of the indicator selection of the assessment tool
Coverage	Data for the indicator are available across schools.
Relevance	The indicator measures some aspect which is relevant for the sustainability improvements of the school food environment.
Interpretability	The indicator explicitly defines a desirable direction of change for the school food environment and collected data are easily comparable across schools.
Usefulness	The indicator is useful for policy, planning, and decision-making in the school food sector.

Source: Authors.

Once having collected all indicators proposed by the participating stakeholders, indicators were reviewed for duplicates. Next, a score was assigned to each indicator based on the measurability scale indicated by the stakeholders and three scoring systems were implemented to quantify all indicator types:

- Qualitative scoring for 31 indicators having two possible options: yes or no. We assign 0 points to the least sustainable option based on the measurability scale indicated by stakeholders using Supplementary Table C and 1 point to the most sustainable one.
- Likert scale scoring for 10 indicators for which more than two options are possible. A Likert scale is used with either 3 or 6 options depending on the measurability scale indicated by stakeholders in Supplementary Table C. Based on the measurability scale we assign 0 points to the least sustainable option and either 2 or 5 points to the most sustainable one.
- Composite scoring for 1 environmental sustainability indicator. We firstly calculate the environmental impact of protein-based foods served as a second course in a weekly menu based on eco-points as suggested by Hartmann et al. (2022) and Wassmann et al. (2023). Then we transform the obtained values into a scale from 0 to 10 for assigning a standardized score. The detailed methodology used for calculating the score of this indicator is illustrated in Supplementary Table D. 0 points correspond to the least sustainable menu (i.e., with higher

[27] The experts were provided with a template asking to indicate for each distinct sustainability target the set of adapted indicators meeting the criteria, their measurability scale, the desired (i.e., most sustainable) outcome, and the type of data collection. As for the data collection it was asked to indicate whether that indicator was suitable for the off-site evaluation of the menu or for the on-site inspections of school canteens. Supplementary Table C details the adopted template.

environmental impact) and 10 points to the most sustainable one (i.e., with lower environmental impact).

B5. Planning and taking action. Workshop III was dedicated to the refinement of the tool, via discussion with the involved stakeholders and took place online. Stakeholders were asked to (1) validate the scoring assigned to each indicator, (2) group the indicators into specific objectives and (3) fill in the tool for a hypothetical situation and report strengths and weaknesses of each indicator. Feedback was collected with a focus group discussion with all 25 participants and used to finalize the tool design.

3.4 Results and discussion

3.4.1 Scoring assessment tool

The assessment tool is composed of 42 indicators across the three sustainability targets of which 28 indicators are designed for off-site evaluation of menus while 14 are for the on-site inspection of school canteens (Table 3.6). Of these, 23 are related to the nutritional target, 10 to the environmental and 9 to the social one. This imbalance in the number of indicators for each target reflect the relative importance that professionals governing the local school food environment involved in the participatory process attach to each target. Minimum and maximum scores of each indicator correspond to the type of scoring system for each of them.

The scoring range of the tool starts at 0 if all indicators are absent and may reach 75 if all indicators reach their maxima. Higher scores for each indicator correspond to greater sustainability. Table 3.6 also shows that 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. There are no thresholds for defining acceptable and non-acceptable sustainability performances, as the scores are meant for relative evaluation across schools and identifying improvements.

Table 3.6. Summary of the assessment tool indicators and score.

	Off-site evaluation	On-site inspection	Total
Numbers of indicators	28	14	42
of which nutritional	21	2	23
of which environmental	7	3	10
of which social	0	9	9
Maximum score	47	28	75
of which maximum nutritional score	21	2	23
of which maximum environmental score	26	14	40
of which maximum social score	0	12	12

Source: Authors.

3.4.2 Nutritional sustainability

Sustainable food systems are first and foremost promoting nutritious and healthy dietary patterns, which result in well-being and positive health outcomes for children (Biesbroek et al., 2023). Hence, 23 of the 42 indicators have been chosen to monitor the quality and adequacy of school food from a nutritional perspective. They are cluster into 3 objectives: guaranteeing meal quality standards (5 indicators), adequate meal frequency (16 indicators), and sufficient nutritional information (2 indicators). 21 indicators (N1-N21) are to be evaluated off-site while the remaining two (N22, N23) by on-site inspection of the school canteens (see Table 3.7). The total score for the nutritional target can take a value between 0 (i.e., lowest sustainability) and 23 (i.e., highest sustainability).

Achieving sustainable diets entails consuming a highly diverse food, in which vegetables, fruits and pulses ensure adequate intakes of micro- and micronutrients (Verger et al., 2021). Hence, we measure the diversity of food offered in school canteens via indicators N3 to N5. Also, the consumption of extra virgin olive oil the usage of iodized salt has been unanimously associated in the literature with decreased illness and reduced disease progressions (Farhan et al., 2023; EFSA, 2014). Adequate consumption of these two products is accounted for in indicators N4 and N5. In line with the Mediterranean dietary pattern (Willett et al., 1995) which has proven to yield multiple positive outcomes on children's health (Azzini et al., 2011) and in line with the dietary reference values for the Italian population (Italian Society of Human Nutrition, 2014), we also monitor the serving frequencies of various food categories by indicators N6 to N21. Making nutrient tables of the school menus and food quantities served available, supports transparency of menu design from a nutritional perspective and can improve healthy eating knowledge among school stakeholders and families (Goggins and Rau, 2016) and is, therefore, measured by indicators N22 and N23.

Table 3.7. Data collection, objectives, indicators, codes, measurability scales, and scores of the tool for the nutritional dimension.

Data Collection	Objective	Indicator	Code	Measurability Scale	Score
Off-site evaluation	Guaranteeing meal quality standard	Different veggies are served every day of the week	N1	No-Yes	0-1
		Different fruits are served every day of the week	N2	No-Yes	0-1
		At least two different types of pulses are served in the menu rotation	N3	No-Yes	0-1
		Use of extra virgin olive oil for dressings	N4	No-Yes	0-1
		Exclusive use of iodized salt	N5	No-Yes	0-1
	Guaranteeing adequate food frequency	Presence of wholemeal, fat-free or low-salt bread minimum 1 time per week	N6	No-Yes	0-1
		Presence of wholemeal or semi-wholemeal pasta minimum 1 time a week	N7	No-Yes	0-1
		Use of other cereals in addition to wheat minimum 1 time a week	N8	No-Yes	0-1
		Pasta with olive oil served maximum 1 time a week	N9	No-Yes	0-1
		Egg pasta served maximum 1 time every 15 days	N10	No-Yes	0-1
		Potatoes served maximum 1 time a week	N11	No-Yes	0-1
		Pulses served minimum 1 time a week	N12	No-Yes	0-1
		Fresh meat served maximum 2 times a week	N13	No-Yes	0-1
		Cured meat served maximum 1 time every 15 days	N14	No-Yes	0-1
		Fish served minimum 1 time a week	N15	No-Yes	0-1
		Eggs served maximum 1 time per week	N16	No-Yes	0-1
		Cheeses served maximum 1 time a week	N17	No-Yes	0-1
		Single dish served maximum 1 time a week	N18	No-Yes	0-1
		Raw vegetables served minimum 2 times a week	N19	No-Yes	0-1
		Fresh fruit served every day	N20	No-Yes	0-1
		Desserts are served only for special events	N21	No-Yes	0-1
On-site inspection	Sufficient information	Presence of complete nutrient table information	N22	No-Yes	0-1
		Presence of food quantity table with subdivision by age group	N23	No-Yes	0-1

Source: Authors.

3.4.3 Environmental sustainability

The second core characteristic of a sustainable food system is low environmental impact and protection of nature and its ecosystem services (section 3.3.1, European Commission, 2019). The tool measures that through 10 indicators relating to 3 objectives: reduce meal impact (4 indicators), choose local and fresh products (3 indicators) and ensure better waste management (3 indicators). Table 3.8 describes the four indicators (E1-E7) for off-site evaluation and the six indicators for on-site inspection (E8-E10). The score for the environmental target can range from 0 to 40.

The second course in school meals can be composed either of animal-based, plant-based proteins or a mix of them (salty cakes). The consumption of animal-based protein, particularly red meat, is associated with greater environmental impact than animal derivatives or pulses (Hartmann et al., 2022; Simon et al., 2023). Therefore, to elaborate an environmental sustainability score for the second courses of the weekly menu the indicator E1 builds on a scoring strategy defined by Hartmann et al. (2022) and further elaborated by (Wassmann et al., 2023), i.e. the eco-points. The eco-points are representing a comprehensive score of food environmental life cycle impact taking into account 20 impact categories (cfr. ISO 14040) based on the 2013 Swiss ecological scarcity method (Hartmann et al., 2022). According to this scoring system, red meat is found to have the highest environmental impact (i.e., lowest sustainability score) and pulses the lowest (i.e., highest sustainability score). Based on these premises, Supplementary Table C presents the method for calculating the score of indicator E1. Indicators E2 and E3 relate to the seasonality of the served fruits and vegetables. Providing local seasonal food in the school menu can reduce the environmental impact of the meal. While debated (Foster et al., 2014), the lower environmental impact of local products in season is evidenced by scholars in different contexts (Röös and Karlsson, 2013; Xiong et al., 2023), and it's one of the core elements of the sustainability strategy of the Emilia-Romagna region. Similarly, locally-sourced fresh produce has a lower carbon footprint compared to processed one. Reduction in transportation and storing, but also fewer inputs (i.e., ingredients, packaging and electricity use) contribute to a lower environmental impact of fresh vegetables (Rasines et al., 2023). This perspective is captured by indicators E5 and E6. For indicator E2 to E6, the average weekly frequence is computed by referring to four observation on as many weekly menus. The lower environmental impact associated with local products compared to imported ones (Schmitt et al., 2016; Striebig et al., 2019) is reflected in indicator E7. Decisions on the materials to be used for the school meal serving and the way these materials are disposed also have a significant impact on the environmental performance of school food cafeterias, as demonstrated by Genovesi et al. (2022). Materials management is considered as sustainable if the canteen uses reusable tableware (E8), segregates waste (E9) and serves only tap water (E10) as opposed to plastic bottles, which in the great majority of cases entails a higher environmental footprint, as demonstrated by Fantin et al. (2014).

Table 3.8. Data collection, objectives, indicators, codes, measurability scales, and scores of the tool for the environmental dimension.

Data collection	Objective	Indicator	Code	Measurability Scale	Score
Off-site evaluation	Reduce meal impact	Environmental impact of protein-based foods served as second course (indicate the average weekly frequency for each food is served)	E1	Pulses Cheese Salty cakes Eggs Fish White meat Red meat	0-10
		Average weekly frequency of seasonal vegetables used for the first course	E2	0-5 times	0-5
		Average weekly frequency of vegetables used for the side dish	E3	0-5 times	0-5
		Average weekly frequency of seasonal fruits	E4	0-5 times	0-5
	Presence of local products in the menu	Average weekly frequency of fresh products for the first course	E5	0-5 times	0-5
		Average weekly frequency of fresh products for the side dish	E6	0-5 times	0-5
		Presence of local products in the menu	E7	No-Yes	0-1
On-site inspection	Ensure better waste	Type of tableware used by the school and the catering service (plates, cutlery, glasses)	E8	Disposable; Mixed mode; Washable	0-2
		Separate waste collection	E9	No-Yes	0-1
		Use of plastic bottle for water	E10	No-Yes	0-1

Source: Authors.

3.4.4 Social sustainability

In line with the sustainable food system definition of European Commission (2019), the tool aims to promote just, inclusive, and socially acceptable food spaces (section 3.3.1). Therefore, nine indicators are devoted to monitoring social sustainability in school food environments. Indicators refer to four objectives: promoting education (1 indicator), improving the eating environment (4 indicators), supporting families' engagement (1 indicator), and minimizing food waste (3 indicators) (Table 3.9). All social indicators are for on-site inspection and their total maximum score can range from 0 to 12.

The educational aspect often associated with the social dimension of food systems (Molin et al., 2021) is monitored by indicator S1. Engaging children in discussions on dietary knowledge is strategic to push towards more conscious consumption behaviours (Chaudhary et al., 2020; Laitinen et al., 2022) and the

the physical eating environment where children consume food can represent a lever to affect their consumption behaviour (Gross et al., 2019). The presence of visible posters on adequate nutrition stimulating educational prompts is therefore proxied by indicator S2. In addition, the existence of a calm ambience with reduced noise in school dining halls which has been reported to reduce distractions for children and create more opportunities for social learning (Steen et al., 2018) is measured by indicator S3. The sizes of tables where children interact with a limited number of peers is considered via indicator S4. The consumption behaviour of children is also subject to the interactions with teachers during meal consumption (Benn and Carlsson, 2014). If teachers sit together with children their interaction with pupils is reinforced and can support the consolidation of correct food consumption practices (indicator S4). Engaging with families via for example parents committees (indicator S3) in schools can be successfully used to improve children's attitudes towards food consumption (Chaudhary et al., 2020) and create trust between families and school actors (Galli et al., 2014). Finally, food waste amounts in school canteens have been identified as a critical social challenge (Derqui et al., 2018), but only a few systematic policy efforts have been made to reduce it (Pancino et al., 2021). Via indicators S4, S5 and S6 the tool monitors the activation of practices to reduce and prevent food waste[28].

[28] The focus on bread and fruits is due to the fact that in Italian schools there's no possibility to take home the leftovers of the first, second and side dish due to sanitary reasons, while taking home breads are fruits is allowed.

Table 3.9. Data collection, objectives, indicators, codes, measurability scales, and scores of the tool for the social dimension.

Data Collection	Objective	Indicator	Code	Measurability Scale	Score
On-site inspection	Promote Education	Presence of food education activities	S1	No; Partly; Yes	0-2
	Improve eating environment	Presence of educational posters on adequate nutrition	S2	No-Yes	0-1
		Presence of soundproofing panels in the school dining hall	S3	No-Yes	0-1
		Size of tables where children sit	S4	>10 children/table; 1-5 children/table;6-10 children/table	0-2
		Position of teachers during meal consumption	S5	In a separate table; With children	0-1
	Families engagement	Presence of parents committee	S6	No-Yes	0-1
	Minimize food waste	Presence of practices for the recovery of edible food for charitable organizations	S7	No-Yes	0-1
		Possibility to take home uneaten bread and fruit	S8	No classes; Some Classes; All Classes	0-2
		Presence of strategies to reduce bread waste (e.g., loaf cut into smaller pieces)	S9	No-Yes	0-1

Source: Authors.

3.4.5 Adaptabilty of the tool to other contexts

The present assessment tool is designed for the school food environments in Italy, specifically for the Italy's NUTS2 region of Emilia-Romagna, but it also can be potentially adapted to school food environments in other regions within Italy, in Europe or internationally. Its structure is simple and flexible to easily incorporate or adapt new indicators in the future.

The tool has been designed based on the methodological framework described in Figure 3.1. For the present tool to be applied as such, the school food service needs to present three main criteria. Firstly, it needs to be governed by a similar policy framework, specifically on the nutritional domain. The nutritional indicators of our tool mirror the Italian recommendations for healthy eating of school-age children

(Italian Society of Human Nutrition, 2014). Despite these recommendations are not far from what suggested internationally - for instance, the consumption of a diversified diet, of extra virgin olive oil, and iodized salt monitored by indicators N1-N5 is recommended by a large body of international literature (Farhan et al., 2023; Verger et al., 2021; World Health Organization, 2007) - the specific food frequencies and use (N6-N21) would need adaptations to the corresponding dietary reference values. Secondly, the decision context should be comparable to the Italian one, in terms of the different actors engaged in the school food environment (e.g., role of teachers and parents), infrastructure of the service (e.g., presence of dining halls, with tables) and organisation of the menus (e.g., seasonal menus). Finally, the school food service where the tool is applied and its governing body, should have access to all data required for the 42 indicators.

Several elements of this score-based tool relate to the preferences of stakeholders, which might not be stable across geographies. Despite the school meals service in Europe (European Commission, 2021) and beyond (Pastorino et al., 2023) needs to address similar objectives, stakeholders can be subjected to different decision variables, or priorities. For instance, it is true that the environmental indicators of the present tool are aimed to shift school food environments in a direction which is globally agreed (Biesbroek et al., 2023). Aspects of meal impact mitigation via reduction of animal-based products and consumption of seasonal fruits and vegetables (E1-E4), of local food products (E5-E7) and waste management improvement (E8-E10) are not limited to the Italian and European context, but do reflect generalisable pathways towards a desired direction (Gardner et al., 2023). However, a participatory process with local stakeholders might help to prioritize the most pressing context-based environmental priorities and would sustain the adaptability of the tool to different contexts. Also for the social indicators, the relationships between canteen environment and children eating behaviour is complex and multifactorial (Liz Martins et al., 2020). Therefore, when applying the tool to other school settings, consulting local stakeholders would allow to capture the social and behavioural specificities of children and adapt indicators accordingly.

3.4.6 Limitations and future research

Some limitations and future research developments emerge, both for the suggested tool and for studying the sustainability of school catering in general. The tool includes indicators which assess nutritional, environmental and social sustainability dimensions. However, they are not equally investigated as each of them is measured by a different number of indicators. This unbalance is a common characteristic of assessment tools (see Table 3.1) and the large majority of nutritional indicators focus on the main function of school food catering which is to provide adequate nutrition to children (FAO, 2019c). Also, Desiderio et al. (2022) point out that social indicators are less mature in the literature. Therefore, future

investigation for expanding the suite of indicators into social and environmental aspects is particularly relevant.

Our tool assigns weights to indicators depending on the measurability scales assigned by stakeholders to each of them. Future research might explore the differences in the importance attached by stakeholders to each indicator and adjust their relative weights accordingly for example via analytic hierarchy processes or principal component analysis (Gan et al., 2017). We did not investigate the economic dimension of school food environments. Future adaptation attempts of the tool can include indicators on the economic implications for catering companies of, for example, selecting specific food products or improving the eating environment. This would offer a more in-depth understanding of the effects that improved sustainability has on the budget.

The understanding of the tool would benefit from being tested on a structured and representative sample of schools to inform policymakers on the average sustainability scores of their food environments. This would also allow identifying reasonable ranges of acceptable and desirable sustainability performances across schools. As almost all of the sustainability assessment tools for school food environments have been developed for Western Europe (Table 3.1), assessing their relevance, applicability and tailoring to other regions would add insight and foster international learning across countries. Developing a common standardised assessment tool for the school food sector broadly applicable, e.g., similar to OECD's Programme for International Student Assessment (OECD, 2023) would allow school food sector stakeholders as well as policymakers across all levels of governance to conduct comparative sustainability assessments.

3.5 Conclusions and policy implications

Sustainable food systems and sustainable dietary patterns not only have the primary role of promoting nutritionally adequate foods, but they need to do so in a way that protects natural ecosystems and supports socially acceptable pathways (Steenson and Buttriss, 2020). Current efforts to attain the SDGs highlight a need to propose frameworks that monitor the sustainability of complementary segments of food systems pertaining to nutritional, environmental, and social determinants (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 quality of collective catering settings, and particularly schools, have received much less attention.

Therefore, we develop a sustainability assessment tool comprising 42 indicators quantifying nutritional, environmental as well as social dimensions of school food environments. The indicators offer a composite sustainability scoring from 0 to 75 including the option to disaggregate the score into each complementary dimension. The selection of a set of indicators legitimated through a consultative

process guarantees a tailored applicability of the assessment to the context needed. Due to the tool's modular structure and flexibility, opportunities for adapting it and applying it to European and international contexts also exist. Both the list of indicators considered, and the methodological procedure used to design the tool can serve as a reference point and a scientific basis for future sustainability assessments in the school food domain and beyond. From a policy perspective, this straightforwardly implementable assessment framework will help guide policymakers to prompt actionable advancements and management practices that will facilitate the sustainable development of school food environments. Thanks to its easy-to-understand score and actionable indicators, the tool allows teachers, municipalities, and regional governments to obtain insights on the extent to which each school contributes to fostering a sustainable food system. It creates a transparent and reproducible mechanism through which schools are enabled to identify and measure gaps for realizing sustainability improvements to effectively govern the direction of change.

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Discussion & Conclusions

Discussion

Contextualizing school food environments

When dealing with the school food sector, multiple contextual factors play a role and might lead to a variance in the extent to which researchers and policymakers perceive and address all three research questions. Effects of these contextual factors in interpreting the research outputs presented in the thesis are worth consideration to guide the appropriate transfer of scientific knowledge into policy actions.

For instance, stakeholders in developing countries would have had different perspectives on SFSCs (RQ1). While in industrialized countries SFSCs are often perceived as high-class and fancified food production methods, in many developing countries they are the traditional and dominating food supply chains (Misleh D., 2022). Due to their geographical differences in social and political significance, integrating products from SFSCs in school canteens would have different implications in developing countries than in industrialized ones. Similarly, determinants for consumption choices and healthy eating behaviours are strictly connected to consumption norms, food environment characteristics and operative circumstances in a specific setting (Dacremont and Sester, 2019). In non-mediterranean food cultures, dishes are often not served in the same order as in Italy, and for which the intervention of Chapter 2 was designed. The same holds for the consumption quantities of different food products discussed in Chapter 2. This means that a choice-architecture intervention that has been effective in one setting might not be neither possible nor useful in another one. In addition, the focus on the three pillars of sustainability addressed in RQ3 can vary depending on geographical locations. In countries where poverty and food security are still an issue, the environmental sustainability investigated would be much less important than in the Italian and European context, while providing sufficient and affordable food would be a priority (Azomahou et al., 2022).

The role of participatory approaches for operationalizing system thinking

The engagement of food system stakeholders adopted in the creation of this thesis advance current scientific efforts to achieve food system sustainability (Biesbroek et al., 2023). Considering the voice of food system protagonists results in strengthening connections between implementers and policy-makers and also profits from a substantially increased capability of capturing localized priorities and values (Bonisoli et al., 2018). The dialogue with food system stakeholders represents a key approach for answering RQ2 and RQ3. For RQ2 it guaranteed the development of an intervention which mirrors the priorities of local stakeholders as well as an accurate applicability of the designed intervention to the local

context. RQ3 was entirely designed to match a specific need of the school food sector (i.e., to monitor integrated sustainability of school food environments) advanced by stakeholders and ensured relevance and direct applicability of the tool.

However, engaging stakeholders does not come without challenges (Fraser et al., 2006). With respect to top-down approaches – intended as processes where decision-making come from groups of experts only (Khadka and Vacik, 2012)-, participatory approaches are likely to be more time-intensive and highly complex due to the need to simultaneously address different interests and to create a shared vocabulary across actors. In Chapter 2 multiple consultations with stakeholders have been advanced to define the intervention design and organize the functioning of data collection. The downside of involving stakeholders into the research of Chapter 3 was to obtain results which cannot be extensively generalizable at large scale, i.e., in very different school contexts, as the tool has been tailored to reflect regional preferences. For instance, the dimensions covered and the relative importance of each indicator in the composite matrix reflect the perspective of stakeholders and the policy framework in which they operate.

In conclusion, to maximize the positive side effects of participatory approaches, researchers should carefully map the main benefits and drawbacks of using bottom-up versus top-down approaches for their research and find ways to correctly address them in the research design.

Future research directions

The exploration of the three RQs brings forward several research directions.

Firstly, future research should strive for more comparative cross-national studies. The review analysis (Chapter 1) focuses on the positive impacts of SFSCs at the global level, but zooming in on the implications of local or regional initiatives can pave the way for a more contextualized understanding. The creation of repeated evidence of the choice-architecture intervention illustrated in Chapter 2 across countries, dietary contexts and time would be a major step ahead for providing ground to isolate general patterns across national or regional dietary habits. Considering the local pertinence of the tool indicators for soliciting context-based priorities of Italian school canteens, future research can also replicate the methodological design we use for tool development (RQ3) for designing assessment frameworks in different settings within and outside Europe.

Second, the school food sector is one of the many segments of collective catering services. To put the role of the school food sector into perspective with other types of public caterings, a comparative food mass flow analysis complementary to the one developed in Chapter 2, but analyzing hospitals or university canteens would be of support. Attention can also be dedicated to testing the scoring tool presented in Chapter 3 in those different catering sectors. By comparing sustainability scores obtained

from school food environments and hospital or university canteens, conclusions on the degree of sustainability advancements of each of these public catering segments can be drawn.

Lastly, actions in the school food sector have direct and indirect implications for SDGs attainment. As done in Chapter 1, and in line with the ambition of the 2030 Agenda for Sustainable Development (UN, 2015), it would be important for future researchers to quantitatively connect the results of scientific experiments in the school food sector, such as the one conducted in Chapter 2, with quantification of their potential contribution towards the SDGs. Such a scrupulous investigation would be better bridging the science-policy interface and would place the field of research on school food at the crossroads of sustainability transformations for improved food systems.

Policy implications

The methodological developments used for the analysis of the thesis unveil several implications for policymaking.

The review study (Chapter 1) is conducted via the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) which guarantees a transparent and reproducible literature search process across multiple resources (Page et al., 2021a). Therefore, the inventory of benefits, corresponding SDGs and recommended actions we provide with this article represents a high-quality resource for urban governance in food system sustainability transitions both from a scientific as well as a policy-making perspective. Various forms of supply chains have a number of positive implications for sustainable development and specifically for SDGs and Milan Pact attainment. However, policymakers should strive for a balanced perspective and commission a complementary analysis of the negative impacts of SFSCs to evaluate the effects of the selection of SFSCs products in procurement schemes for schools. The deployment of guidelines from public procurers to progressively introduce food products from these chains in schools can be facilitated by national food policies. Tailoring tax or subsidy incentives on procurement schemes at national level would support the market access of these chains and offer a valuable pathway for reaching a vast plethora of consumers.

The study explained in Chapter 2 reports a choice-architecture intervention on the largest, most diverse and methodologically most robustly chosen sample achieved so far in the literature. Particularly we analyze the largest amount of heterogeneity across schools achieved (26 schools) covering the second largest sample of pupils (760) across similar interventions in school canteens. This unique sample, together with the transparently documented internal and external validity of the study design (Roe and Just, 2009), provides results of a generalizability far beyond the one of previous interventions which focus on single or a few education institutions which were not randomly selected. We offer local policymakers actionable insights on where, and where not, this intervention can be implemented to reach the desired

outcome. It is in the hands of policymakers to confront results of this intervention with similar large scale impact analyses on the same school population to draw insights on the comparative effectiveness of interventions, taking into account the cost of implementation of the intervention (close to zero in the case of our choice-architecture experiment) with the magnitude of impact achieved. Additionally, we also provide a solid quantification of food waste flows, measured via direct weighting of foods that can be used to adequately plan future food waste reduction strategies via for example prioritizing measures on the food categories which are currently most wasted.

For designing the sustainability assessment tool for school food environments (Chapter 3), the sustainability assessment procedure proposed by Sala et al. (2015) has been followed which provides a detailed and structured framework for the steps to be explored for designing sustainability assessment tools. By documenting the value judgments, the sustainability principles and targets, the decision context and the methodological choices on which the tool is based we provide researchers and policy practitioners full transparency on the methodological choices taken. Applications of the tool proposed in Chapter 3 offer valuable inputs for schools' coordinators and local governments to identify specific weaknesses in school food sustainability advancements. The sustainability scoring presented offers results separately per sustainability dimension helping decision-makers to understand clearly the tradeoffs and plan specific actions to improve the sustainability performances of their school food environments.

Conclusions

We set out three research questions (RQs) and we develop three chapters where answers for each question are provided. A summary of the answers for each of the RQ is listed in Table 1, while the full methodological details along with strengths and limitations of each answer are discussed in each Chapter. In Chapter 1 the thesis provides the first exhaustive inventory of the benefits of short chains reported in the literature and analyses their links to core global sustainability goals. The review systematically collects, structures, and analyses the existing scientific and grey literature on these benefits. It classifies and uniquely connects them with specific SDGs and recommended actions of the Milan Urban Food Policy Pact to understand to which extent the benefits of these chains match the globally set policy ambitions (RQ1). Results, highlighted in several multidimensional infographics, prove that these benefits make a major contribution to the attainment of 10 SDG targets and 9 Milan Pact recommended actions. Also, we find that research on short food chains has been concentrated in Europe and Northern America and has been dominated by qualitative analyses.

Chapter 2 measures the effectiveness of a choice-architecture intervention on 3rd grade children in primary schools for reducing food waste. The intervention is co-designed with school catering stakeholders and consists in inverting the sequence in which school lunch dishes assembled in the context of the Mediterranean diet are served. 26 Italian schools are randomly selected and randomly assigned to control and treatment groups via a randomized-control trial design (RQ2). Results demonstrate that serving the side dish of vegetables before all other courses does not prove effective in reducing vegetable waste across the full sample of schools, although heterogeneous changes in vegetable food waste are observed when analyzing school clusters in each district separately. The same applies to the impact of serving vegetables first on the quantity of the first and second course wasted.

Chapter 3 develops an innovative assessment tool to evaluate the nutritional, environmental, and social sustainability of school food environments. The tool aims to provide practitioners with an easy-to-use mechanism to evaluate the sustainability of the school eating environment (RQ3). Based on a participatory action research design, 25 stakeholders are engaged in a participatory process to define a list of indicators for school food environments assessment on the nutritional, environmental, and social targets. The assessment tool is composed of 42 comprehensive indicators of which 28 indicators are designed for off-site evaluation of menus while 14 are for the on-site inspection of school canteens. Of these, 23 are related to nutritional, 10 to environmental and 9 to social sustainability. The weights of each indicator correspond to the type of scoring system assigned to each of them. The composite score for the three sustainability dimensions is obtained by a summation of all indicators.

Table 1. Answers to the research questions explored in the thesis.

Research question (RQ)	Answer (A)
RQ1: *What is the potential of short food supply chains for accelerating progress towards the international policy goals for food system sustainability transformations?*	*A1: Short food supply chains have been reported to contribute to reaching ten Sustainable Development Goals targets and nine Milan Urban Food Policy Pact recommended actions.*
RQ2: *Does the choice-architecture intervention of changing the sequence in which school canteens dishes are served promote sustainable diets by reducing vegetable food waste?*	*A2: Serving the vegetable side dish as a first course does not have a homogenous effect on decreasing vegetable food waste across all sampled schools, for some districts a significant effect is detected for others not.*
RQ3: *How to measure the sustainability of school canteens by integrating their nutritional implications with their environmental and social effects?*	*A3: A sustainability assessment tool is developed which incorporates 42 indicators which measure complementary dimensions of nutritional, environmental, and social sustainability of school food environments.*

Source: Authors.

Further research and policy implications are also suggested for each of the three RQs to prioritize the next scientific efforts that can be beneficial for maximizing the potential of school environments.

In conclusion, the current thesis contributes to the body of literature with extensive evidence on multiple aspects of school food environments and their sustainability improvements. The growing demand for investigations, data interpretations and sustainability tools in the context of school feeding, requires redoubled commitment bridging researchers, politicians, and civil-society stakeholders towards common objectives. In the wake of this awareness, such research is key in accompanying the many platforms, policy developments and governance structures currently emerging to improve school food environments, in line with the UN commitment, the School Meal Coalition and the Milan Urban Food Policy Pact.

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Supplementary Materials

Supplementary Materials – Chapter 1

Supplementary Figure A. Documentation of the Literature Review.

*Documents not being in suitable formats for the analysis (i.e., conference proceedings, newspapers).
Source: Authors.

Supplementary Table A. Description of the database and search query.

Database	Search query
Scopus	*((TITLE-ABS-KEY (("short food supply chain*" OR "local food system*" OR "alternative food network*" OR ("food" AND "on-farm selling") OR ("food" AND "farmer* market*") OR ("food" AND "farmer* shop*") OR "community supported agriculture" OR ("food" AND "box scheme*") OR ("food" AND "solidarity purchasing*

	group") OR ("food" AND "consumer* managed shop*")) AND ("benefit*" OR "positive impact*")))) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (EXCLUDE (PUBYEAR , 1999) OR EXCLUDE (PUBYEAR , 1998) OR EXCLUDE (PUBYEAR , 1996) OR EXCLUDE (PUBYEAR , 1995) OR EXCLUDE (PUBYEAR , 1981)) AND (LIMIT-TO (LANGUAGE , "english"))*

Source: Authors.

Supplementary Table B. Bibliography of the 69 studies resulting from the PRISMA method.

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Source: Authors.

Supplementary Table C. Examples of the data analysis process.

Raw text line of benefits from literature	Coding through keywords extraction	Categorisation in subcategory and pillar	Policy objective content extraction
Expand knowledge about the production and consumption of food that they would not have acquired in a conventional market relationship	Expand knowledge; production; consumption	Communication (Information)	**RA 19:** Promote participatory education, training, and research (..) to increase social and economic equity (..) and facilitate access to adequate and nutritious foods. **SDG 12.8:** (..) ensure that people everywhere have the relevant information and awareness for sustainable development (..)
Carries out an essential role in preserving the culture of mountain pasture cheesemaking and protecting the rural landscape and the biodiversity of the meadows	mountain pasture; preserving; biodiversity	Biodiversity (Environment)	**RA 22:** Apply an ecosystem approach (..) to enhance opportunities for agroecological production, conservation of biodiversity and farmland, climate change adaptation, tourism, leisure and other ecosystem services. **SDG 15.4:** (..) ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development

Source: Authors.

Supplementary Table D. Benefits categories, subcategories and short description.

Categories	Subcategories	Short description
Product quality	Freshness	Providing fresh products
	Safety	Providing food with reduced risks of foodborne diseases
	Taste	Providing food with improved organoleptic characteristics
	Certification	Providing food which is certified formally or informally
	Speciality	Providing food which respect local traditions and characteristics
	Nutritional value[1]	Providing food which is nutritionally adequate
	Appearance or display[2]	Improved food's colour, shape, uniformity and mass, and optical characteristics
Space and time	Short distance and time[3]	Food which is local and convenient from a space and time perspective
	No preservation[4]	Food with minimum processing for food preservation
Information	Label	Food complemented by a label
	Traceability and transparency[5]	Information on the origin of the food, on the way it is produced and distributed
	Communication	Opportunities for education, learning and knowledge exchange on food
Economy	Price	Prices which are profitable for producers and good for consumers
	Profitability	Higher savings and lower costs leading to increased profitability
	Job	Providing employment occasions
	Income	Sustainable revenues for farmers
	Local development	Support the local communities
Environment	Production pollution	Reduce usage of chemicals and pesticides
	Water usage	Adequacy of water use
	Energy usage	Adequacy of energy use
	Food waste	Efficiency of food waste management
	Biodiversity[1]	Safeguard marine and land biodiversity
	Animal welfare[1]	Farming systems that improve life conditions of animals
Society	Health	Improved physical and psychological well-being of producers and consumers
	Relationship[6]	Development of relationships, linkages and networks
	Fairness	People are treated with just behaviours
	Trust	Strengthen reliance and confidence
	Culture	Strengthen the cultural heritage of the food supply chain

Novelties with respect to Hoang et al (2021):

[1]Inlcuded from Doernberg et al. (2022).

[2] Moved from 'Information' to 'Product quality' since considered among the sensory attributes that influence quality perception (Mihafu F. D, Issa J. Y, Kamiyango M. W. Implication of Sensory Evaluation and Quality Assessment in Food Product Development: A Review. Curr Res Nutr Food Sci 2020)

[3]Aggregated in one subcategory since both refer to geographic proximity of production and consumption.

[4]Pre-processing included in no-preservation since having an overlapping meaning.

[5]Traceability coupled with transparency, since having cross-cutting meaning.

[6] Linkage included in the relationship subcategory.

Source: Authors.

Supplementary Table E. Sample sizes and methodologies used by the 69 documents considered.

Year	Document	Sample Size	Methodology[1]					
			Observation	Survey	Mathematical Modelling	Inter-view	Focus Group	Others
2001	Trobe (2001)	146 customers		x				
2004	Goland & Bauer (2004)	10 growers						x
2006	Kirwan (2006)	40 producers and 37 consumers		x				
	Lea et al. (2006)	20 consumers and 12 farmers				x		
2007	Forbes & Harmon (2007)	17 SFSCs		x		x		
2008	Smithers et al. (2008)	237 individuals						x
2009	Conner et al. (2009)	699 individuals		x			x	x
2010	Colasanti et al. (2010)	63 individuals				x	x	
	Iizaka & Suda (2010)	72 farmers		x				
2011	Alonso & O'Neill (2011)	572 consumers		x				
	Brinson et al. (2011)	17 SFSCs				x		
2012	Slow Food & Slow Food Foundation for Biodiversity (2012)	1 SFSC						x
		1 SFSC						x
		1 SFSC						x
		1 SFSC						x
		1 SFSC						x
		1 SFSC						x
		1 SFSC						x
		1 SFSC						x
		1 SFSC						x
		1 SFSC						x
2013	Pole & Gray (2013)	565 consumers		x				
		1 SFSC		x		x	x	x
	Kneafsey et al. (2013)	1 SFSC		x			x	x
		1 SFSC		x			x	x
2014	Alia et al. (2014)	61 individuals	x					
	Dodds et al. (2014)	300 consumers		x				
	Galzki et al. (2014)	11 regions			x			
	McClenachan et al. (2014)	15 SFSCs				x		x
	Poulsen et al. (2014)	28 individuals				x	x	
2015	Bimbo et al. (2015)	NR[2]						x
	Cook et al. (2015)	NR[2]	x			x		
	Drake & Lawson (2015)	445 individuals		x				

	Lavín et al. (2015)	452 individuals		x		x		
	Simoncini (2015)	2 SFSCs						x
2016	de Luca et al. (2016)	2 SFSCs						x
	Giampietri et al. (2016)	503 consumers		x				
	Lowery et al. (2016)	24 SFSCs						x
	FAO/INRA (2016)	4 SFSCs		x		x	x	
		NR[2]	x			x		x
2017	Bellante (2017)	51 individuals		x		x		
	Bosworth & Hegarty (2017)	401 individuals		x				
	Brinkley (2017)	1 country				x		
	Chaparro Africano & Calle Collado (2017)	10 SFSCs				x		
	Cotter et al. (2017)	28 individuals					x	
	Maestripieri (2017)	2965 individuals		x				
	Rossi et al. (2017)	255 individuals		x				x
2018	Benedek et al. (2018)	156 individuals		x				
	Crawford et al. (2018)	633 customers		x				
	Paul (2018)	16 individuals		x				
	Romagnoli et al. (2018)	488 individuals		x				
	FAO/MUFPP (2018)	1 SFSC						x
	FAO/MUFPP (2018b)	1 SFSC						x
2019	Birtalan et al. (2019)	35 individuals		x				
	Carlson & Bitsch (2019)	4 SFSCs	x			x		x
	Galt et al. (2019)	1558 individuals and 111 farmers		x				
	Harrison et al. (2019)	20 individuals				x		x
	Matzembacher & Meira (2019)	32 individuals	x			x		x
	Samoggia et al. (2019)	35 farmers				x		
	Schoolman (2019)	Longitudinal data for 1 country						x
	Zhang et al. (2019)	625 farmers		x				
2020	Basu et al. (2020)	Nationally representative data of 1 country			x			
	Diekmann et al. (2020)	874 individuals		x				
	Feuerstein-Simon et al. (2020)	60 individuals						x

	Hendrickson et al. (2020)	114 participants					x	
	Koutsou & Sergaki (2020)	912 consumers		x				
	Maier et al. (2020)	9 individuals				x		x
	Pato (2020)	5 individuals						
	Sanyé-Mengual et al. (2020)	406 individuals		x				
	Schoolman (2020)	698 growers		x				
	Testa et al., (2020)	1 SFSC		x				
2021	Borsatto et al. (2021)	NR[2]		x				
	Bui et al. (2021)	338 farmers		x		x		
	Butterfield & Ramírez (2021)	411 individuals						
	Escobar-López et al. (2021)	159 individuals		x				
	Havadi-Nagy (2021)	NR[2]		x				x
	Hoang (2021)	93 individuals				x	x	
	Medici et al. (2021)	9 SFSCs	x			x		
	Röhrig et al. (2021)	9 SFSCs				x		
	Van Vlaanderen et al. (2021)	58 individuals		x				
	Wang et al. (2021)	532 individuals		x				
		Total Number	**6**	**37**	**2**	**23**	**10**	**32**
		Percentage (%)	**5**	**34**	**2**	**21**	**9**	**29**

[1] Short explanation of each research methodology. **Observation:** Includes several techniques of participants and field observations. **Survey:** Includes questionnaire types with open-ended and closed question. **Mathematical Modelling:** Includes microsimulation models, and scenarios building. **Interview:** Includes interactive forms of data collection such as face-to-face, via phone or online. **Focus Group:** Includes group discussions to collect views, ideas, opinions. **Others:** Include audits, desk analysis, case studies and secondary data collection.

[2] NR, Not reported

Source: Authors.

Supplementary Table F. Entropy concentration index (S) (a) across categories (b) within sub-categories, (c) of benefits categories across organisational structures, (d) of organisational structures across benefits categories and (e) of organisational structures across continents.

	Variable	S
(a)	Benefits categories	0.895
(b)	Economy subcategories	0.962
	Product quality subcategories	0.863
	Environment subcategories	0.819
	Society subcategories	0.774
	Space and time subcategories	0.650
	Information subcategories	0.486
(c)	Economy	0.874
	Product quality	0.832
	Society	0.818
	Environment	0.752
	Space and Time	0.695

	Information	0.637
(d)	SSC	0.918
	CSA	0.881
	Others	0.863
	FM	0.849
	AFN	0.840
	LFS	0.648
	BS	0.564
	SPG	0.387
(e)	CSA	0.689
	FM	0.672
	SSC	0.653
	LFS	0.523
	AFN	0.515
	Others	0.386
	BS	0.251
	SPG	0

Source: Authors

Supplementary Table G. Organisational structures of short food supply chains considered in the study,

Organisational structure	Short description	Source
Alternative food network (AFN)	"[..] a broad embracing term to cover newly emerging networks of producers, consumers, and other actors that embody alternatives to the more standardised industrial mode of food supply [...]"	Rentin et al. (2003)[1]
Box scheme (BS)	"A box-scheme entails a subscription by customers (or groups of customers) to the regular (weekly, biweekly, monthly) delivery of a specific quantity of fresh vegetables and fruits, the offering varying according to the season and availability at the farm."	Belletti and Marescotti (2020)[2]
Community supported agriculture (CSA)	"[..] a direct partnership based on the human relationship between people and one or several producer(s), whereby the risks, responsibilities and rewards of farming are shared, through a long-term, binding agreement."	Urgenci (2016)[3]
Farmers market (FM)	"[..] recurrent markets at fixed locations where farm products are sold directly by farmers themselves with a common organization and under a same image and/or some shared rules."	Belletti and Marescotti (2020)[2]; Brown (2001)[4]
Local food system (LFS)	System where "[..] a product that has been produced close to the consumption area or, to be more precise, close to the place of purchase (a shop, a restaurant, a farm)."	Belletti and Marescotti (2020)[2]
Others	This naming includes extra types of SFSCs such as peasant farming, urban agriculture and Slow Food Presidium which were not catalogued by Belletti and Marescotti (2020)[2] but emerged from the collected literature.	-
Short supply chain (SSC)	General term to define "a supply chain involving a limited number of economic operators, committed to co-operation, local economic development, and close geographical and social relations between producers, processors and consumers."	Regulation (EU) No 1305/2013[5]
Solidarity purchasing group (SPG)	"Groups of consumers who purchase collectively through a direct relationship with producers, according to shared ethical principles."	Belletti and Marescotti (2020)[2]; Brunori et al. (2012)[6]

with short description and source.

[1] Renting, H., Marsden, TK., and Banks, J. (2003). Understanding alternative food networks: exploring the role of short food supply chains in rural development. Environment and Planning A, 35

[2] Belletti, G., & Marescotti, A. (2020). Short Food Supply Chains for Promoting Local Food on Local Markets. *United Nations Industrial Development Organization*, 56.

[3] Urgenci (2016). European Declaration on Community Supported Agriculture. https://urgenci.net/wp-content/uploads/2016/09/European-CSA-Declaration_final-1.pdf

[4] Brown A. (2001), "Counting farmers' markets", Geographical Review, 91(4), pp.655-674.

[5] European Union. (2013). REGULATION (EU) No 1305/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 december 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005. In *Official Journal of the European Union* (Issue 1305).

[6] Brunori G., Rossi A., Malandrin V. (2010), "Co-producing transition: innovation processes in farms adhering to Solidarity-based Purchase Groups (GAS) in Tuscany, Italy", International Journal of Sociology of Agriculture & Food, 18(1), pp.28-53

Source: Authors.

Supplementary Table H. Number (N.) and percentage (%) of benefits in each pillar and chain organisational structure.

Benefits pillar	Community Supported Agriculture		Others		Short supply chains		Farmers Markets		Alternative Food Networks		Local Food Systems		Box Schemes		Solidarity Purchasing Groups	
	N.	%	N.	%	N.	%	N.	%	N.	%	N.	%	N.	%	N.	%
Products quality	13	27%	8	17%	11	23%	9	19%	3	6%	1	2%	3	6%	0	0%
Space and Time	4	33%	1	8%	4	33%	2	17%	1	8%	0	0%	0	0%	0	0%
Information	10	33%	12	40%	5	17%	1	3%	2	7%	0	0%	0	0%	0	0%
Economy	15	21%	11	15%	19	26%	10	14%	12	16%	3	4%	2	3%	1	1%
Environment	15	24%	22	35%	14	22%	3	5%	4	6%	5	8%	0	0%	0	0%
Society	40	33%	29	24%	21	17%	12	10%	9	7%	9	7%	1	1%	1	1%
Total	**97**	**28%**	**83**	**24%**	**74**	**21%**	**37**	**11%**	**31**	**9%**	**18**	**5%**	**6**	**2%**	**2**	**1%**

Source: Authors.

Supplementary Table I. List of benefits by category, subcategory, document, organisational structure, continent, qualitative and quantitative, SDGs targets and MUFPP RA.

Category	Subcategory	Document	Organisational structure	Continent	Qualitative or quantitative	SDGs target	MUFPP RA
Society	Relationship	Alia et al. (2014)	Farmers market	North America	Qualitative	11.a	18
	Relationship	Alonso et O'Neill (2011)	Farmers market	North America	Qualitative	10.2	18
	Relationship	Bellante (2017)	Alternative Food Network	South America	Qualitative	11.a	18
	Relationship	Bellante (2017)	Alternative Food Network	South America	Qualitative	11.a	24
	Relationship	Bellante (2017)	Alternative Food Network	South America	Qualitative	10.2	17
	Relationship	Birtalan et al. (2019)	Community Supported Agriculture	Europe	Qualitative	11.a	18
	Relationship	Borsatto et al. (2021)	Local Food System	South America	Qualitative	10.2	18
	Relationship	Bosworth, et al. (2017)	Community Supported Agriculture	Europe	Qualitative	10.2	18
	Relationship	Bosworth, et al. (2017)	Community Supported Agriculture	Europe	Qualitative	17.17	18

	Relationship	Brinkley (2017)	Local Food System	North America	Qualitative	11.a	18
	Relationship	Brinkley (2017)	Local Food System	North America	Qualitative	17.17	18
	Relationship	Brinson et al. (2011)	Community Supported Agriculture	North America	Qualitative	11.a	32
	Relationship	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	17.17	2
	Relationship	Carlson et al (2019)	Community Supported Agriculture	Europe	Qualitative	10.2	18
	Relationship	Carlson et al (2019)	Community Supported Agriculture	Europe	Qualitative	11.a	18
	Relationship	Conner et al. (2009)	Farmers market	North America	Qualitative	11.a	32
	Relationship	Crawford et al. (2018)	Farmers market	Oceania	Qualitative	11.a	18
	Relationship	De Luca et al. (2016)	Alternative Food Network	Europe	Qualitative	11.a	32
	Relationship	Dodds et al. (2014)	Farmers market	North America	Qualitative	11.a	32
	Relationship	Dodds et al. (2014)	Farmers market	North America	Qualitative	10.2	18
	Relationship	Drake & Lawson (2015)	Community Supported Agriculture	North America	Qualitative	10.2	18
	Relationship	Feuerstein-Simon et al. (2020)	Community Supported Agriculture	North America	Qualitative	12.8	19
	Relationship	Hendrickson et al. (2020)	Local Food System	North America	Qualitative	11.a	18
	Relationship	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	11.a	32
	Relationship	Iizaka et al. (2010)	Farmers market	Asia	Qualitative	11.a	32
	Relationship	Kirwan (2006)	Farmers market	Europe	Qualitative	11.a	32
	Relationship	Kirwan (2006)	Farmers market	Europe	Qualitative	11.a	32
	Relationship	Koutsou & Sergaki(2020)	Short Food Supply Chain	Europe	Qualitative	11.a	17

	Relationship	Lea et al. (2006)	Community Supported Agriculture	Oceania	Qualitative	11.a	32
	Relationship	Lea et al. (2006)	Community Supported Agriculture	Oceania	Qualitative	11.a	32
	Relationship	Matzembacher et al. (2019)	Community Supported Agriculture	South America	Qualitative	10.2	18
	Relationship	Medici et al. (2021)	Community Supported Agriculture	Europe	Qualitative	10.2	19
	Relationship	Poulsen et al. (2014)	Community Supported Agriculture	North America	Qualitative	10.2	17
	Relationship	Poulsen et al. (2014)	Community Supported Agriculture	North America	Qualitative	11.a	18
	Relationship	Romagnoli et al. (2018)	Short Food Supply Chain	South America	Qualitative	11.a	18
	Relationship	Romagnoli et al. (2018)	Short Food Supply Chain	South America	Qualitative	11.a	18
	Relationship	Romagnoli et al. (2018)	Short Food Supply Chain	South America	Qualitative	11.a	18
	Relationship	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	10.2	18
	Relationship	Samoggia et al. (2019)	Community Supported Agriculture	North America	Qualitative	11.a	18
	Relationship	Samoggia et al. (2019)	Community Supported Agriculture	North America	Qualitative	11.a	18
	Relationship	Samoggia et al. (2019)	Community Supported Agriculture	North America	Qualitative	11.a	17
	Relationship	Schoolman (2020)	Local Food System	North America	Qualitative	17.17	2
	Relationship	Schoolman (2020)	Local Food System	North America	Qualitative	17.17	2

	Relationship	Smithers et al. (2008)	Farmers market	North America	Qualitative	10.2	18
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	24
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	4.4	21
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	18
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	24
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	24
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	17.17	18
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	18
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	24
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	17.17	2
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	19
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	17.17	18
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	24
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	17.17	2
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	24
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	17.17	12
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	24
	Relationship	Slow Food (2012)	Others	Europe	Qualitative	11.a	18
	Relationship	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	11.a	18
	Relationship	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	11.a	18
	Relationship	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	11.a	19
	Relationship	FAO/INRA (2016)	Community Supported Agriculture	Africa	Qualitative	17.17	2
	Relationship	FAO/INRA (2016)	Box scheme	Africa	Qualitative	10.2	32
	Others	Bellante (2017)	Alternative Food Network	South America	Qualitative	2.3	21
	Others	Bellante (2017)	Alternative Food Network	South America	Qualitative	5.5	21
	Others	Bellante (2017)	Alternative Food Network	South America	Qualitative	2.3	7
	Others	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	5.1	16

	Others	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	10.2	17
	Others	Butterfield et al. (2021)	Community Supported Agriculture	North America	Qualitative	10.2	17
	Others	Carlson et al (2019)	Community Supported Agriculture	Europe	Qualitative	10.2	7
	Others	Carlson et al (2019)	Community Supported Agriculture	Europe	Qualitative	2.3	24
	Others	Carlson et al (2019)	Community Supported Agriculture	Europe	Qualitative	11.a	18
	Others	Chaparro et al. (2017)	Others	South America	Qualitative	10.2	18
	Others	Galzki et al. (2014)	Local Food System	North America	Qualitative	2.1	20
	Others	Hendrickson et al. (2020)	Local Food System	North America	Qualitative	11.4	32
	Others	Lavín et al. (2015)	Alternative Food Network	Oceania	Qualitative	2.5	7
	Others	Maestripietri (2017)	Solidarity purchasing group	Europe	Qualitative	5.5	16
	Others	Paul et al. (2018)	Community Supported Agriculture	North America	Qualitative	2.4	24
	Others	Poulsen et al. (2014)	Community Supported Agriculture	North America	Qualitative	2.4	20
	Others	Sanyé-Mengual et al. (2020)	Others	Europe	Qualitative	11.4	22
	Others	Wang et al. (2021)	Short Food Supply Chain	Asia	Qualitative	11.a	18
	Others	Wang et al. (2021)	Short Food Supply Chain	Asia	Qualitative	11.a	2
	Others	Slow Food (2012)	Others	Europe	Qualitative	2.3	18
	Others	Slow Food (2012)	Others	Europe	Qualitative	4.4	32
	Others	Slow Food (2012)	Others	Europe	Qualitative	8.6	21

	Others	Slow Food (2012)	Others	Europe	Qualitative	11.a	17
	Others	FAO/MUFPP (2018)	Short Food Supply Chain	Europe	Qualitative	13.1	20
	Health	Basu et al. (2020)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Health	Bimbo et al. (2015)	Farmers market	Europe	Qualitative	2.1	8
	Health	Borsatto et al. (2021)	Local Food System	South America	Qualitative	2.1	21
	Health	Chaparro et al. (2017)	Others	South America	Qualitative	2.4	22
	Health	Chaparro et al. (2017)	Others	South America	Qualitative	2.4	7
	Health	Dodds et al. (2014)	Farmers market	North America	Qualitative	2.1	7
	Health	Drake & Lawson (2015)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Health	Escobar-López et al. (2021)	Alternative Food Network	Europe	Qualitative	2.4	7
	Health	Feuerstein-Simon et al. (2020)	Community Supported Agriculture	North America	Qualitative	2.1	28
	Health	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	2.1	7
	Health	Matzembacher et al. (2019)	Community Supported Agriculture	South America	Qualitative	2.1	7
	Health	Pato (2020)	Short Food Supply Chain	Europe	Qualitative	2.1	7
	Health	Poulsen et al. (2014)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Health	Poulsen et al. (2014)	Community Supported Agriculture	North America	Qualitative	2.4	20
	Health	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.1	7

	Health	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Health	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Health	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Health	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	2.4	7
	Culture	Birtalan et al. (2019)	Community Supported Agriculture	Europe	Qualitative	11.4	7
	Culture	Chaparro et al. (2017)	Others	South America	Qualitative	12.8	19
	Culture	Chaparro et al. (2017)	Others	South America	Qualitative	11.4	19
	Culture	Pato (2020)	Short Food Supply Chain	Europe	Qualitative	11.a	32
	Culture	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	11.4	19
	Culture	Samoggia et al. (2019)	Community Supported Agriculture	North America	Qualitative	11.4	7
	Culture	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	11.4	22
	Culture	Slow Food (2012)	Others	Europe	Qualitative	12.8	18
	Culture	Slow Food (2012)	Others	Europe	Qualitative	2.5	24
	Trust	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	11.a	32
	Trust	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	11.a	32
	Trust	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	11.a	18
	Trust	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	11.a	32

Economy	Others	Bellante (2017)	Alternative Food Network	South America	Qualitative	11.a	24
	Others	Bellante (2017)	Alternative Food Network	South America	Qualitative	11.a	17
	Others	Benedek et al. (2018)	Short Food Supply Chain	Europe	Qualitative	2.3	6
	Others	Borsatto et al. (2021)	Local Food System	South America	Qualitative	10.2	18
	Others	Chaparro et al. (2017)	Others	South America	Qualitative	2.3	16
	Others	Chaparro et al. (2017)	Others	South America	Qualitative	2.3	24
	Others	Cook et al. (2015)	Others	Asia	Qualitative	2.3	16
	Others	Havadi-Nagy (2021)	Alternative Food Network	Europe	Qualitative	2.3	24
	Others	Iizaka et al. (2010)	Farmers market	Asia	Qualitative	2.3	24
	Others	Kirwan (2006)	Farmers market	Europe	Qualitative	11.a	32
	Others	Koutsou & Sergaki(2020)	Short Food Supply Chain	Europe	Qualitative	2.3	24
	Others	Lavín et al. (2015)	Alternative Food Network	Oceania	Qualitative	2.1	7
	Others	Lea et al. (2006)	Community Supported Agriculture	Oceania	Qualitative	2.3	24
	Others	Medici et al. (2021)	Community Supported Agriculture	Europe	Qualitative	11.a	17
	Others	Trobe (2001)	Farmers market	Europe	Qualitative	2.3	24
	Others	Zhang et al. (2019)	Short Food Supply Chain	Asia	Qualitative	2.3	6
	Others	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.3	24
	Profitability	Bellante (2017)	Alternative Food Network	South America	Qualitative	2.4	11
	Profitability	Brinson et al. (2011)	Community Supported Agriculture	North America	Qualitative	2.3	24

	Profitability	Carlson et al (2019)	Community Supported Agriculture	Europe	Qualitative	2.3	24
	Profitability	Chaparro et al. (2017)	Others	South America	Qualitative	2.3	16
	Profitability	Forbes & Harmon (2007)	Community Supported Agriculture	North America	Qualitative	2.3	7
	Profitability	Galt et al. (2019)	Community Supported Agriculture	North America	Qualitative	2.3	16
	Profitability	Hoang (2021)	Short Food Supply Chain	Asia	Quantitative	2.3	16
	Profitability	Kirwan (2006)	Farmers market	Europe	Qualitative	2.3	24
	Profitability	Maestripietri (2017)	Solidarity purchasing group	Europe	Qualitative	2.3	32
	Profitability	Paul et al. (2018)	Community Supported Agriculture	North America	Qualitative	2.3	16
	Profitability	Testa et al. (2020)	Alternative Food Network	Europe	Qualitative	2.3	24
	Profitability	Zhang et al. (2019)	Short Food Supply Chain	Asia	Qualitative	2.3	24
	Profitability	Slow Food (2012)	Others	Europe	Qualitative	15.4	24
	Profitability	FAO/INRA (2016)	Box scheme	Africa	Quantitative	2.3	24
	Local Development	Crawford et al. (2018)	Farmers market	Oceania	Qualitative	2.3	21
	Local Development	Dodds et al. (2014)	Farmers market	North America	Qualitative	11.a	18
	Local Development	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	11.a	21
	Local Development	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	11.a	20
	Local Development	Kirwan (2006)	Farmers market	Europe	Qualitative	11.a	18

	Local Development	Pato (2020)	Short Food Supply Chain	Europe	Qualitative	11.a	16
	Local Development	Samoggia et al. (2019)	Community Supported Agriculture	North America	Qualitative	11.a	21
	Local Development	Smithers et al. (2008)	Farmers market	North America	Qualitative	2.3	18
	Local Development	Slow Food (2012)	Others	Europe	Qualitative	11.a	7
	Local Development	Slow Food (2012)	Others	Europe	Qualitative	4.4	32
	Local Development	Slow Food (2012)	Others	Europe	Qualitative	11.a	22
	Local Development	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	11.a	7
	Local Development	FAO/INRA (2016)	Community Supported Agriculture	Africa	Qualitative	2.3	22
	Local Development	FAO/MUFPP (2018)	Local Food System	Asia	Qualitative	11.a	16
	Price	Bellante (2017)	Alternative Food Network	South America	Qualitative	2.c	24
	Price	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	2.3	24
	Price	Chaparro et al. (2017)	Others	South America	Qualitative	2.c	24
	Price	Havadi-Nagy (2021)	Alternative Food Network	Europe	Qualitative	2.c	24
	Price	Hoang (2021)	Short Food Supply Chain	Asia	Quantitative	2.c	24
	Price	Iizaka et al. (2010)	Farmers market	Asia	Qualitative	2.c	24

	Price	Lea et al. (2006)	Community Supported Agriculture	Oceania	Qualitative	2.1	7
	Price	Röhrig et al. (2021)	Alternative Food Network	Europe	Qualitative	2.c	24
	Price	Romagnoli et al. (2018)	Short Food Supply Chain	South America	Qualitative	2.c	17
	Price	Slow Food (2012)	Others	Europe	Qualitative	2.c	24
	Price	Slow Food (2012)	Others	Europe	Qualitative	2.c	24
	Price	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.c	7
	Price	FAO/INRA (2016)	Box scheme	Africa	Qualitative	2.3	24
	Income	Benedek et al. (2018)	Short Food Supply Chain	Europe	Qualitative	10.1	24
	Income	Brinson et al. (2011)	Community Supported Agriculture	North America	Qualitative	2.3	16
	Income	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	2.3	24
	Income	Giampietri et al. (2016)	Farmers market	Europe	Qualitative	2.3	16
	Income	Havadi-Nagy (2021)	Alternative Food Network	Europe	Qualitative	2.3	16
	Income	Hoang (2021)	Short Food Supply Chain	Asia	Quantitative	10.1	16
	Income	Matzembacher et al. (2019)	Community Supported Agriculture	South America	Qualitative	10.1	16
	Income	Paul et al. (2018)	Community Supported Agriculture	North America	Qualitative	10.1	16
	Income	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	2.3	16
	Income	Testa et al. (2020)	Alternative Food Network	Europe	Qualitative	10.1	16
	Income	FAO/MUFPP (2018)	Local Food System	Asia	Qualitative	2.3	32
	Job	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	8.5	16

	Job	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	8.5	16
	Job	Havadi-Nagy (2021)	Alternative Food Network	Europe	Qualitative	8.5	16
	Job	FAO/INRA (2016)	Community Supported Agriculture	Africa	Qualitative	11.a	16
Environment	Production pollution	Borsatto et al. (2021)	Local Food System	South America	Qualitative	2.4	22
	Production pollution	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	2.4	22
	Production pollution	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	2.4	26
	Production pollution	Conner et al. (2009)	Farmers market	North America	Qualitative	2.4	22
	Production pollution	Crawford et al. (2018)	Farmers market	Oceania	Qualitative	2.4	22
	Production pollution	Forbes & Harmon (2007)	Community Supported Agriculture	North America	Qualitative	2.4	22
	Production pollution	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	2.4	7
	Production pollution	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	2.4	7
	Production pollution	Lea et al. (2006)	Community Supported Agriculture	Oceania	Qualitative	2.4	7
	Production pollution	McClenachan et al. (2014)	Community Supported Agriculture	North America	Qualitative	14.2	22
	Production pollution	Medici et al. (2021)	Community Supported Agriculture	Europe	Qualitative	2.4	22
	Production pollution	Medici et al. (2021)	Community Supported Agriculture	Europe	Qualitative	2.4	22
	Production pollution	Pato (2020)	Short Food Supply Chain	Europe	Qualitative	2.4	22

	Production pollution	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	2.4	22
	Production pollution	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	2.4	22
	Production pollution	Schoolman (2019)	Local Food System	North America	Qualitative	2.4	22
	Production pollution	Slow Food (2012)	Others	Europe	Qualitative	2.4	7
	Production pollution	Slow Food (2012)	Others	Europe	Qualitative	2.4	22
	Production pollution	Slow Food (2012)	Others	Europe	Qualitative	2.4	22
	Production pollution	Slow Food (2012)	Others	Europe	Qualitative	2.4	22
	Production pollution	FAO/INRA (2016)	Community Supported Agriculture	Africa	Qualitative	2.1	7
	Biodiversity	Borsatto et al. (2021)	Local Food System	South America	Qualitative	2.4	22
	Biodiversity	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	2.4	22
	Biodiversity	Goland et al. (2004)	Local Food System	North America	Qualitative	15.5	7
	Biodiversity	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	15.5	22
	Biodiversity	Iizaka et al. (2010)	Farmers market	Asia	Qualitative	2.5	22
	Biodiversity	McClenachan et al. (2014)	Community Supported Agriculture	North America	Qualitative	14.4	22
	Biodiversity	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	15.5	22
	Biodiversity	Simonicini (2015)	Alternative Food Network	Europe	Qualitative	2.5	22
	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	2.5	7
	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	2.5	7
	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	2.5	22

	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	2.5	22
	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	2.5	22
	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	2.5	22
	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	15.4	22
	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	2.5	22
	Biodiversity	Slow Food (2012)	Others	Europe	Qualitative	15.4	22
	Others	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	2.4	22
	Others	Chaparro et al. (2017)	Others	South America	Qualitative	2.4	22
	Others	Cook et al. (2015)	Others	Asia	Qualitative	2.4	24
	Others	Escobar-López et al. (2021)	Alternative Food Network	Europe	Qualitative	2.4	20
	Others	Havadi-Nagy (2021)	Alternative Food Network	Europe	Qualitative	2.4	7
	Others	Hendrickson et al. (2020)	Local Food System	North America	Qualitative	2.4	21
	Others	McClenachan et al. (2014)	Community Supported Agriculture	North America	Qualitative	14.2	22
	Others	McClenachan et al. (2014)	Community Supported Agriculture	North America	Qualitative	14.2	22
	Others	McClenachan et al. (2014)	Community Supported Agriculture	North America	Qualitative	13.3	19
	Others	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.4	7
	Others	Sanyé-Mengual et al. (2020)	Others	Europe	Qualitative	2.4	22
	Others	Slow Food (2012)	Others	Europe	Qualitative	2.4	7
	Others	Slow Food (2012)	Others	Europe	Qualitative	2.4	22
	Others	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.4	7
	Animal welfare	Slow Food (2012)	Others	Europe	Qualitative	2.4	7
	Animal welfare	Slow Food (2012)	Others	Europe	Qualitative	2.4	7

	Animal welfare	Slow Food (2012)	Others	Europe	Qualitative	2.4	22
	Animal welfare	Slow Food (2012)	Others	Europe	Qualitative	2.4	7
	Food waste	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	12.5	37
	Food waste	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	12.3	37
	Food waste	McClenachan et al. (2014)	Community Supported Agriculture	North America	Qualitative	14.4	22
	Energy usage	Bui et al. (2021)	Short Food Supply Chain	Asia	Qualitative	2.4	28
	Energy usage	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	2.4	22
	Water usage	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	6.4	26
	Water usage	Maier et al. (2020)	Alternative Food Network	Europe	Qualitative	6.3	26
Products quality	Others	Bellante (2017)	Alternative Food Network	South America	Qualitative	2.1	7
	Others	Borsatto et al. (2021)	Local Food System	South America	Qualitative	2.1	28
	Others	Conner et al. (2009)	Farmers market	North America	Qualitative	2.1	7
	Others	Cotter et al. (2017)	Others	North America	Qualitative	2.1	7
	Others	Dodds et al. (2014)	Farmers market	North America	Qualitative	2.1	7
	Others	Dodds et al. (2014)	Farmers market	North America	Qualitative	2.1	7
	Others	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	2.1	7
	Others	Lavín et al. (2015)	Alternative Food Network	Oceania	Qualitative	2.1	7
	Others	Matzembacher et al. (2019)	Community Supported Agriculture	South America	Qualitative	2.1	7
	Others	Romagnoli et al. (2018)	Short Food Supply Chain	South America	Qualitative	2.1	7

	Others	Smithers et al. (2008)	Farmers market	North America	Qualitative	2.1	7
	Others	van Vlaanderen et al. (2021)	Box scheme	North America	Qualitative	2.1	7
	Others	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.1	7
	Others	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.1	7
	Freshness	Colasanti et al. (2010)	Farmers market	North America	Qualitative	2.1	8
	Freshness	Crawford et al. (2018)	Farmers market	Oceania	Qualitative	2.1	8
	Freshness	Diekmann et al. (2020)	Others	North America	Qualitative	2.1	8
	Freshness	Feuerstein-Simon et al. (2020)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Freshness	Forbes & Harmon (2007)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Freshness	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	2.1	7
	Freshness	Kirwan (2006)	Farmers market	Europe	Qualitative	2.1	7
	Freshness	Lea et al. (2006)	Community Supported Agriculture	Oceania	Qualitative	2.1	7
	Freshness	Lowery et al. (2016)	Farmers market	North America	Qualitative	2.1	8
	Freshness	Pole and Gray (2013)	Community Supported Agriculture	North America	Qualitative	2.1	7
	Freshness	Trobe (2001)	Farmers market	Europe	Qualitative	2.1	7
	Freshness	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.1	7
	Freshness	FAO/INRA (2016)	Community Supported Agriculture	Africa	Qualitative	2.1	8
	Nutritional profile	Chaparro et al. (2017)	Others	South America	Qualitative	2.1	7

	Nutritional profile	Feuerstein-Simon et al. (2020)	Community Supported Agriculture	North America	Qualitative	2.1	8
	Nutritional profile	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.1	8
	Nutritional profile	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.1	8
	Nutritional profile	Samoggia et al. (2019)	Community Supported Agriculture	North America	Qualitative	2.1	8
	Nutritional profile	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	2.1	7
	Nutritional profile	FAO/INRA (2016)	Box scheme	Africa	Qualitative	2.1	7
	Nutritional profile	FAO/INRA (2016)	Box scheme	Africa	Quantitative	2.1	7
	Speciality	De Luca et al. (2016)	Alternative Food Network	Europe	Qualitative	11.4	7
	Speciality	Slow Food (2012)	Others	Europe	Qualitative	11.4	7
	Speciality	Slow Food (2012)	Others	Europe	Qualitative	11.4	7
	Speciality	Slow Food (2012)	Others	Europe	Qualitative	11.4	7
	Speciality	Slow Food (2012)	Others	Europe	Qualitative	11.4	7
	Speciality	Slow Food (2012)	Others	Europe	Qualitative	11.4	7
	Speciality	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	11.4	7
	Certification	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.1	7
	Certification	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.4	28
	Certification	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.4	7
	Taste	Birtalan et al. (2019)	Community Supported Agriculture	Europe	Qualitative	2.1	7
	Taste	Koutsou & Sergaki(2020)	Short Food Supply Chain	Europe	Qualitative	2.1	7

	Safety	Samoggia et al. (2019)	Community Supported Agriculture	North America	Qualitative	2.1	7
Information	Communication	Carlson et al (2019)	Community Supported Agriculture	Europe	Qualitative	12.8	19
	Communication	Chaparro et al. (2017)	Others	South America	Qualitative	2.4	7
	Communication	Drake & Lawson (2015)	Community Supported Agriculture	North America	Qualitative	12.8	19
	Communication	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	12.8	7
	Communication	Kirwan (2006)	Farmers market	Europe	Qualitative	12.8	7
	Communication	Lea et al. (2006)	Community Supported Agriculture	Oceania	Qualitative	12.8	19
	Communication	Matzembacher et al. (2019)	Community Supported Agriculture	South America	Qualitative	12.8	19
	Communication	Matzembacher et al. (2019)	Community Supported Agriculture	South America	Qualitative	12.8	19
	Communication	Röhrig et al. (2021)	Alternative Food Network	Europe	Qualitative	12.8	19
	Communication	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	12.8	19
	Communication	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	12.8	19
	Communication	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	12.8	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	13.3	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19

	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19
	Communication	Slow Food (2012)	Others	Europe	Qualitative	12.8	19
	Communication	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	12.8	19
	Communication	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	4.4	24
	Communication	FAO/INRA (2016)	Community Supported Agriculture	Africa	Qualitative	12.8	24
	Traceability and transparency	Diekmann et al. (2020)	Others	North America	Qualitative	12.8	19
	Traceability and transparency	Matzembacher et al. (2019)	Community Supported Agriculture	South America	Qualitative	12.8	19
	Traceability and transparency	Röhrig et al. (2021)	Alternative Food Network	Europe	Qualitative	12.8	7
	Traceability and transparency	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	12.8	7
	Label	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	2.1	7
Space and	Short distance and time	Chaparro et al. (2017)	Others	South America	Qualitative	2.4	21

	Short distance and time	Dodds et al. (2014)	Farmers market	North America	Qualitative	2.4	20
	Short distance and time	Giampietri et al. (2016)	Farmers market	Europe	Qualitative	11.a	18
	Short distance and time	Harrison et al. (2019)	Short Food Supply Chain	Oceania	Qualitative	2.4	28
	Short distance and time	Havadi-Nagy (2021)	Alternative Food Network	Europe	Qualitative	2.1	24
	Short distance and time	Hoang (2021)	Short Food Supply Chain	Asia	Qualitative	2.1	28
	Short distance and time	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	11.a	7
	Short distance and time	Samoggia et al. (2019)	Community Supported Agriculture	Europe	Qualitative	11.a	7
	Short distance and time	Kneafsey et al. (2013)	Short Food Supply Chain	Europe	Qualitative	11.a	7
	Short distance and time	FAO/MUFPP (2018)	Short Food Supply Chain	Europe	Qualitative	2.1	7
	No preservation	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.1	8
	No preservation	Rossi et al. (2017)	Community Supported Agriculture	North America	Qualitative	2.1	8

Source: Authors.

Supplementary Table J. List of Sustainable Development Goals (SDGs) targets, ordered by the number of reported benefits and distinguished by rich and poor evidence based on percentiles.

	SDG targets	No. of reported benefits	Cumulative no. of reported benefits	Percentile
Targets with rich evidence	11.a	68	68	20
	2.1	63	131	38
	2.4	52	183	53
	2.3	38	221	64
	12.8	29	250	72
	10.2	18	268	77
	11.4	14	282	81
	2.5	11	293	84
	17.17	11	304	87
	2.c	10	314	90
Targets with poor evidence	10.1	5	319	92
	4.4	4	323	93
	8.5	3	326	94
	14.2	3	329	95
	15.4	3	332	95
	15.5	3	335	96
	5.5	2	337	97
	13.3	2	339	97
	14.4	2	341	98
	5.1	1	342	98
	6.3	1	343	99
	6.4	1	344	99
	8.6	1	345	99
	12.3	1	346	99
	12.5	1	347	100
	13.1	1	348	100

Source: Authors.

Supplementary Table K. List of Sustainable Development Goals (SDGs) connected with short food supply chains, their targets, and their short descriptions.

SDGs	SDGs Target	Short description
2	2.1	(..) end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round
	2.3	(..) double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment
	2.4	(..) ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality
	2.5	(..) maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks (..) and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge (..)
	2.c	Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, (..) to help limit extreme food price volatility
4	4.4	(..) increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship
5	5.1	End all forms of discrimination against all women and girls everywhere
	5.5	Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision making in political, economic and public life
6	6.3	(..) improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
	6.4	(..) increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
8	8.5	By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value
	8.6	By 2020, substantially reduce the proportion of youth not in employment, education or training
10	10.1	By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average
	10.2	By 2030, empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status
11	11.4	Strengthen efforts to protect and safeguard the world's cultural and natural heritage

	11.a	Support positive economic, social and environmental links between urban, peri-urban and rural areas (..)
12	12.3	(..) halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains (..)
	12.5	(..) reduce waste generation through prevention, reduction, recycling and reuse
	12.8	(..) ensure that people everywhere have the relevant information and awareness for sustainable development (..)
13	13.1	Strengthen resilience and adaptive capacity to climate related hazards and natural disasters in all countries
	13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
14	14.2	(..) sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, (..) to achieve healthy and productive oceans
	14.4	(..) regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices (..)
15	15.4	(..) ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development
	15.5	Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species
17	17.17	Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships

Source: UN. (2015). Transforming Our World: The 2030 Agenda for Sustainable Development.

Supplementary Table L. List of Recommended Actions (RAs), ordered by the number of connected benefits and distinguished by rich and poor evidence based on percentiles.

	Recommended Action (RAs)	N. of connected benefits	Cumulative n. of connected benefits	Percentile
RAs with rich evidence	RA7	87	87	25
	RA22	43	130	37
	RA24	42	172	49
	RA18	42	214	61
	RA19	30	244	70
	RA16	22	266	76
	RA32	21	287	82
	RA8	12	299	86
	RA17	10	309	89
RAs with poor evidence	RA21	10	319	92
	RA2	7	326	94
	RA20	7	333	96
	RA28	6	339	97
	RA26	3	342	98
	RA6	2	344	99

RA37	2	346	99
RA11	1	347	100
RA12	1	348	100

Source: Authors

Supplementary Table M. List of Milan Urban Food Policy Category and Recommended Actions (RAs), connected to short food supply chains, and their short descriptions.

Category	Recommended Actions (RAs)	Short description
Governance	RA2	Enhance stakeholder participation at the city level through political dialogue
	RA6	Develop a disaster risk reduction strategy
Sustainable diets and nutrition	RA7	Promote sustainable diets
	RA8	Address non-communicable diseases associated with poor diets and obesity
	RA11	Explore regulatory and voluntary instruments
	RA12	Encourage joint action by health and food sectors
Social and economic equity	RA16	Promote decent employment for all
	RA17	Encourage and support social and solidarity economy activities
	RA18	Promote networks and support grassroots activities
	RA19	Promote participatory education, training, and research (..) to increase social and economic equity (..) and facilitate access to adequate and nutritious foods.
Food production	RA20	Promote and strengthen urban and peri-urban food production
	RA21	Seek coherence between the city and nearby rural food production
	RA22	Apply an ecosystem approach (..) to enhance opportunities for agroecological production, conservation of biodiversity and farmland, climate change adaptation, tourism, leisure and other ecosystem services.
	RA24	Help provide services to food producers in and around cities,
	RA26	Improve (waste) water management and reuse
Food supply and distribution	RA28	Support improved food storage, processing, transport and distribution
	RA32	(..) link urban buyers to urban, peri-urban and rural sellers (..) building social cohesion and trust, supporting cultural
Food waste	RA37	Save food by facilitating recovery and redistribution for human consumption of safe and nutritious foods

Source: MUFPP. (2015). Milan Urban Food Policy Pact and Framework for Action.

Supplementary Materials – Chapter 2

Supplementary Table A. Description of the stakeholders involved.

# of stakeholders	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 local sanitary service	Nutritionists and doctors responsible for the regional school meal design	Health
1	Emilia-Romagna regional service of innovation, quality, promotion and internationalisation 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

Supplementary Table B. Stakeholders' involvement for the intervention co-design.

A first workshop was organized to inform stakeholders by introducing them to the steps of an intervention co-design. The second workshop aimed to consult, involve them, and collaborate with them to co-design the intervention. In the first phase of the workshop starting from the priorities of the school food sector, stakeholders were called to define four objectives for the interventions using Miro board (Miro©, 2022). In the second phase of the workshop, stakeholders were then organized into four groups of around 6 participants each as suggested by Agar & MacDonald (1995) to translate the set of identified objectives into the interventions' definition, following the abovementioned steps. In the third workshop stakeholders were guided into the selection of the intervention to be implemented. Each of the proposed interventions went through a collective discussion to identify the resources needed, the timing, and potential challenges and stakeholders agreed on the most proper one accordingly to these criteria. Supplementary Figure A illustrates the stakeholders' participation process.

Source: Authors.

Supplementary Figure A. Flow of the stakeholders' participation process.

Source: Authors.

Supplementary Figure B. Map of the 26 schools included in the analysis.

Source: Authors.

Supplementary Table C. Comparabilty of treatment and control group.

Characteristics	Treatment group	Control group	
N of classes	20	19	
N of schools	13	13	
Average school size*	272.4	200	diff non sign
Average class size	20.2	18.8	diff non sign
Proportion of schools in rural areas **	0.10	0.05	diff non sign
Proportion of schools in coastal areas **	0.10	0.21	diff non sign
Number of catering providers	3	3	

* Source: https://cercalatuascuola.istruzione.it/
** Source: Derugba (Degree of urbanization) classification by EUROSTAT, 2021 - Local Administrative Units (LAU) - NUTS - Nomenclature of territorial units for statistics - Eurostat (europa.eu)
Source: Authors

Supplementary Table D. List of variables collected at class level on the organisation of school meal and food environment.

Factors influencing consumption quantities	Variables used to investigate the factor	Description	Values
Social distraction and canteen crowding (Steen et al., 2018; Liz Martins et al., 2020)	Disposition of lunch tables	How are children sitting during lunch time?	• In individual tables with one child each • In small tables with less than 10 children • In big tables with more than 10 children • Others
Presence of teachers (Liz Martins et al., 2020)	Eating position of teachers	Where do teachers eat?	• Sitting together with the children • Sitting in a separate table • Other
	Behaviour of teachers	Do teachers encourage children to eat?	• Always • Often • Sometimes • Rarely • Never
Education and awareness (Myers et al., 2018)	Presence of informational posters on food waste and healthy eating	In the place where children eat, are there any informational poster on food waste and healthy eating?	• Yes, both on food waste and healthy eating • Yes, either on food waste or healthy eating • No
	Existence of specific rules on eating behaviour	Is there any written or non-written rule on minimum portion children should eat before asking for the next serving?	• Yes • No
	Behaviour of children	Do children complain about the meal?	• Always • Often • Sometimes • Rarely • Never
School location (Boschini et al. 2020)	School location	Where is the school located?	• Urban area (cities) • Rural area • Peri-urban area (towns and suburbs)

Source: Authors

Supplementary Table E. Results of the non-parametric test on ranks (Wilcoxon signed-rank test on the median) on the PF, SF, SW, PW, CF (gr/pupil) between the control and treatment group.

Variable	N of in the Control group	N of in the Treatment group	Exact p-value (bivariate analysis)	p-value lower (univariate analysis)	p-value upper (univariate analysis)
gpPF_FD_PRE_median	94	98	0.856	0.428	0.572
gpPF_SeD_PRE_median	94	98	0.497	0.752	0.248
gpPF_SiD_PRE_median	94	98	0.299	0.15	0.85
gpPF_tot_PRE_median	94	98	0.792	0.396	0.604
gpSF_FD_PRE_median	94	98	0.604	0.302	0.698
gpSF_SeD_PRE_median	94	98	0.838	0.419	0.581
gpSF_SiD_PRE_median	**94**	**98**	**0.079**	**0.039***	**0.961**
gpSF_tot_PRE_median	94	98	0.3	0.15	0.85
gpSW_FD_PRE_median	94	98	0.241	0.88	0.12
gpSW_SeD_PRE_median	94	98	0.257	0.871	0.129
gpSW_SiD_PRE_median	94	98	0.439	0.78	0.22
gpSW_tot_PRE_median	**94**	**98**	**0.14**	**0.93**	**0.07***
gpCF_FD_PRE_median	94	98	0.754	0.623	0.377
gpCF_SeD_PRE_median	94	98	0.389	0.805	0.195
gpCF_SiD_PRE_median	94	98	0.55	0.725	0.275
gpCF_tot_PRE_median	94	98	0.307	0.846	0.154
gpPW_FD_PRE_median	94	98	0.374	0.187	0.813
gpPW_SeD_PRE_median	**94**	**98**	**0.004***	**0.002***	**0.998**
gpPW_SiD_PRE_median	**94**	**98**	**0.011***	**0.005***	**0.995**
gpPW_tot_PRE_median	**94**	**98**	**0.002***	**0.001***	**0.999**

Notes: FD = First Dish, SeD =Second Dish. SiD = Side Dish, tot= FD+ SeD+SiD, PF= Prepared Food, SF=Served Food, SW=Service Waste, PW=Plate Waste, CF=Consumed Food.
Exact p-value test of H0: gp*_tot (Control group) = gp*_tot (Treatment group). p-value lower test of H0: gp*_tot (Control group) < gp*_tot (Treatment group). p-value upper test of H0: gp*_tot (Control group) > gp*_tot (Treatment group).
The variables naming reads as follows: Average quantities in gr/pupil_Dish Type_PRE (= at T0) _median (=median comparison between control and treatment group).
Bold p-values carrying a * indicates tests who indicate significant differences in the quantity of food (gr/pupil) in the control group compared with the treatment group.
Source: Authors

Supplementary Figure C. Distribution of the deviation of the median weight for control and treatment group at T0 and T1.

Source: Authors.

Supplementary Table F. Summary of unique combinations of FD, SeD and SiD in the treatment and control group at T0 and T1.

	T0		T1		Total
	#	%	#	%	#
Treatment	57	47%	54	51%	111
Control	64	53%	56	49%	120
Total	121	100%	110	100%	231

Source: Authors

Supplementary Table G. Full list of the 127 unique combinations of Fist Dish (FD), Second Dish (SeD) and Side Dish (SiD) in the treatment and control group at T0 and T1.

First Dish (FD)	Second Dish (SeD)	Side Dish (SiD)	Full sample		Treatment group, T0		Control group, T0		Treatment group, T1		Control group, T1	
			Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Pasta with veggies	Fish (fresh)	Raw veggies and salads	16	4%	4	4%	3	3%	5	5%	4	4%
Rice	Cakes (pies, salty cakes etc.)	Fennel	10	3%	2	2%	2	2%	2	2%	4	4%
Soups	Meat (white, fresh)	Raw veggies and salads	9	2%	5	5%	1	1%	2	2%	1	1%
Pasta with veggies	Fish (fresh)	Carrots	8	2%	4	4%	1	1%	2	2%	1	1%
Pasta with veggies	Meat (beef, fresh)	Cauliflower	8	2%	3	3%	1	1%	3	3%	1	1%
Pasta with veggies	Pulses (processed)	Peas	8	2%	2	2%	2	2%	2	2%	2	2%
Soups	Meat (white, fresh)	Cabbage	8	2%	2	2%	2	2%	2	2%	2	2%
Pasta with veggies	Meat (white, fresh)	Potatoes	6	2%	2	2%	1	1%	2	2%	1	1%
Soups	Cheese (matured)	Raw veggies and salads	6	2%	2	2%	1	1%	2	2%	1	1%
Pasta with meat	Cakes (pies, salty cakes etc.)	Spinach	6	2%	1	1%	2	2%	1	1%	2	2%
Rice	Fish (processed)	Green peas	6	2%	3	3%	0	0%	3	3%	0	0%
Pizza	Cheese (fresh)	Raw veggies and salads	6	2%	3	3%	0	0%	3	3%	0	0%
Pasta with pulses	Meat (white, fresh)	Raw veggies and salads	6	2%	1	1%	2	2%	1	1%	2	2%
Fresh Pasta	No SeD	Others	6	2%	0	0%	2	2%	0	0%	4	4%
Pasta with veggies	Cheese (fresh)	Raw veggies and salads	6	2%	0	0%	2	2%	0	0%	4	4%
Pasta with fish	Pulses (processed)	Fennel	6	2%	2	2%	2	2%	0	0%	2	2%
Fresh Pasta	Meat (white, fresh)	Cabbage	6	2%	2	2%	2	2%	2	2%	0	0%
Rice	Pulses (natural)	Carrots	6	2%	3	3%	0	0%	3	3%	0	0%
Rice	Cakes (pies, salty cakes etc.)	Others	5	1%	2	2%	1	1%	2	2%	0	0%
Fresh Pasta	Cakes (pies, salty cakes etc.)	Carrots	5	1%	3	3%	1	1%	0	0%	1	1%
Pasta with oil	Cheese (matured)	Raw veggies and salads	5	1%	1	1%	1	1%	3	3%	0	0%
Pasta with oil	Meat (white, fresh)	Carrots	4	1%	2	2%	1	1%	0	0%	1	1%
Pasta with oil	Eggs	Peas	4	1%	0	0%	2	2%	0	0%	2	2%
Soups	Meat (white, fresh)	Potatoes	4	1%	0	0%	2	2%	0	0%	2	2%

Pasta with meat	Meat (beef, fresh)	Raw veggies and salads	4	1%	0	0%	2	2%	0	0%	2	2%
Rice	Fish (fresh)	Carrots	4	1%	0	0%	2	2%	0	0%	2	2%
Pasta with veggies	Eggs	Green peas	4	1%	1	1%	1	1%	1	1%	1	1%
Pasta with pulses	Cakes (pies, salty cakes etc.)	Carrots	4	1%	0	0%	1	1%	0	0%	3	3%
Pasta with fish	Fish (fresh)	Raw veggies and salads	4	1%	0	0%	2	2%	0	0%	2	2%
Rice	Meat (beef, fresh)	Others	4	1%	0	0%	2	2%	0	0%	2	2%
Pasta with veggies	Cheese (fresh)	Green peas	4	1%	2	2%	0	0%	2	2%	0	0%
Pasta with oil	Fish (processed)	Potatoes	4	1%	2	2%	0	0%	2	2%	0	0%
Fresh Pasta	No SeD	Carrots	4	1%	2	2%	0	0%	2	2%	0	0%
Rice	Cheese (fresh)	Green peas	4	1%	0	0%	2	2%	0	0%	2	2%
Pasta with fish	Pulses (processed)	Raw veggies and salads	4	1%	0	0%	2	2%	0	0%	2	2%
Fresh Pasta	No SeD	Raw veggies and salads	4	1%	0	0%	2	2%	0	0%	2	2%
Fresh Pasta	Meat (preserved)	Others	4	1%	0	0%	1	1%	1	1%	2	2%
Soups	Cakes (pies, salty cakes etc.)	No SiD	4	1%	0	0%	2	2%	0	0%	2	2%
Pasta with oil	Meat (white, fresh)	Raw veggies and salads	4	1%	0	0%	2	2%	0	0%	2	2%
Soups	Fish (fresh)	Carrots	4	1%	2	2%	2	2%	0	0%	0	0%
Fresh Pasta	Eggs	Raw veggies and salads	4	1%	1	1%	0	0%	3	3%	0	0%
Pasta with veggies	Eggs	Fennel	4	1%	0	0%	2	2%	1	1%	1	1%
Soups	Meat (white, fresh)	Fennel	4	1%	2	2%	0	0%	2	2%	0	0%
Fresh Pasta	Cheese (matured)	Raw veggies and salads	4	1%	1	1%	1	1%	1	1%	1	1%
Pasta with veggies	Fish (fresh)	Others	3	1%	0	0%	1	1%	2	2%	0	0%
Pasta with oil	Pulses (natural)	Zucchini	3	1%	3	3%	0	0%	0	0%	0	0%
Pasta with veggies	Meat (white, fresh)	Fennel	3	1%	0	0%	0	0%	3	3%	0	0%
Fresh Pasta	Cakes (pies, salty cakes etc.)	Zucchini	3	1%	0	0%	0	0%	3	3%	0	0%
Pasta with oil	Pulses (natural)	Carrots	3	1%	0	0%	0	0%	3	3%	0	0%
Soups	Cheese (fresh)	Raw veggies and salads	3	1%	1	1%	1	1%	0	0%	1	1%
Rice	Pulses (processed)	Raw veggies and salads	3	1%	2	2%	0	0%	1	1%	0	0%
Pasta with veggies	Fish (processed)	Potatoes	3	1%	1	1%	2	2%	0	0%	0	0%

Soups	Meat (pig, fresh)	Potatoes	3	1%	0	0%	2	2%	1	1%	0	0%
Fresh Pasta	Cakes (pies, salty cakes etc.)	Raw veggies and salads	3	1%	3	3%	0	0%	0	0%	0	0%
Soups	Meat (white, fresh)	Others	3	1%	3	3%	0	0%	0	0%	0	0%
Pasta with pulses	Eggs	Others	2	1%	0	0%	0	0%	2	2%	0	0%
Rice	Cakes (pies, salty cakes etc.)	Potatoes	2	1%	0	0%	1	1%	0	0%	1	1%
Pasta with oil	Fish (fresh)	Raw veggies and salads	2	1%	0	0%	1	1%	0	0%	1	1%
Rice	Fish (processed)	Raw veggies and salads	2	1%	0	0%	1	1%	0	0%	1	1%
Pasta with pulses	Meat (pig, fresh)	Raw veggies and salads	2	1%	0	0%	1	1%	0	0%	1	1%
Pasta with veggies	Meat (white, fresh)	Spinach	2	1%	0	0%	1	1%	0	0%	1	1%
Pasta with oil	Meat (white, fresh)	Others	2	1%	0	0%	1	1%	0	0%	1	1%
Rice	Meat (white, fresh)	Carrots	2	1%	1	1%	0	0%	1	1%	0	0%
Pizza	Meat (preserved)	Raw veggies and salads	2	1%	1	1%	0	0%	1	1%	0	0%
Pasta with pulses	Cakes (pies, salty cakes etc.)	Cabbage	2	1%	0	0%	2	2%	0	0%	0	0%
Pasta with veggies	Eggs	Others	2	1%	1	1%	0	0%	1	1%	0	0%
Pasta with veggies	Fish (fresh)	Potatoes	2	1%	0	0%	2	2%	0	0%	0	0%
Pasta with veggies	Fish (processed)	Green peas	2	1%	0	0%	0	0%	0	0%	2	2%
Fresh Pasta	Cheese (fresh)	Cabbage	2	1%	0	0%	0	0%	0	0%	2	2%
Soups	Fish (fresh)	Cabbage	2	1%	0	0%	1	1%	0	0%	1	1%
Pasta with veggies	Pulses (processed)	Carrots	2	1%	0	0%	1	1%	0	0%	1	1%
Pizza	No SeD	Raw veggies and salads	2	1%	0	0%	1	1%	0	0%	1	1%
Rice	Meat (white, fresh)	Fennel	2	1%	0	0%	1	1%	0	0%	1	1%
Soups	Meat (beef, fresh)	Potatoes	2	1%	1	1%	1	1%	0	0%	0	0%
Rice	Pulses (processed)	Cabbage	2	1%	0	0%	0	0%	1	1%	1	1%
Rice	Meat (beef, fresh)	Peas	2	1%	1	1%	0	0%	1	1%	0	0%
Pizza	Cheese (matured)	Raw veggies and salads	2	1%	1	1%	0	0%	1	1%	0	0%
Others	Cakes (pies, salty cakes etc.)	Raw veggies and salads	2	1%	0	0%	1	1%	0	0%	1	1%
Soups	Cakes (pies, salty cakes etc.)	Carrots	2	1%	0	0%	1	1%	0	0%	1	1%
Soups	Meat (beef, fresh)	Peas	2	1%	1	1%	0	0%	1	1%	0	0%

Rice	Pulses (processed)	Green peas	2	1%	0	0%	2	2%	0	0%	0	0%
Pasta with pulses	No SeD	Cauliflower	2	1%	0	0%	2	2%	0	0%	0	0%
Rice	Meat (pig, fresh)	Green peas	2	1%	0	0%	0	0%	0	0%	2	2%
Rice	Cheese (fresh)	Potatoes	1	0%	1	1%	0	0%	0	0%	0	0%
Pasta with oil	Meat (white, fresh)	Cabbage	1	0%	1	1%	0	0%	0	0%	0	0%
Others	No SeD	Raw veggies and salads	1	0%	1	1%	0	0%	0	0%	0	0%
Soups	Eggs	Carrots	1	0%	1	1%	0	0%	0	0%	0	0%
Rice	Cheese (matured)	Potatoes	1	0%	0	0%	0	0%	1	1%	0	0%
Pasta with veggies	Meat (white, fresh)	Carrots	1	0%	0	0%	0	0%	1	1%	0	0%
Pasta with oil	Fish (fresh)	Green peas	1	0%	0	0%	0	0%	1	1%	0	0%
Rice	Cakes (pies, salty cakes etc.)	Green peas	1	0%	0	0%	0	0%	0	0%	1	1%
Pasta with veggies	Meat (beef, fresh)	Others	1	0%	1	1%	0	0%	0	0%	0	0%
Fresh Pasta	Fish (fresh)	Raw veggies and salads	1	0%	1	1%	0	0%	0	0%	0	0%
Pasta with veggies	Meat (beef, fresh)	Potatoes	1	0%	0	0%	0	0%	1	1%	0	0%
Fresh Pasta	Fish (processed)	Raw veggies and salads	1	0%	0	0%	0	0%	1	1%	0	0%
Pasta with meat	Cheese (matured)	Cabbage	1	0%	0	0%	1	1%	0	0%	0	0%
Fresh Pasta	Cheese (matured)	Cabbage	1	0%	0	0%	0	0%	0	0%	1	1%
Pasta with fish	Cheese (fresh)	Potatoes	1	0%	0	0%	1	1%	0	0%	0	0%
Rice	Meat (pig, fresh)	Raw veggies and salads	1	0%	0	0%	1	1%	0	0%	0	0%
Pasta with fish	Cheese (fresh)	Raw veggies and salads	1	0%	0	0%	0	0%	0	0%	1	1%
Rice	Meat (pig, fresh)	Spinach	1	0%	0	0%	0	0%	0	0%	1	1%
Pasta with pulses	Meat (beef, fresh)	Cabbage	1	0%	1	1%	0	0%	0	0%	0	0%
Pasta with pulses	Eggs	Raw veggies and salads	1	0%	1	1%	0	0%	0	0%	0	0%
Soups	Meat (beef, fresh)	Cabbage	1	0%	0	0%	0	0%	1	1%	0	0%
Pasta with veggies	Fish (processed)	Others	1	0%	0	0%	0	0%	1	1%	0	0%
Soups	Meat (pig, fresh)	Others	1	0%	1	1%	0	0%	0	0%	0	0%
Others	Others	Others	1	0%	1	1%	0	0%	0	0%	0	0%
Rice	Pulses (processed)	Others	1	0%	0	0%	0	0%	1	1%	0	0%

Others	Others	Spinach	1	0%	0	0%	0	0%	1	1%	0	0%
Fresh Pasta	Meat (beef, fresh)	Others	1	0%	0	0%	1	1%	0	0%	0	0%
Pasta with oil	Meat (preserved)	Green peas	1	0%	0	0%	1	1%	0	0%	0	0%
Fresh Pasta	Meat (preserved)	Green peas	1	0%	0	0%	0	0%	0	0%	1	1%
Pasta with pulses	Eggs	Cabbage	1	0%	0	0%	1	1%	0	0%	0	0%
Pasta with meat	Cakes (pies, salty cakes etc.)	Carrots	1	0%	0	0%	1	1%	0	0%	0	0%
Pasta with oil	Meat (white, fresh)	Green peas	1	0%	0	0%	0	0%	0	0%	1	1%
Pasta with veggies	Eggs	Cabbage	1	0%	1	1%	0	0%	0	0%	0	0%
Pasta with veggies	Fish (fresh)	Fennel	1	0%	1	1%	0	0%	0	0%	0	0%
Pasta with meat	Cakes (pies, salty cakes etc.)	Raw veggies and salads	1	0%	1	1%	0	0%	0	0%	0	0%
Others	Fish (processed)	Others	1	0%	0	0%	0	0%	0	0%	1	1%
Rice	Meat (pig, fresh)	Fennel	1	0%	1	1%	0	0%	0	0%	0	0%
Pasta with oil	Fish (fresh)	Carrots	1	0%	1	1%	0	0%	0	0%	0	0%
Rice	Meat (white, fresh)	Green peas	1	0%	1	1%	0	0%	0	0%	0	0%
Soups	Eggs	Cabbage	1	0%	0	0%	0	0%	1	1%	0	0%
Soups	Meat (white, fresh)	Peas	1	0%	0	0%	0	0%	1	1%	0	0%
Soups	Cheese (fresh)	Carrots	1	0%	0	0%	0	0%	1	1%	0	0%
Pasta with veggies	Meat (pig, fresh)	Raw veggies and salads	1	0%	0	0%	0	0%	1	1%	0	0%
Pasta with oil	Fish (fresh)	Fennel	1	0%	0	0%	0	0%	1	1%	0	0%
Total			373	100%	98	100%	94	100%	91	100%	90	100%

Source: Authors

Supplementary Figure D. Distribution of the deviation of the median weights of PW% for control and treatment group at T0 and T1.

Source: Authors.

Supplementary Table H . Correlation between the class composition of our sample and Fist Dish (FD), Second Dish (SeD) and Side Dish (SiD) PW%.

	PW% tot	PW% FD	PW% SeD	PW% SiD
Correlation with missing_children	-0.0235	-0.0134	-0.0230	0.0031
N. observation	373	373	354	369
P value	0.6516	0.7965	0.6659	0.9534

Source: Authors.
Note: Spearman's rank correlation coefficients Test of H0: missing_children and PW%_* are independent.

Supplementary Table I. Description of the model used to estimate the Average Treatment Effect.

Included variables	Included for the AUSL analysis		Included for the full sample analysis	
Time fixed effect	✓	$\phi_{t,a}$	✓	ϕ_t
Group fixed effect	✓	$\alpha_{i,a}$	✓	α_i
Treatment dummies	✓	$\sum \delta_{post,a}$	✓	δ_{post}
Types of food dummies ($Ca_c^{u,d}$)	✓	$\sum \beta_{Ca}$	✓	$\sum \beta_{Ca}$
Covariates ($X^{u,d}$)	✓	$\sum \beta_X$	✓	$\sum \beta_X$
List of covariates included in the model (See Supplementary Table D)	✓	- Disposition of lunch table - Eating position of teachers - Behaviour of teachers - Presence of posters - Existence of specific rules on eating behaviour - Behaviour of children - School location	✓	- Disposition of lunch table - Eating position of teachers - Behaviour of teachers - Presence of posters - Existence of specific rules on eating behaviour - Behaviour of children - School location
Error term	✓	$\varepsilon_{i,t,a}$	✓	$\varepsilon_{i,t}$

Source: Authors

The ATE is estimated using the following model disaggregating by each AUSL:

$$PW\%_c{}^{u,d,a} = \alpha_{i,a} + \phi_{t,a} + \sum \delta_{post,a}\, D_{i,t,a}^{u,d} + \sum \beta_{ca} Ca_c^{u,d} + \sum \beta_X\, X^{u,d} + \varepsilon_{i,t,a}$$

The model simplifies in the following model when estimating the effect for the whole sample:

$$PW\%_c{}^{u,d} = \alpha_i + \phi_t + \delta_{post}\, D_{i,t}^{u,d} + \sum \beta_{ca} Ca_c^{u,d} + \sum \beta_X\, X^{u,d} + \varepsilon_{i,t}$$

Supplementary Table J. Summary table of the variables used for the analysis.

Variable name	Variable defintion	Masurement unit	Notes
gp*PF*, gp*SF*, gp*SW*, gp*CF*, gp*PW*	*PF, SF, SW, CF, PW*	gr/pupil	This variable exists for FD, SeD, SiD, Tot
Dev_gp*PF*, Dev_gp*SF*, Dev_gp*SW*, Dev_gp*CF*, Dev_gp*PW*	$z^{*gr} = \frac{weight\ obs}{median\ of\ all\ obs\ of\ this\ weight} - 1$	%	This variable exists for FD, SeD, SiD, Tot
PW%	[PW/(PF-SW)]	%	This variable exists for FD, SeD, SiD, Tot
Dev_PW%	$z = \frac{weight\ obs}{median\ of\ all\ obs\ of\ this\ weight} - 1$	%	This variable exists for FD, SeD, SiD, Tot

Note: FD = First Dish, SeD =Second Dish. SiD = Side Dish, tot= FD+ SeD+SiD, PF= Prepared Food, SF=Served Food, SW=Service Waste, PW=Plate Waste, CF=Consumed Food.
Source: Authors

Supplementary Table K. Collected data of the Italian school population to estimate plate waste at national level.

Variable	Description	Data
Italian school children	Students enrolled in Italian public primary schools, having lunch at school	962.358[1]
Italian school days	Number of yearly school days	206[2]

[1] Source: https://dati.istruzione.it/espscu/. Year 2021/2022. Date updated the 31/08/2022.
[2] Source: https://scuola.regione.emilia-romagna.it/. Calendar 2021/2022. Since each region has specific festivities resulting in slightly different yearly school days, we consider the school days of the region Emilia-Romagna as a reference.

Supplementary Table L. Results of the non-parametric test on ranks (Wilcoxon signed-rank test on the median) on the PF, SF, SW, PW, CF (gr/pupil) between the big and small catering providers.

Variables	N of Big Catering Providers	N of Small Catering Providers	Exact p-value (bivariate analysis)	p-value lower (univariate analysis)	p-value upper (univariate analysis)
gpPF_FD_PREcprov	**137**	**10**	**0.025***	**0.012***	**0.988**
gpPF_SeD_PREcprov	137	10	0.31	0.843	0.158
gpPF_SiD_PREcprov	**137**	**10**	**0.029***	**0.986**	**0.014***
gpPF_tot_PREcprov	137	10	0.494	0.25	0.751
gpSF_FD_PREcprov	**137**	**10**	**0.008***	**0.003***	**0.997**
gpSF_SeD_PREcprov	137	10	0.428	0.784	0.217
gpSF_SiD_PREcprov	**137**	**10**	**0.058**	**0.971**	**0.029***
gpSF_tot_PREcprov	137	10	0.194	0.099	0.902
gpSW_FD_PREcprov	137	10	0.349	0.822	0.179
gpSW_SeD_PREcprov	137	10	0.388	0.795	0.206
gpSW_SiD_PREcprov	**137**	**10**	**0.062**	**0.974**	**0.026***
gpSW_tot_PREcprov	137	10	0.193	0.904	0.097
gpCF_FD_PREcprov	**137**	**10**	**0.***	**0. ***	**1.**
gpCF_SeD_PREcprov	137	10	0.406	0.795	0.206
gpCF_SiD_PREcprov	137	10	0.352	0.822	0.179
gpCF_tot_PREcprov	**137**	**10**	**0.028***	**0.014***	**0.987**
gpPW_FD_PREcprov	**137**	**10**	**0.01***	**0.996**	**0.004***
gpPW_SeD_PREcprov	137	10	0.639	0.323	0.679
gpPW_SiD_PREcprov	137	10	0.124	0.938	0.063
gpPW_tot_PREcprov	**137**	**10**	**0.021***	**0.99**	**0.01***

Source: Authors.

Notes: FD = First Dish, SeD =Second Dish. SiD = Side Dish, tot= FD+ SeD+SiD, PF= Prepared Food, SF=Served Food, SW=Service Waste, PW=Plate Waste, CF=Consumed Food.
Exact p-value test of H0: gp*_tot (Big catering providers) = gp*_tot (Small catering providers). p-value lower test of H0: gp*_tot (Big catering providers) < gp*_tot (Small catering providers). p-value upper test of H0: gp*_tot (Big catering providers) > gp*_tot (Small catering providers).
Bold p-values carrying a * indicates tests who indicate significant differences in big catering providers in comparison to small catering providers.

Supplementary Table M. Results of the non-parametric test on ranks (Wilcoxon signed-rank test on the median) on the SW (gr/pupil).

Variable	N	N_neg	N_pos	Exact p-value (bivariate analysis)	p-value lower (univariate analysis)	p-value upper (univariate analysis)
gpSW_FD_Control_T0	94	0	43	2.27e-13	1	1.14e-13
gpSW_FD_ Control_T1	90	0	38	7.28e-12	1	3.64e-12
gpSW_FD_ Treat_T0	98	0	33	2.33e-10	1	1.16e-10
gpSW_FD_ Treat_T1	91	0	28	7.45e-09	1	3.73e-09
gpSW_SeD_ Control_T0	94	0	35	5.82e-11	1	2.91e-11
gpSW_SeD_ Control_T1	90	0	33	2.33e-10	1	1.16e-10
gpSW_SeD_Treat_T0	98	0	27	1.49e-08	1	7.45e-09
gpSW_SeD_ Treat_T1	91	0	19	3.81e-06	1	1.91e-06
gpSW_SiD_ Control_T0	94	0	46	2.84e-14	1	1.42e-14
gpSW_SiD_ Control_T1	90	0	45	5.68e-14	1	2.84e-14
gpSW_SiD_ Treat_T0	98	0	38	7.28e-12	1	3.64e-12
gpSW_SiD_ Treat_T1	91	0	30	1.86e-09	1	9.31e-10
gpSW_tot_ Control_T0	94	0	55	5.55e-17	1	2.78e-17
gpSW_tot_ Control_T1	90	0	49	3.55e-15	1	1.78e-15
gpSW_tot_ Treat_T0	98	0	40	1.82e-12	1	9.09e-13
gpSW_tot_ Treat_T1	91	0	34	1.16e-10	1	5.82e-11

Source: Authors

Exact p-value test of H0: gpSW_* $\neq$ 0. p-value lower test of H0: gpSW_* < 0. p-value upper test of H0: gpSW_* > 0.

Supplementary Table N. Results of the t-test on the means for PW% at T0 in comparison to T1.

Variable	N at T0	N at T1	Means of PW% at T0	Means of PW% at T1	Exact p-value (bivariate analysis)	p-value lower (univariate analysis)	p-value upper (univariate analysis)
AUSL 1							
PW%_FD_Control_time_1	20	20	0.281	0.217	0.254	0.873	0.127
PW%_FD_Treatment_time_1	30	28	0.321	0.28	0.394	0.803	0.197
PW%_SeD_Control_time_1	20	20	0.255	0.301	0.384	0.192	0.808
PW%_SeD_Treatment_time_1	29	28	0.327	0.341	0.82	0.41	0.59
PW%_SiD_Control_time_1	**20**	**20**	**0.538**	**0.405**	**0.051***	**0.974**	**0.026***
PW%_SiD_Treatment_time_1	30	28	0.492	0.511	0.806	0.403	0.597
PW%_tot_Control_time_1	20	20	0.284	0.256	0.34	0.83	0.17
PW%_tot_Treatment_time_1	30	28	0.357	0.348	0.836	0.582	0.418
AUSL 2							
PW%_FD_Control_time_2	**5**	**5**	**0.445**	**0.158**	**0.063**	**0.968**	**0.032***
PW%_FD_Treatment_time_2	5	5	0.541	0.612	0.73	0.365	0.635
PW%_SeD_Control_time_2	**5**	**5**	**0.37**	**0.211**	**0.054**	**0.973**	**0.027***
PW%_SeD_Treatment_time_2	**5**	**5**	**0.338**	**0.546**	**0.027***	**0.013***	**0.987**
PW%_SiD_Control_time_2	5	5	0.606	0.468	0.446	0.777	0.223
PW%_SiD_Treatment_time_2	**5**	**5**	**0.721**	**0.847**	**0.076**	**0.038***	**0.962**
PW%_tot_Control_time_2	**5**	**5**	**0.438**	**0.222**	**0.027***	**0.987**	**0.013***
PW%_tot_Treatment_time_2	5	5	0.52	0.622	0.407	0.203	0.797
AUSL 3							
PW%_FD_Control_time_3	**25**	**24**	**0.384**	**0.528**	**0.028***	**0.014***	**0.986**
PW%_FD_Treatment_time_3	15	14	0.198	0.229	0.482	0.241	0.759
PW%_SeD_Control_time_3	21	20	0.388	0.503	0.075	0.037	0.963
PW%_SeD_Treatment_time_3	**15**	**14**	**0.378**	**0.243**	**0.089**	**0.956**	**0.044***
PW%_SiD_Control_time_3	**25**	**24**	**0.552**	**0.771**	**0.000**	**0.000**	**1.000**
PW%_SiD_Treatment_time_3	15	14	0.458	0.414	0.58	0.71	0.29
PW%_tot_Control_time_3	**25**	**24**	**0.405**	**0.55**	**0.005***	**0.002***	**0.998**
PW%_tot_Treatment_time_3	15	14	0.267	0.249	0.536	0.732	0.268
AUSL 4							
PW%_FD_Control_time_4	20	18	0.263	0.246	0.727	0.636	0.364
PW%_FD_Treatment_time_4	10	8	0.258	0.303	0.429	0.215	0.785
PW%_SeD_Control_time_4	18	16	0.231	0.209	0.652	0.674	0.326
PW%_SeD_Treatment_time_4	8	6	0.478	0.419	0.587	0.707	0.293
PW%_SiD_Control_time_4	18	16	0.341	0.309	0.632	0.684	0.316
PW%_SiD_Treatment_time_4	**10**	**8**	**0.681**	**0.472**	**0.035***	**0.982**	**0.018***
PW%_tot_Control_time_4	20	18	0.253	0.246	0.818	0.591	0.409
PW%_tot_Treatment_time_4	10	8	0.362	0.338	0.615	0.693	0.307
AUSL 5							
PW%_FD_Control_time_5	5	5	0.189	0.135	0.379	0.81	0.19
PW%_FD_Treatment_time_5	15	15	0.512	0.452	0.266	0.867	0.133
PW%_SeD_Control_time_5	4	4	0.274	0.21	0.679	0.661	0.339
PW%_SeD_Treatment_time_5	15	15	0.427	0.429	0.98	0.49	0.51
PW%_SiD_Control_time_5	5	5	0.379	0.336	0.514	0.743	0.257

PW%_SiD_Treatment_time_5	15	15	0.731	0.767	0.387	0.193	0.807
PW%_tot_Control_time_5	5	5	0.259	0.204	0.232	0.884	0.116
PW%_tot_Treatment_time_5	15	15	0.551	0.527	0.493	0.754	0.246
AUSL 6							
PW%_FD_Control_time_6	10	8	0.472	0.397	0.434	0.783	0.217
PW%_FD_Treatment_time_6	10	8	0.281	0.276	0.949	0.526	0.474
PW%_SeD_Control_time_6	10	8	0.41	0.593	0.201	0.101	0.899
PW%_SeD_Treatment_time_6	10	8	0.534	0.476	0.467	0.767	0.233
PW%_SiD_Control_time_6	10	8	0.601	0.586	0.878	0.561	0.439
PW%_SiD_Treatment_time_6	10	8	0.621	0.706	0.404	0.202	0.798
PW%_tot_Control_time_6	10	8	0.464	0.463	0.985	0.508	0.492
PW%_tot_Treatment_time_6	10	8	0.407	0.356	0.305	0.847	0.153
AUSL 7							
PW%_FD_Control_time_7	4	5	0.144	0.221	0.412	0.206	0.794
PW%_FD_Treatment_time_7	8	8	0.131	0.236	0.429	0.215	0.785
PW%_SeD_Control_time_7	4	5	0.487	0.576	0.627	0.314	0.686
PW%_SeD_Treatment_time_7	8	8	0.329	0.305	0.849	0.575	0.425
PW%_SiD_Control_time_7	4	5	0.643	0.501	0.432	0.784	0.216
PW%_SiD_Treatment_time_7	8	8	0.372	0.399	0.835	0.418	0.582
PW%_tot_Control_time_7	4	5	0.252	0.308	0.57	0.285	0.715
PW%_tot_Treatment_time_7	8	8	0.211	0.267	0.547	0.274	0.726
AUSL 8							
PW%_FD_Control_time_8	5	5	0.166	0.134	0.522	0.739	0.261
PW%_FD_Treatment_time_8	5	5	0.423	0.442	0.858	0.429	0.571
PW%_SeD_Control_time_8	5	5	0.213	0.273	0.645	0.322	0.678
PW%_SeD_Treatment_time_8	5	5	0.358	0.417	0.719	0.36	0.64
PW%_SiD_Control_time_8	**5**	**5**	**0.352**	**0.636**	**0.007***	**0.004***	**0.996**
PW%_SiD_Treatment_time_8	5	5	0.329	0.369	0.674	0.337	0.663
PW%_tot_Control_time_8	5	5	0.209	0.229	0.716	0.358	0.642
PW%_tot_Treatment_time_8	5	5	0.381	0.397	0.639	0.319	0.681
FULL SAMPLE							
PW%_FD_Control_time	94	90	0.317	0.31	0.817	0.591	0.409
PW%_FD_Treatment_time	98	91	0.322	0.325	0.904	0.452	0.548
PW%_SeD_Control_time	87	83	0.316	0.365	0.145	0.072	0.928
PW%_SeD_Treatment_time	95	89	0.388	0.37	0.572	0.714	0.286
PW%_SiD_Control_time	92	88	0.5	0.522	0.533	0.267	0.733
PW%_SiD_Treatment_time	98	91	0.55	0.553	0.933	0.467	0.533
PW%_tot_Control_time	94	90	0.33	0.347	0.501	0.251	0.749
PW%_tot_Treatment_time	98	91	0.376	0.373	0.885	0.558	0.442

Source: Authors.

Notes: The average plate waste percentage PW% of the vegetable side dish SiD for the treatment group is highlighted in grey. FD = First Dish, SeD =Second Dish. SiD = Side Dish, tot= FD+ SeD+SiD.

Exact p-value test of H0: diff = mean(T0) - mean(T1) = 0. p-value lower test of H0: diff = mean(T0) - mean(T1) < 0. p-value upper test of H0: diff = mean(T0) - mean(T1) > 0.

The variables naming reads as follows: Average plate waste percentage PW%_Dish Type_Group in which the test is conducted_Group for which the test is compared_AUSL number. As an example, "PW%_FD_Control_time_1" stands for the PW% of the FD in the control group at T1 in comparison to T0 for AUSL 1.

Bold p-values carrying a * indicates tests who indicate significant differences in the *PW%* at T0 in comparison to T1.

Supplementary Figure E. Mean of plate waste percentage (*PW%*) in the control and treatment group at T0 and T1 with 95% confidence intervals.

Source: Authors.

Supplementary Table O. Descriptive statistics of the full sample of plate waste percentages *PW%*.

Variable	Mean	95% CI		CV	p50	IQR	IQR/p50
Control group, pre-intervention (T0)							
PW% FD	32%	28%	36%	61%	26%	24%	94%
PW% SeD	32%	27%	36%	62%	29%	29%	101%
PW% SiD	50%	45%	55%	46%	46%	38%	84%
PW% tot	33%	30%	36%	44%	29%	20%	68%
Control group, during intervention (T1)							
Variable	Mean	95% CI		CV	p50	IQR	IQR/p50
PW% FD	31%	26%	36%	75%	25%	24%	97%
PW% SeD	37%	31%	42%	67%	32%	42%	131%
PW% SiD	52%	47%	58%	48%	51%	40%	77%
PW% tot	35%	31%	39%	56%	29%	21%	71%
Treatment group, pre-intervention (T0)							
Variable	Mean	95% CI		CV	p50	IQR	IQR/p50
PW% FD	32%	28%	36%	60%	31%	30%	97%
PW% SeD	39%	34%	43%	55%	35%	35%	100%
PW% SiD	55%	50%	60%	46%	58%	46%	81%
PW% tot	38%	35%	41%	41%	37%	24%	65%
Treatment group, during intervention (T1)							
Variable	Mean	95% CI		CV	p50	IQR	IQR/p50
PW% FD	33%	28%	37%	66%	28%	22%	79%
PW% SeD	37%	33%	41%	55%	35%	32%	92%
PW% SiD	55%	50%	61%	47%	56%	41%	73%
PW% tot	37%	34%	41%	45%	35%	23%	67%

Note: FD = first dish, SeD = second dish, SiD = vegetable side dish (target of the intervention), tot= FD+ SeD+SiD.
Source: Authors.

Supplementary Table P. Robustness check on time correlations for equation 4.

	Controls AUSL1	Controls AUSL2	Controls AUSL3	Controls AUSL4	Controls AUSL5	Controls AUSL6	Controls AUSL7	Controls AUSL8
Control T1	0.025	-0.256	0.002	0.313	-0.108	0.200	0.117	0.039
	(0.067)	(0.311)	(0.119)	(0.291)	(0.019)	(0.212)	(0.075)	(0.113)
Control T2	0.103	-0.012	-0.181	-0.024	-0.039	0.134	-0.235	-0.051
	(0.055)	(0.291)	(0.106)	(0.124)	(0.042)	(0.168)	(0.259)	(0.032)
Control T3	0.130	-0.143	-0.056	0.085	0.021	0.176	-0.046	0.153
	(0.068)	(0.062)	(0.109)	(0.180)	(0.075)	(0.049)	(0.116)	(0.095)
Control T4	0.020	-0.374	-0.111	-0.013	-0.223	0.057		0.057
	(0.091)	(0.155)	(0.195)	(0.105)	(0.102)	(0.192)		(0.173)
Treatment T1	-0.079	-0.114	0.136	-0.075	-0.024	0.090	-0.331	0.267
	(0.076)	(0.048)	(0.090)	(0.055)	(0.007)	(0.240)	(0.185)	(0.201)
Treatment T2	-0.128	-0.454	0.196	0.136	-0.146	0.029	-0.305	0.376
	(0.119)	(0.260)	(0.113)	(0.163)	(0.028)	(0.215)	(0.178)	(0.173)
Treatment T3	-0.059	-0.298*	0.187	-0.067	-0.176	0.081	-0.204**	0.245
	(0.105)	(0.034)	(0.105)	(0.078)	(0.070)	(0.025)	(0.041)	(0.041)

Treatment T4	0.011	-0.227	0.046	0.049	-0.069	0.195	-0.204**	0.518
	(0.055)	(0.171)	(0.120)	(0.144)	(0.053)	(0.229)	(0.045)	(0.144)
Treatment T5	-0.132	-0.381	0.172	0.110	-0.150		0.131	0.217
	(0.142)	(0.230)	(0.178)	(0.087)	(0.026)		(0.073)	(0.056)
r1vs0.TREAT	0.131	0.264***	-0.259***	-0.148**	0.079***	0.100	0.247*	-0.245
	(0.113)	(0.000)	(0.028)	(0.028)	(0.000)	(.)	(0.084)	(.)
Constant	0.460***	0.820**	0.587***	0.406**	0.713**	0.498*	0.510**	0.300*
	(0.048)	(0.047)	(0.096)	(0.069)	(0.023)	(0.057)	(0.066)	(0.038)
Observations	98	20	78	52	40	36	25	20
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Authors.

Notes: cluster standard errors in brackets. The asterisks mean: * p < 0.1 ** p < 0.05 *** p < 0.01.

Supplementary Table Q. Robustness check for the catering providers for equations 5.

	PW% SiD	PW% SeD	PW% FD
Small Catering Provider	0.021	-0.046	0.004
	(0.066)	(0.053)	(0.055)
Medium Catering Provider	-0.214***	-0.113	-0.122*
	(0.054)	(0.087)	(0.063)
Big catering provider	0.087	-0.145	0.382***
	(0.150)	(0.088)	(0.104)
Observations	369	354	373
R-squared	0.876	0.811	0.797
Treatment	Yes	Yes	Yes

Source: Authors.

Notes: cluster standard errors in brackets. The asterisks mean: * p < 0.1 ** p < 0.05 *** p < 0.01. FD = first dish, SeD = second dish, SiD = vegetable side dish (target of the intervention).

Supplementary Materials – Chapter 3

Supplementary Table A. Description of the stakeholders involved.

# of stakeholders	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 local sanitary service	Nutritionists and doctors responsible for the regional school meal design	Health
1	Emilia-Romagna regional service of innovation, quality, promotion and internationalisation 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.

Supplementary Table B. List of indicators for public canteens assessment from Gogging and Rau (2016).

N	Indicators
1	Percentage of total food organic certified
2	Percentage of fruit and vegetables organic certified
3	Changing menus to suit seasons
4	Displaying a seasonal food calendar for the region
5	Growing own herbs/ vegetables
6	Using fairly traded coffee, tea and bananas
7	Percentage of total food and drink budget spent on meat
8	Percentage of total meat budget spent on red meat
9	Animal welfare certification for meat products
10	Percentage of main course dishes containing meat
11	Seafood sourced fromrecognized accredited scheme which incorporates sustainability
12	Type of egg used (e.g. organic, free-range, regular, bottled)
13	Egg Traceability and quality assurance
16	Source available for customers (e.g. filtered water free of charge, tap water, bottled water only)
17	Origin of bottled water

18	Staff trained in waste minimization
19	Separate composting for organic material
20	Donating edible unused food
21	Using cooking techniques that minimize quantities of oils and fats used
22	Other waste reduction initiatives
23	Provenance of five key foods to local, regional, national or international origin
24	Number of intermediaries between producer and consumer
25	Nutrition information on menus
26	Health/sustainability promotion activities
27	Customer surveys
28	Menu information re food provenance
29	Good choice of allergen-free dishes and options
30	Hosting information events (re tendering) for small and local producers
31	Incorporating specifications into contracts that increase opportunities for smaller and local producers
32	Activities to promote local food
33	Staff training in product information (origin, environmental and social quality of products)

Source: Goggins, G., Rau, H., 2016. Beyond calorie counting: assessing the sustainability of food provided for public consumption. J. Clean. Prod. 112, 257–266. https://doi.org/10.1016/j.jclepro.2015.06.035

Supplementary Table C. Template used for the co-creation of the tool indicators.

Indicator/s	Measurability scale	Desired outcome	Data collection
Which indicator can we use to measure this sustainability target in school canteens?	What are the values this indicator can take?	What is the most desirable value for this indicator?	Where and how this data can be collected?
To be completed	*To be completed*	*To be completed*	*To be completed*

Source: Authors

Supplementary Table D. Methodological note on the development of the environmental sustainability indicator E1.

For defining the score of the indicator E1 "*Environmental Impact of Protein-Based Foods Served as a Second Course*" we implemented a two steps approach. First, we calculate the environmental impact of protein-based foods served as a second course in a weekly menu using eco-points and then we transform the obtained values into a scale from 0 to 10 for assigning a standardized score.

The calculation of the environmental impact of each protein-based food served as a second course in a weekly menu uses eco-points. Initially the eco-points for each portion for each protein-based food served as second course are obtained as specified in eq. 1:

Eq 1. $eg_n = e_n * g_n$

In eq. 1, e_n represents the eco-points for each of the seven protein-based foods served as second course $n = \{1,2,..,7\}$, expressed per gram of food. The eco-points are derived from Wassmann et al. (2023)[29], based on a methodology outlined by Hartmann et al. (2022)[30]; g_n is the daily portion of each protein-based food served as second course (*n)* expressed in gr/pupil and derived from the guidelines on the adequacy of school meals (Regional Sanitary Service ER, 2023). Annex A details the calculations of the eco-points per portion which range from a minimum value of 150 eco-points per daily portion (environmental impact of a portion of pulses) to a maximum value of 1440 eco-points per daily portion (environmental impact of a portion of red meat).

Annex A. Eco-points for each portion of protein-based food served as second course.

Protein-based food served as second course (n)	**Eco-points (e_n)**	**Daily portion of each protein-based food served as second course (g_n)**	**Eco-points per portion (eg_n)**
Pulses	2.5	60	150
Cheese	11	30	330
Pudding	12	40	480
Eggs	13	50	650
Fish	18	60	1.100
White meat	23	45	1.035
Red meat	32	45	1.440

Subsequently, to obtain the environmental impact of the protein-based food served as the second course for the weekly menu (I_{E1}), school professionals are asked to indicate in E1 the weekly frequency of each protein-based food served as second course (f_n). $f_n = \{0; 1; 2; 3; 4; 5\}$ takes value 0 if the dish is not served in the weekly menu, value 1 values if the dish is served once in the weekly menu, and so on. I_{E1} is thus calculated as a sum of the eco-points associated with all protein-based food served as second course (*n*) in the weekly menu for the frequency with which these foods are served in the weekly menu (f_n) as described in Eq. 2.

Eq. 2

$$I_{E1} = \sum_{n=1}^{7} eg_n * f_n$$

As a second step, we aimed to standardize the environmental impact into a score from 0 to 10. The choice of using a score from 0 to 10 stemmed by the need to capture variability in the use of different proteins for the second course, and to have a higher potential to show significant score changes when implementing a more environmentally friendly menu. To this scope, we first calculate the theoretical maximum environmental impact of the weekly menu ($\max_n I_{E1}$) which is the environmental impact associated with selecting all the

[29] Wassmann, B., Siegrist, M., Hartmann, C., 2023. The role of heuristics for composing an environmentally friendly meal. J. Clean. Prod. 402, 136818. https://doi.org/10.1016/j.jclepro.2023.136818

[30] Hartmann, C., Furtwaengler, P., Siegrist, M., 2022. Consumers' evaluation of the environmental friendliness, healthiness and naturalness of meat, meat substitutes, and other protein-rich foods. Food Qual. Prefer. 97, 104486. https://doi.org/10.1016/j.foodqual.2021.104486

protein-based foods served as second course for 5 times a week (see eq. 3 and Annex B for details on the calculation of $\max_n I_{E1}$).

Eq. 3

$$\max_n I_{E1} = \sum_{n=1}^{7} eg_n * \max_n f_n = 25.925$$

Annex B. Maximum environmental impact for each protein-based food served as second course.

Food Categories	Eco-points per portion (eg_n)	Maximum weekly frequencies ($\max_n f_n$)	Maximum eco-points by protein food category ($eg_n * \max_n f_n$)	$\max_n I_{E1}$
Pulses	150	5	750	**25.925**
Cheese	330	5	1.650	
Salty cakes	480	5	2.400	
Eggs	650	5	3.250	
Fish	1.100	5	5.500	
White meat	1.035	5	5.175	
Red meat	1.440	5	7.200	

Then, based on $\max_n I_{E1}$, we set 11 equal intervals of P_{E1}. We assign to each interval a score $x_{E1} = \{0; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10\}$, where 0 corresponds to the highest environmental impact of the protein-based food served as second course for a weekly menu (I_{E1}) and 10 to the lowest environmental impact of the protein-based food served as second course for a weekly menu (I_{E1}). Annex C details the scores associated with each environmental impact interval (x_{E1}).

Annex C. Score x_{E1} for each environmental impact interval.

Interval	x_{E1}
$O < I_{E1} < 2.356$	10
$2.356 < I_{E1} < 4.713$	9
$4.713 < I_{E1} < 7.070$	8
$7.070 < I_{E1} < 9.427$	7
$9.427 < I_{E1} < 11.784$	6
$11.784 < I_{E1} < 14.140$	5
$14.140 < I_{E1} < 16.497$	4
$16.497 < I_{E1} < 18.854$	3
$18.854 < I_{E1} < 21.211$	2
$21.211 < I_{E1} < 23.568$	1
$23.568 < I_{E1} < 25.925$	0