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Building sustainable city region food systems to increase resilience and cope with crises

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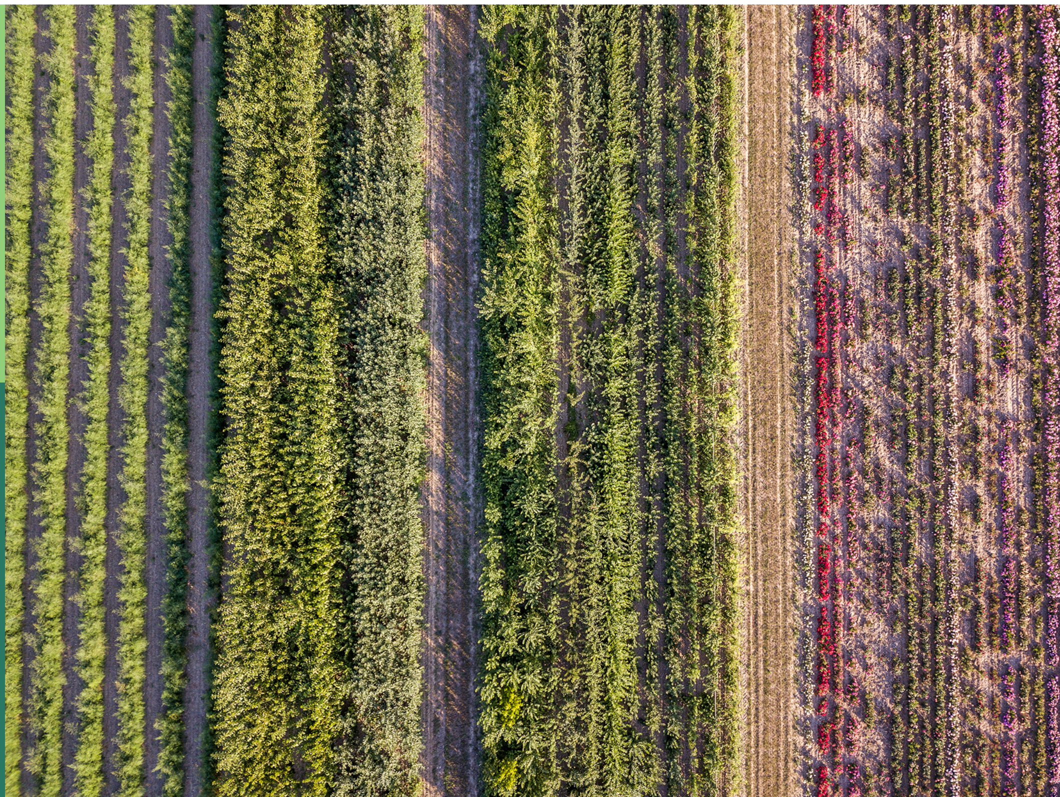

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Building sustainable city region food systems to increase resilience and cope with crises

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Table of contents

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PERSPECTIVE
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Envisioning the Future of European Food Systems: Approaches and Research Priorities After COVID-19

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The COVID-19 pandemic unveiled the fragility of food sovereignty in cities and confirmed the close connection urban dwellers have with food. Although the pandemic was not responsible for a systemic failure, it suggested how citizens would accept and indeed support a transition toward more localized food production systems. As this attitudinal shift is aligned with the sustainability literature, this work aims to explore the tools and actions needed for a policy framework transformation that recognizes the multiple benefits of food systems, while considering local needs and circumstances. This perspective paper reviews the trends in production and consumption, and systematizes several impacts emerged across European food systems in response to the first wave of pandemic emergency, with the final aim of identifying challenges and future strategies for research and innovation toward the creation of resilient and sustainable city/region food systems. The proposal does not support a return to traditional small-scale economies that might not cope with the growing global population. It instead stands to reconstruct and upscale such connections using a "think globally act locally" mind-set, engaging local communities, and making existing and future citizen-led food system initiatives more sustainable. The work outlines a set of recommended actions for policy-makers: support innovative and localized food production, training and use of information and communication technology for food production and distribution; promote cross-pollination among city/region food systems; empower schools as agents of change in food provision and education about food systems; and support the development of assessment methodologies and the application of policy tools to ensure that the different sustainability dimensions of the food chain are considered.

Keywords: city/region food system, SARS-CoV-2 pandemic, sustainable food systems, food initiatives, food security

INTRODUCING CITY/REGION FOOD SYSTEMS: THE FOODE VISION

A diffuse concern about food systems' resilience has grown throughout Europe in face of the current COVID-19 crisis (Bakalis et al., 2020). Although scarcity of food was not a real threat, the crisis increased awareness on the potential exposure of food systems to new shocks and crises, especially in terms of food access (Béné, 2020), consumer behavior, small-scale productions, and alternative food networks (Galanakis, 2020). The pandemic and the related lockdown measures favored more formal and consolidated national and global supply chains, particularly in urban contexts. In fact, localized and sustainable food production and distribution experiences had to face additional challenges, such as interruptions in the supply or demand chains due to the lockdown and the need to identify new distributions channels (FAO, 2020a,b). Under these circumstances, a policy framework that takes into consideration local needs and conditions and recognizes the multiple benefits associated with localized and sustainable food production and distribution experiences (Nicholls et al., 2020) becomes more urgent than ever.

The international sustainability agenda has started to acknowledge the urgency of this shift, recommending increased diversity of plant-based foods, reduced consumption of meat, substantial cuts in food waste, and re-localization of supply chains (SCBD, 2020). Similarly, the Sustainable Development Goals Target 2 has mandated countries to ensure sustainable food production systems and double productivity and incomes of small-scale food producers (United Nations, 2015).

With reference to urban food systems, after the Global call for action conference of the World Urban Forum (2014), the City/Region Food System (CRFS) approach started to gain increasing attention within the international debate. At that time, stakeholders were already aware that a territorial and holistic food system approach was the most suitable way to tackle the upcoming global challenges.

Afterwards, the CRFS framework was introduced by Jennings et al. (2015) and defined as: "the complex network of actors, processes, relationships that has to do with food production, processing marketing, and consumption in a given geographical region which includes a more or less concentrated urban center and its surrounding peri-urban and rural hinterland."

Other than representing a multidimensional way of action, the CRFS approach entails two significant innovations. First, it aims at creating a food governance structure that considers local circumstances, understanding that cities exist within a geography and that decisions about food should operate across the urban-rural continuum. Second, such an outlook recognizes the ecological, socio-economic, and governance linkages that characterize food systems. These different dimensions not only deserve equal attention but are also recognized as mutually reinforcing (Jennings et al., 2015).

The CRFS has then become a new lens of analysis, paving the way for a more sustainable, resilient, fair, and healthy food system worldwide (World Urban Forum, 2014), and can help today in the identification of innovative solutions to cope with the aftermaths of the COVID-19 crisis.

This paper builds on the FoodE H2020 project, which sees the collaboration of 24 partners from eight European countries and aims to engage local organizations in the design, implementation, and monitoring of environmentally, economically, and socially sustainable CRFS. The goal of this paper is to offer a systematic view of European food systems response to COVID-19, highlighting the major trends and impacts and discussing the potential policy implications related to the future of CRFS.

METHODOLOGY

The work adopted a mixed-method approach integrating a literature review with the opinion of experts and stakeholders from a wide range of organizations and European countries.

Starting from the CRFS definition, a literature review was carried out to identify the most critical food system areas affected by the COVID-19 pandemic. The literature was systematized by a mixed method of research based on scientific papers and materials coming from gray literature. Concerning the peer review literature, the high number of documents acquired and revised have been collected through SCOPUS and Web Of Science. The gray literature review was carried out through Google Scholar, expert opinions, direct interviews, as well as daily press in various languages, and blogs. Collected information was clustered into five food system areas: (1) agriculture, fisheries, and production systems; (2) innovative business models for increased resilience and sustainability; and (3) evolving technologies; (4) consumers behavior changes and adaptations; and (5) schools and education. For each area a dedicated working group was created. Working groups were composed of 4–5 experts belonging to a wide range of food stakeholders types including universities and research institutes, small and medium enterprises, non-governmental organizations, and municipalities.

TABLE 1 | Involved participants in the stakeholder's workshop, per country, and organization.

Country	Organization	Number of participants
Italy	Alma Mater Studiorum – Università di Bologna	15
	Comune di Bologna	3
	Università degli Studi di Napoli Federico II	3
	Flytech	3
France	Institut des Sciences et Industries du Vivant et de l'Environnement	1
	Institut National de Recherche pour l'Agriculture, l'alimentation et l'environnement	1
	Commune de Romainville	2
Germany	Fachhochschule Südwestfalen	2
	Institut für Landes- und Stadtentwicklungsforschung gGmbH	2
	Nolde Erwin and Partner	1
Netherlands	Hague Corporate Affairs BV	3
	Stichting Wageningen Research	2
Norway	Gallis Miljø Og Kommunikasjon - Nabolagshager	1
	Polar Permaculture Solutions	1
Romania	Asociaţia Mai Bine	1
Slovenia	Arctur Računalniški Inženiring	3
	Društvo Urbani Cebelar	1
Spain	Universitat Autònoma de Barcelona	5
	Universidad de La Laguna	1
	Total participants	**52**

The work was organized in three rounds. In the first round each working group collaborated independently to gather data, summarize relevant information, and discuss ongoing trends. The second round was represented by a large workshop engaging a wider number of stakeholders (**Table 1**) providing feedbacks and opinions on each of the five areas. The third round consisted in an iterative consultation process within the five working groups with the aim to integrate and review expert inputs. The joint revision enabled the systematization of the process and the harmonization of all provided contents. To follow a food supply chain logic the five groups were then reduced to three: (1) food production, covering agriculture, fisheries, and production systems, (2) food distribution, covering innovative business models for increased resilience and sustainability and evolving technologies, (3) food consumption, covering consumers behavior changes and adaptations and schools and education (EP, 2020) (**Figure 1**).

FOOD TRENDS RELATED TO THE COVID-19 CRISIS

The first wave of the COVID-19 outbreak did not lead to a major disruption of the European food systems, but it shed light on some specific challenges for each segment of the food chain, revealing footprints of a shift citizens might wish to embrace. The subsequent sections outline and discuss the main observed effects in food production, distribution, and consumption stages.

Food Production

Production suffered from a consistent limitation of transport lines and a generalized closing of borders. Suddenly, during the spring season, workers were unable to reach their farms, making it harder to carry out the harvest, catch and management of seasonal products. Simultaneously, the compulsory social distancing and personal protective equipment hampered the daily work in the fields. Safety measures created difficulties in production at all stages, especially for those informal chains where health and safety conditions were already limited. In these cases, implementing such measures proved challenging and led to either increased likelihood of infection or reduced production.

To buffer the labor shortage burdens, a variety of public and private actors developed apps and online platforms to match farmers' demands of seasonal staff and support mitigating production activities logistical disruptions (Laborde et al., 2020; Mitaritonna and Ragot, 2020). Despite having a consistent success, these services could not fully offset the problem, and food losses remained a major tangible concern (IOM., 2020). Other than the challenges in the fields, the stocking of products which could not reach the market at the pre-COVID19 rate, became a central issue. Only those commercial facilities having extensive capacity and enough flexibility, were able to transform products through canning or freezing techniques, while many others were left with unsold fresh products in the warehouses.

Finally, the shutdown of the Hotellerie-Restaurant-Café services, which represent a crucial market for many farmers and small producers, worsened the difficulties, reducing the sales volumes of many.

Food Distribution

The shift toward online shopping and takeaway consumption, both for fresh ingredients and ready to eat meals, led to a structural transformation of small and medium food initiatives, deeply modifying the customer relationship and sales channels. For many CRFS, whose major value proposition consists of the relational connections delivered inside and outside their organizations, the effects of social distancing measures were perceived as more severe than those experienced among more traditional food suppliers (Pulighe and Lupia, 2020). Only, in some cases, both newcomers and experienced online platforms developed communication tools that allowed maintaining such relational dimension.

Workers, but also volunteers, struggled to reach their food initiatives, creating also in this case a labor shortage (especially for food delivery) that ultimately resulted in a consistent gap within the food chain operational structure. Similarly, the logistic disruption led to inputs shortages (OECD, 2020), which made it harder to proceed with the business as usual especially for the initiatives with lower bargaining power (FAO, 2020a).

The shutdown of food and farmers' markets, together with restaurants and school canteens, contributed to the failure of

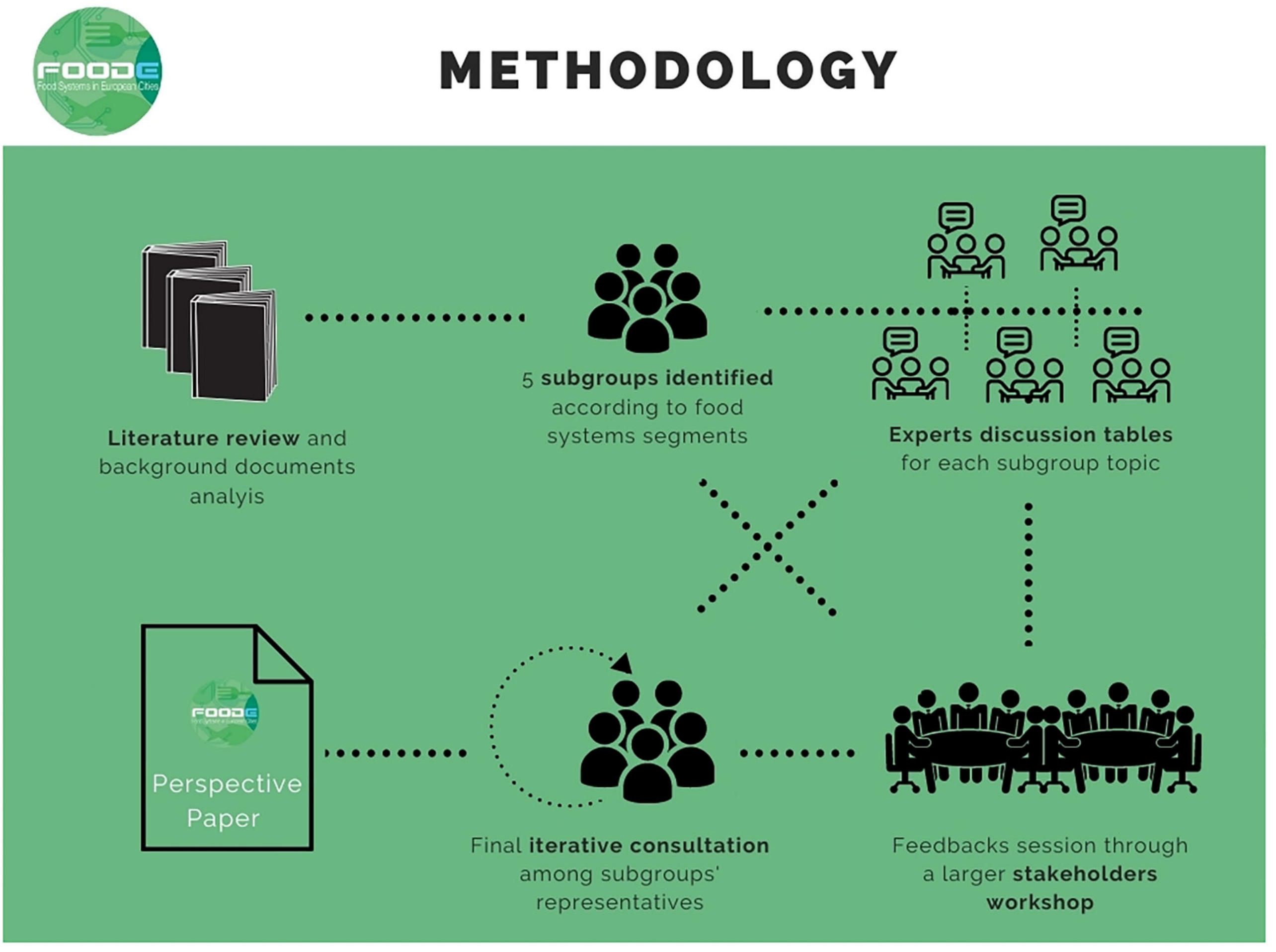

FIGURE 1 | Perspective paper methodological development.

local offer and alternative food networks. Only consolidated distribution hubs, such as supermarkets and conveniences stores, remained open at an early stage, reducing the range of choices for food actors. In some countries, as in the case of Italy, consumers were encouraged to shop in the nearest store (Gazzetta Ufficiale della Repubblica Italiana., 2020).

Large retailers were less endangered than specialist and niche shops, which were often obliged to rely on local governmental support to overcome structural and technological barriers (FAO, 2020c).

The closure of the Hotellerie-Restaurant-Café sector also had additional implications. The sector usually purchases products with different packaging as compared with home consumers. Thus, part of the packaged products was no longer marketable, leading to increased food waste (Petetin, 2020).

Food Consumption

The consumer trends that have emerged during the COVID-19 pandemic represent a major signal of change. From a household perspective, a typical consumer was motivated to maintain his or her physical and mental health and had more time available, while being more cost-conscious due to the uncertain economic situation (Accenture, 2020). As a result, consumers often adopted a back-to-basics approach to nutrition, with more home cooking and baking (Bernstein, 2020; Nielsen, 2020; OCU, 2020). Notably, citizens also stockpiled non-perishable goods, such as canned food, tomato sauce, pasta, flour, and yeast (OCU, 2020; Rogers, 2020).

Meanwhile, an increased sensitivity toward food sustainability, healthier diets, and an effort to establish stronger bonds with the origin of food emerged (Cohen, 2020; Rodríguez-Pérez et al., 2020). As an example, higher attention was given to ingredients selection, recipes scouting, and online cooking classes.

A surge in demand for short-supply chains and home delivery options, often supported by digital solutions, was observed in many countries (Hobbs, 2020). Local small-scale suppliers received larger attention by consumers since they were associated with higher safety standards and better food quality (Rizou et al., 2020). In some cases, the consumers' demand on online delivery channels consistently far exceeded the available distribution capacities (Hobbs, 2020; Nielsen, 2020).

With regards to food waste, the preliminary evidence provided by large national surveys (Roberts and Downing, 2020; Waste Watcher, 2020) confirmed a reduction of household food waste thanks to more time for in-home food management and cooking and a better planning for grocery shopping.

Despite observing several positive trends, vulnerable groups faced severe barriers in food consumption during the lockdown. Primarily, the shutdown of school canteens affected food security and habits for entire families. According to the United Nations, World Food Programme (2020), about 320 million children saw their schools temporarily closing due to COVID-19.

Pre-COVID-19 policies in European school canteens enabled to offer high-quality food, with relevant positive effects on pupils' dietary intake (Clinton-McHarg et al., 2018; Micha et al., 2018). Consequently, the lockdown measures likely put poorer children under nutritional stress, since the school meal might represent their only adequate food intake (Dunn et al., 2020). This effect was further aggravated by the difficulties of food banks, which experienced a drop in financial resources and a shortage of volunteers (FEBA, 2020).

Impacts on Food System

Due to the exogenous nature of this shock, the COVID-19 provoked a series of new behavioral shifts. Changes were quite unpredictable, leading to layered environmental, economic, governmental, and social impacts. As analyzed, observed adjustments immediately shaped consumption and production habits leading to new supply chain patterns. Depending on the governmental attitudes and capabilities, some of the rapidly emerging trends along the entire supply chain are probably destined to have a temporary nature. Others are likely to have longer-term implications.

Thanks to specific policy interventions detrimental reactions that have not shown to improve European food systems, should succeed in remaining short-term and limited to the emergency period, while beneficial shifts should be framed to guarantee their long-term viability. The results from such an uncertain and challenging period will depend on the diffused ability to correctly manage these positive and negative impacts cycles as described in **Figure 2.** The extent to which these mutual cycles will be reiterated will determine whether more resilient and sustainable food systems will emerge from the COVID-19 crisis.

Short-Term Impacts

Short-term impacts emerged clearly. For instance, the negative impact of social distancing measures that prevented the Hotellerie-Restaurant-Café service from using table service for their customers, has led the increasing home delivery options as a possible solution for restaurants (Laguna et al., 2020). However, this trend is likely to disappear once the emergency period will end. However, the effect might depend on the time extension of these measures, as reduced capacity would not be economically viable for an extended period (Dube et al., 2020).

In general, the relational dimension of CRFS limited by the crisis will likely be re-established or re-designed over time, creating new interactive formats, and making it easier for all actors to start working back on what CRFS initiatives consider as their core value proposition.

Similarly, the home cooking trends, connecting more deeply consumers and producers, will probably change once workers will start getting back to their regular work shifts and workplaces (Fernández-Aranda et al., 2020). Despite not leading to a long-lasting positive modification of consumers eating habits, the pandemic cooking pattern might influence the food consumption vision for quite some time. Time availability and more simple food planning and management (e.g., in most of the cases all the meals were consumed at home by all the members of the family) represented key drivers in reducing food waste. However, although some of the new skills and habits might remain, the return to the pre-COVID-19 working schedule and lifestyle will probably limit the progresses obtained during the lockdown.

In certain countries, the effects of COVID-19 on household income and food security have been dramatic and were extended to a rather large share of families (Power et al., 2020; The Food Foundation, 2020). This was worsened by the changes in children's consumption patterns whose social programs and school canteens were suspended. Parents with lower awareness of healthy diets and less disposable time for cooking might have offered a less virtuous alternative to school canteens, both by reducing the attention to their children's food care and by offering them more packaged and ready-to-eat products. This phenomenon did not only affect children's diets but might have contributed to higher consumption of foods featuring larger environmental impacts and lower nutritional values.

Similarly, in some cases, new consumption behaviors also produced further unintended environmental consequences, depending on the type and amount of food purchased, as well as the related packaging. The diffusion of food delivery and last-mile emergency logistics might have resulted in increased pollution, even though partially outpaced by lockdown traffic reduction. Additionally all delivered food, required great amounts of packaging materials, whose sustainable alternatives were often too expensive to be adopted by small-scale activities.

As anticipated, according to individual priorities, these immediate changes might be converted into long-term behavioral trends, positively affecting people's daily lives. Somewhat consciously, people changed the perception of the food systems, possibly giving higher importance to local networks and adapting their shopping preferences to a new level of awareness (Béné, 2020). Growing demand for environmentally and socially ethical products has gone hand in hand with higher awareness, and these jointly will boost local food production and consumption (Hobbs, 2020). If such an intention were properly sustained, the diffusion of proximity production and distribution systems such as urban gardening and local scale farming may encourage the implementation of shorter food chains.

Long-Term Impacts

Considering long-term implications, lockdown trends also showed an increase in the online demand for foods and beverages. Once consumers have sunk the learning costs required

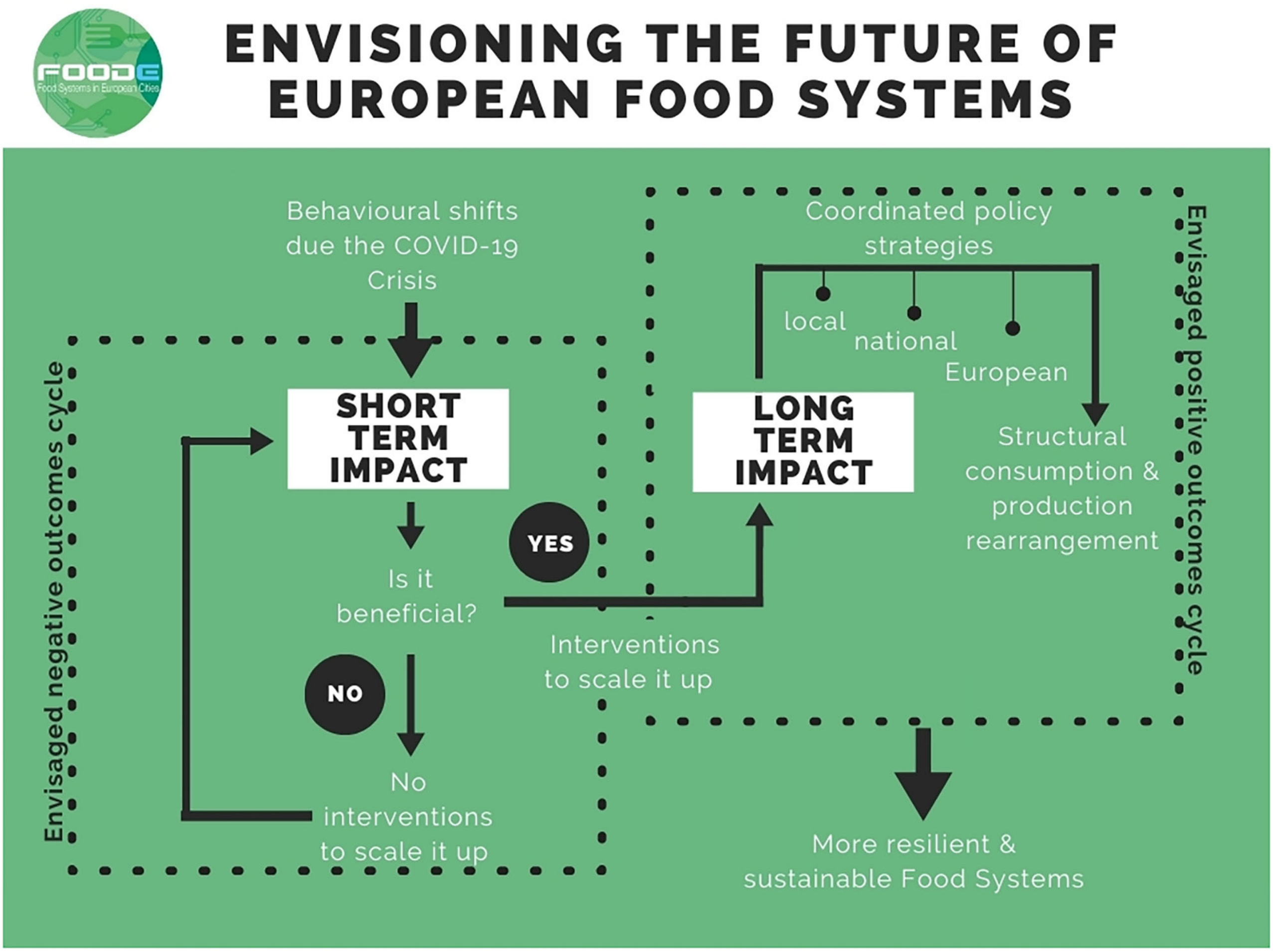

FIGURE 2 | Impacts on the European CRFS—Envisaged negative and positive outcomes cycles.

to adopt these types of food delivery and firms have adapted their spaces and operations to these shifts, changes are likely to persist well beyond the COVID-19, even though to a reduced extent.

If these digital accelerations can be seen as a virtuous innovation phenomenon for the whole sector, such a rapid transition may risk excluding smaller CRFS, ensuring major benefits only for more consolidated structures (Belavina et al., 2017; Arnalte-Mur et al., 2020). Moreover, smallholders may already face larger difficulties in recovering from the economic effects of the crisis, due to their lower business capacity.

The pandemic helped food stakeholders understanding the importance of strategic and local partnerships, both to increase their value and improve their ability to cope with possible future crises. If correctly handled, this might entail a higher number of cooperative initiatives, open innovation ecosystems, and shared networks.

Given the increased time children spent at home and the largest number of meals shared with the family, the lockdown period could have raised parent's awareness on the importance of the daily meal, giving them more time to understand children food habits, preferences, and food attitudes. Once school catering started to re-open, such dedication might end up in an increased parents' involvement in food education activities and in the design of school food quality, in terms of both food types and producers' selections. Food supply might be rethought, taking advice on the economic impact its management has on local farmers.

POLICY-IMPLICATIONS: TOWARD THE FOOD SYSTEM WE WANT AND NEED

The COVID-19 outbreak and the related responses allow to understand and evaluate the kind of possible and, indeed, desirable reforms, from a systemic point of view. In many aspects, bottom-up actions by producers and participatory consumer proposals prove to be in line with the emerging European policy agenda (EC, 2020), which indicates the commitment to address food systems imbalances.

To reinforce this perspective and improve resilience in food supply chains local, national, and European governments should consider to:

- Encourage a diversification in food provision, including local food production, as a mean for a more resilient supply chain, promoting more substantial and innovative small-scale production systems, whose social contribution has been highlighted by the pandemic. The strategy might include actions aimed at promoting the existence of local CRFS, favoring investments into marketing and information and communication technology use for those activities that are lagging through. Examples include *ad-hoc* training, call for actions, and public competition opportunities. In the long run, this could help accelerate CRFS and improve competitiveness with respect to more consolidated channels.
- Promote open discussion tables and forums, partnerships, and reciprocal learning to ensure cross-pollination and best practices exchange among CRFS. Besides facilitating reciprocal supports, this will help increasing the bargaining power of CRFS initiatives, making them more equipped against future time of crisis.
- Address schools as a central re-starting point. Involving teachers, families, and students in the definition of sustainable diet patterns, promoting food educational campaigns, and responsible shopping choices can help to transform cheerful consumer's behavioral change into systemic and long-lasting habits. To this scope, the provision of food in schools should put those principles in effect and should be combined with educational approaches on the community and territorial services. Similarly, open-air educational projects as urban or school vegetable gardens (Pennisi et al., 2020) can represent promising alternatives.
- Ensure that the development of policy tools include evaluations on different sustainability dimensions of the food chain. Given the evidence of the multifaceted benefits delivered by food initiatives, it is crucial to make sure all food values and attributes are considered when making decisions.

CONCLUSIONS

The first wave of the COVID-19 outbreak emphasized the need to establish new governance mechanisms engaging public authorities, citizens, small and medium enterprises, and non-profit organizations in the conceptualization and design of new models for sustainable CRFS that deliver environmental, societal, and economic benefits. The second wave of the outbreak and the related lockdown measures will offer the chance to assess whether previous adaptations resurfaced (in case of short-term) or continued (in case of long-term) and whether policies put in place to scale up beneficial transitions were successful.

Further research commitment and stakeholders' involvement should aim at unveiling the most urgent questions, offering reasonable ground to drive the envisaged food planning.

How new systemic organizational structure and policy frameworks transforming the positive shifts into more permanent and sustainable behaviors can be created? Which type of measurements are needed to support a more holistic and integrated view on food production, distribution, and consumption to ensure equal importance at economic, societal, and environmental needs? What should be the role of government in this transition? The ability to make city/regions more resilient will crucially depend on policy stakeholders' commitment to prioritize these challenges in the local and global sustainability agenda.

DATA AVAILABILITY STATEMENT

The original contributions generated for the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MV, GB, SB, FC, AM, FO, JP, MP, KS, and FD equally contributed to the concept of the study, its framework, the coordination and activities of subgroups, and writing of the manuscript. SA, A-MA, TB, IB, ACo, ACr, ACu, RF-K, AG, AL, PM, EN, JP-F, GP, BP, LR-D, IR, YR, VS-G, AS, SS, MdS, ST, PT, GT, BV, and GV equally contributed to the activities of subgroups and the review of the manuscript. All authors contributed to the article and approved the submitted version.

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Potential Key Factors, Policies, and Barriers for Rooftop Agriculture in EU Cities: Barcelona, Berlin, Bologna, and Paris

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The main objective of this study is to contribute a framework and to provide an overview of potential key factors, policies, and barriers associated with the integration of rooftop urban agriculture (RUA), building on stakeholders' perspectives in four European cities (Barcelona, Berlin, Bologna, and Paris). The research was developed in two phases, namely, a workshop and a survey of stakeholders involved in RUA from the four cities. Education, environmental, research, technological innovation, food production, and social factors play an important role in implementing RUA. Productive spaces, cultural values, social cohesion, social rural-urban links, and the high cost of urban land are highlighted as factors that "promote" RUA. In contrast, the cost of water and pollution are major contextual factors that constrain RUA. Policies related to food trade and urban planning are those that most limit RUA development. Major architectural and technical barriers related to the limits on building heights, historical buildings, a lack of specific building codes, building design and roof accessibility were identified. The high cost of infrastructure and policies that prohibit RUA product sales emerged as economic constraints. Major differences among the cities studied included the perceived effect of urban policies on RUA diffusion as well as the perceived relevance of economic and pollution factors. This study revealed that extensive dissemination and the development of appropriate information about RUA are needed. The creation of new regulations, as well as modifications to urban and building codes to support RUA, is also envisaged. This approach will consider a more flexible land-use policy that allows agriculture to take place in cities as well as marketing frameworks for RUA products. For future studies, it would be useful to apply the framework developed in this study to a larger sample. A study is also needed to confirm hypothetical differences between cities.

Keywords: stakeholders, perceptions, local food production, urban sustainability, buildings

INTRODUCTION

In recent decades, the world population has undergone revolutionary changes. Population dynamics have resulted in the rapid growth of the global population since 1950. Today, 55% of the world's population lives in urban areas, and according to projections, by 2050, 68% of the world's population is expected to live in cities (United Nations, 2018). Cities, as spaces where human activity is more concentrated, must develop a key role in the management of the present and future of humankind and the development of a more sustainable organizational model (European Commission United Nations Human Settlements Programme, 2016).

Land and water systems face the risk of a progressive collapse of their productive capacity under a combination of demographic pressure and unsustainable agricultural practices. Intensive forms of agriculture can cause serious environmental damage, with food crops also competing for land, water, and energy resources (Bilan et al., 2018). Factors such as rapid urban growth, scarce resources, and the effects of climate change contribute to highly vulnerable food systems (FAO, 2011; Martellozzo et al., 2014). The COVID-19 pandemic has underlined the need for modifications and changes in the governance of food systems. To address food resilience, it has been suggested that European governments promote local production involving innovative small-scale initiatives, whose social benefits have been emphasized by the pandemic (Vittuari et al., 2021). Indeed, the integration of food production within cities may offer opportunities to address these challenges (Armanda et al., 2019).

Cities, especially those with a high population density, lack sufficient space for agricultural uses. In this sense, real estate speculation and the increase in population density in urban areas have led to a decrease in the availability of vacant lands where urban agriculture (UA) may be developed (Gasperi et al., 2016). Thus, given the multiple benefits in terms of social, economic, and environmental functions provided by UA and the growing interest in the creation of sustainable cities with improved quality of life, city farming, made up of a diversified set of growing systems and business strategies (Orsini et al., 2020), is being widely promoted (Taylor and Hochuli, 2017). Among possible strategies for fostering urban food production, vacant building rooftops have been proposed as locations where the transformation from underused to productive spaces may take place (Orsini et al., 2014; Toboso-Chavero et al., 2018).

Urban Agriculture Benefits and Barriers

In recent years, a growing number of UA projects have been established on existing buildings, for example, using façades and rooftops as crop production space (Thomaier et al., 2015). Rooftop urban agriculture (RUA) can play an important role in improving adaptation to climate change (De Zeeuw et al., 2011), can reduce the urban heat island effect (Alexandri and Jones, 2008; Susca et al., 2011; Lee et al., 2014), and may ultimately lower energy and greenhouse gas emissions by decreasing the distance that food products are transported (Heinberg and Bomford, 2009). Other benefits are also associated with the integration of disadvantaged population groups and the promotion of social cohesion (Draper and Freedman, 2010; Lovell, 2010), while also providing economic benefits within communities.

However, even in the face of such benefits, several concerns must be addressed for the successful integration of UA in cities (Fletcher et al., 2012), with urban planning and economic, social, and environmental issues representing the main challenges. Policies, regulations, and land-use zoning bylaws can also act as barriers to UA (Roehr and Kunigk, 2009). Until recently, many municipalities excluded agriculture or related activities within their regulations for residential land use. For instance, until June 2010, the City of Los Angeles (California, USA) prohibited residents from growing crops in residential-zoned areas (Fletcher et al., 2012). Restriction on sales of food products grown in residential areas is also a barrier and major concern, although exceptions exist. In 2012, the Berkeley Planning Commission adopted the definition of "Non-Processed Edibles," which includes locally produced fruit, vegetables, nuts, honey, and shell eggs, but not meat, allowing the sale of such items in residential districts, provided that they meet certain safety requirements (Fletcher et al., 2012). Other cities were also highly active in implementing policies to support UA, including New York City, Washington DC, Chicago, Toronto and Singapore, where pioneering programs related to food production on building rooftops were launched. The New York City council also included the use of rooftops for food production in local plans (The New York City Council, 2010). Additionally, the city of Chicago reformed city laws regarding UA, allowing urban farms on rooftops (Urban Sustainability Exchange, 2011; City of Chicago, 2020). Globally, North America (81) and Europe (49) are the world regions with the highest number of RUA projects (Appolloni et al., 2021).

Rooftop Urban Agriculture Integration in European Cities

In Europe, the lack of land has led to exploring new ways to promote horticulture in cities, with pioneering practices of RUA taking place, for example, in Barcelona, Berlin, Bologna, and Paris.

In Barcelona (Spain), a pilot rooftop greenhouse (RTG) started to operate in the ICTA-ICP building of the Universitat Autonòma de Barcelona in 2014 (Fertilecity, 2018). Other local examples of RUA include the L'Hort al terrat (Garden on the roof) program, promoted by the City Council and aimed at fostering the integrated production of different kinds of vegetables (Barcelona City Council, 2018b). Additionally, the recently released Barcelona's Climate Plan 2018–2030 considers RUA implementation as a means to mitigate climate change and improve the quality of life in the city (Barcelona City Council, 2018a). Barcelona will also host the international meeting of the Milan Pact, becoming the World Capital of Sustainable Food in 2021 (Barcelona City Council, 2020).

In Berlin (Germany), commercial urban farming enterprises have developed different prototypes and technologies for food production on buildings (Specht et al., 2016b). The high potential for integrating RUA was recently detailed (Altmann et al., 2018), and RUA projects are already operative, including two open-air rooftop gardens and one RTG, located on the Humboldt University building (Tao et al., 2020).

Bologna (Italy) was one of the first cities in Italy to adopt a local plan for adaptation to climate change. Greening strategies were proposed to mitigate the effects of urban heat islands, with the ambitious objectives of integrating 5 hectares of urban vegetable gardens and greening intervention on ten public buildings (Comune di Bologna, 2014). Although the actual development was on a smaller scale e.g., three temporary pilot community rooftop gardens installed on the 10th floor of social housing buildings (Orsini et al., 2014), new RUA projects are currently being developed, including an educational rooftop greenhouse at the multifunctional space SALUS (Pennisi et al., 2020).

Paris (France) has been very active in promoting projects concerning biodiversity, greening, UA and food initiatives (Delgado, 2018). According to the Paris Climate Action Plan, the city promotes UA on roofs of municipal buildings. One of the objectives is to install 100 hectares of green roofs and walls, one-third of which will be devoted to urban agriculture (City of Paris, 2018). Accordingly, the Parisculteurs program was launched in 2016 for installing urban agriculture on buildings (Collé et al., 2018).

While the RUA sector is growing steadily in different European cities, economic, social, environmental, legal, technical, and architectural limitations are also being identified, as will be detailed in the following section.

Rooftop Urban Agriculture Barriers in European Cities

Although pioneering RUA projects exist, most suffer from a lack of promotion, specific laws, legal procedures, and urban codes (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2013). Studies in Barcelona, Berlin, and Bologna developed a preliminary classification of such barriers (Cerón-Palma et al., 2012; Specht et al., 2015, 2016a; Sanyé-Mengual et al., 2016; Specht and Sanyé-Mengual, 2017). Social obstacles include limited acceptance by users, the conceptualization and perception of UA, by many stakeholders, that it is not "true" agriculture, and the urgent need for training qualified technical personnel (Sanyé-Mengual et al., 2016; Specht et al., 2016a; Specht and Sanyé-Mengual, 2017). Social and health risks have also been repeatedly identified in several surveys on citizen perceptions (Sanyé-Mengual et al., 2016, 2018b; Specht and Sanyé-Mengual, 2017). Additionally, the possible environmental impacts associated with materials used for the construction of RTG facilities require careful consideration (Cerón-Palma et al., 2012). The low level of income generated by RUA products and difficulties in developing a viable business model were found to be the principal economic concerns (Palmer et al., 2016; Specht and Sanyé-Mengual, 2017). Technological and architectural barriers included the visual/aesthetic impact (especially within historical centers), structural load limitations in buildings, building height limits according to the building size, and the overall building envelope (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2016; Specht et al., 2016a). Legal challenges range from the lack of RUA regulations in current urban building codes and the difficulties in managing food safety protocols and certification schemes within small-scale farms. While the few studies that have been conducted have identified the barriers, opportunities, and risks associated with urban agriculture, there is a gap in identifying specific policies and key factors that can contribute to or limit urban agriculture on rooftops.

Approaches for Identifying Rooftop Urban Agriculture Barriers and Opportunities

Table 1 presents studies conducted to identify barriers and opportunities for implementing RUA in European cities from the point of view of stakeholders or citizens.

As revealed in **Table 1**, Barcelona and Berlin are the cities where the greatest number of studies have been conducted. Interviews are the most frequent method used for data collection (Specht et al., 2015, 2016a; Sanyé-Mengual et al., 2016; Specht and Sanyé-Mengual, 2017). Most of the key approaches are related to barriers, opportunities and risk. Regarding related approaches, two studies identified the level of relevance of benefits and risks (Specht et al., 2016a; Specht and Sanyé-Mengual, 2017), one study identified key issues for implementing UA (Specht et al., 2015), another compared its results on RUA with findings of previous studies (Sanyé-Mengual et al., 2016), and finally, one study used a Likert-scale evaluation to identify the degree of social acceptance of uses of open and green spaces, including RTGs and rooftop farms in the city of Bologna (Sanyé-Mengual et al., 2016).

Studies that consider data collection methods where stakeholders interact and share their knowledge and experiences to address barriers, opportunities, key factors, and policies regarding the implementation of RUA projects, as well as quantitative approaches about the frequency and degree of relevance of such projects, are also lacking. RUA is advancing driven by local initiatives, affected by both the circumstances of each location and the restrictions (or support) that exist in each case. There is, therefore, a crucial need to identify the key factors, policies, and barriers associated with the implementation of RUA in cities, especially when there are recent experiences. The identification of these little-explored aspects is relevant and helpful to find common factors, collect constraints, ways to overcome them and propose lines of action. This would likely help in the development of policies and programs to promote urban agriculture more efficiently and overcome constraints. These actions could bring various social, educational, environmental, and economic benefits in the urban context, as well as contribute to building more resilient cities.

The present study includes four cities from different European regions where incentives to support RUA have recently emerged and projects have already been built with different focuses, ranging from social inclusion to technological development and research. This study primarily elaborates on a participatory workshop. Participatory workshops are processes by which communities of practitioners can collaboratively share knowledge and personal experiences and reflect on the challenges they face and the methods for addressing them (Mor et al., 2012). Research methodology workshops aim to produce reliable and valid data about the domain in question

TABLE 1 | Studies of barriers and opportunities from stakeholders' perceptions.

City	Data collection			Key approach	Related approach				References
	I	S	Q		K	R	C	S	
Barcelona		•		Barriers and opportunities					Cerón-Palma et al., 2012
Berlin	•			Opportunities and challenges	•				Specht et al., 2015
Barcelona	•			Barriers and opportunities			•		Sanyé-Mengual et al., 2016
Berlin	•			Benefits and risks		•			Specht et al., 2016a
Berlin and Barcelona	•			Risks		•			Specht and Sanyé-Mengual, 2017
Bologna			•	Social acceptance				•	Sanyé-Mengual et al., 2018b
Germany and U.S.	•			Perception of sustainability, acceptance factors, and acceptance barriers					Specht et al., 2019

Data collection was performed using interviews (I), seminars of discussion (S), and questionnaires (Q). Related approaches: key factors (K), relevance (R) of benefits and risks, comparison with previous studies on RUA (C), and scale of acceptance (S).

and regarding forward-oriented processes in addition to fulfilling participants' expectations to achieve something related to their own interests (Ørngreen and Levinsen, 2017). The workshop cocreates a space for negotiating collaborative meanings, not just between participants but also between researchers and participants who discuss, perform, and learn during the workshop (Ørngreen and Levinsen, 2017).

In this context, the main objective of this research is to provide an exploratory overview of potential key factors, policies, and barriers associated with the integration of RUA from stakeholders' perceptions in four European cities (Barcelona, Berlin, Bologna, and Paris). The specific objectives of this work are (1) to identify key factors for integrating RUA and their level of relevance, (2) to identify context factors and their perceived effect on RUA diffusion, (3) to identify policies and their perceived effect on RUA diffusion and (4) to identify barriers to RUA and the frequency with which they occur.

MATERIALS AND METHODS

An exploratory method and non-probability sampling were used. The results are therefore not to be considered statistically or demographically representative of stakeholders from Barcelona, Berlin, Bologna, and Paris. The exploratory approach was considered appropriate because it offers preliminary insights into a previously little or unexplored topic (Hernández-Sampieri, 2014).

Figure 1 shows the workflow, structured in two phases and seven stages. The first phase consisted of a workshop. The main goal of the workshop was to obtain an overview of key factors, contextual factors, policies, and barriers to RUA integration in cities based on stakeholders' experiences. The second phase aimed at identifying, and quantifying, stakeholders' perceptions about key factors relevant to integrating RUA, contextual factors and policies that promote or hinder RUA, and the frequency with which barriers occur. Within Phase 1, the research included a definition of the case studies (stage 1), the participant definition (stage 2), and data collection (stage 3). Phase 2 included key factor and barrier definitions (stage 4), a second round of participant definitions (stage 5), data collection (stage 6), and analysis (stage 7). Each of these stages is described in detail in the following subsections.

Phase 1 Workshop

The first phase consisted of a workshop with international stakeholders from diverse EU cities. A participatory workshop was developed to build knowledge concerning to RUA.

Definition of Case Studies

Four cities from Europe, Barcelona, Berlin, Bologna, and Paris were chosen as case studies, given that they recently hosted some highly innovative RUA projects aimed at social inclusion, technological development and research. Among them, policies for supporting RUA have been implemented only in Paris (Paris City Council, 2018), whereas in other cities, existing regulations do not specifically target these kinds of projects (Cerón-Palma et al., 2012; Orsini et al., 2014; Freisinger et al., 2015). **Table 2** shows a summary of the main characteristics of the case studies. Barcelona is a compact Mediterranean city (Rueda, 2007; Parés et al., 2013). It has 1.6 million inhabitants in 101 km^2 and features a population density of 16,420 inhabitants/km^2 (Statistical Institure of Catalonia, 2020), being among the densest and most compact municipalities in Europe (Barcelona City Council, 2018a). The lack of land has led to exploring new ways to promote horticulture in the city, such as the RTG located on the ICTA-ICP building with a focus on research for technology innovation (Fertilecity, 2018). The city of Berlin has 3.7 million inhabitants (Berlin Business Location Center, 2019) who live over a surface of 892 km^2 (OECD, 2010) with a population density of 4,147 inhabitants/km^2 (Environmental Atlas Berlin, 2018). Today, among existing RUA projects, two rooftop gardens have a particularly social focus, whereas an RTG for applied research in botany and plant biology can be found at the Humboldt University building. Bologna is the main city of the Emilia Romagna Region, situated in northcentral Italy, and with a population of 394,463 inhabitants in 140.7 km^2, resulting in a population density of 2,802 inhabitants/km^2 (ISTAT, 2010, 2021). Paris has 2.2 million inhabitants living on a surface area of 105 km^2. This results in one of the highest urban densities in the world, reaching values in inner Paris of 20,755 inhabitants

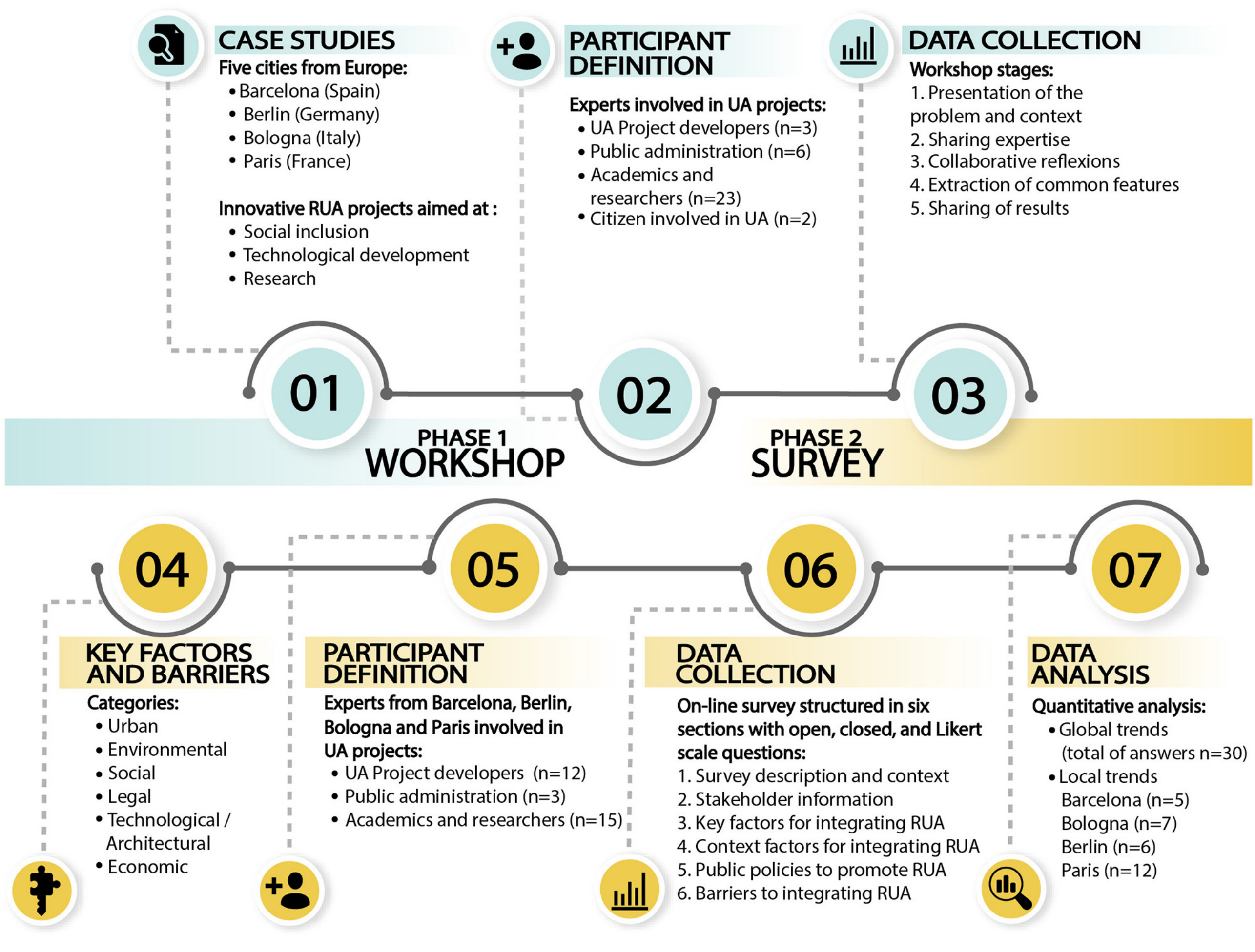

FIGURE 1 | Workflow for identifying key factors, policies and barriers in RUA projects based on stakeholder perceptions in four European cities.

TABLE 2 | Summary of cases studies.

City	Inhabitants (million)	Population density (inhabitants/km^2)	Rooftop urban agriculture projects		
			Technological development	Research	Social inclusion
Barcelona	1.6	16,420	•	•	•
Berlin	3.7	4,147		•	•
Bologna	0.4	2,802			•
Paris	2.2	20,755		•	•

per km^2 (INSEE, 2017). The City Council was recently very active in promoting projects targeting biodiversity preservation, greening, UA and food initiatives (Delgado, 2018). In 2016 and 2017, the first and second editions of the Parisculteurs program were launched, creating social inclusion and research spaces (Collé et al., 2018).

Participants' Definition

The second stage of the research consisted of the identification and classification of the UA experts to be involved. This included UA project developers (e.g., architects, agronomists), public administrators (with responsibilities in assigning municipal licenses and developing urban planning strategies), academics and researchers, and citizens involved in UA initiatives. Furthermore, relevant stakeholders from the cities of Barcelona, Berlin, Bologna, and Paris were identified and invited to define the state of the art of RUA in their cities.

Data Collection

To collect data from stakeholders, a workshop (Cerón-Palma et al., 2012) was conducted at the ICTA-ICP building (located in Barcelona) in September 2017. During the workshop session, interventions were recorded by the workshop organizers. The five stages developed in the workshop for data collection are described below.

(1) Problem and context. The workshop began with an introduction about the problem and context of RUA panorama. This part of the workshop was presented by a member of the project team who is a lawyer specializing in environmental issues. As a second step of this phase, international speakers were presented.
(2) Sharing expertise. International experiences from Barcelona, Berlin, Bologna, and Paris were shared. The presentations set the context of key factors, policies, and barriers for integrating RUA, problems in the target domain, also RUA projects already built or in the project phase were presented. Experiences were shared by specialists on UA: from Barcelona, the Technical Director of the Municipal Institute of Urban Landscape from the Barcelona City Council; in the case of Italy, a representative from the Research Center on Urban Environment for Agriculture and Biodiversity of the University of Bologna; from Paris, a member of Agroparistech; and in the case of Berlin, a master's student enrolled in the Interdisciplinary Studies in Environmental, Economic and Social Sustainability program from the UAB.
(3) Collaborative reflections. A discussion session was held among the participants. The participants were asked to reflect and share experiences and perceptions about the following questions:
    - Which are the key factors for integrating RUA?
    - Which are the policies that promote RUA?
    - What are the barriers to integrating RUA?
(4) Extraction and grouping of features. Key factors, policies, and barriers from stages 2 and 3 were grouped.
(5) Sharing of results. Findings from the workshop were presented by the moderator of the session to all participants and final debate on the results obtained was developed.

Phase 2 Survey

The research then evolved into a survey, integrating results from phase 1 (workshop) with a comprehensive literature review. This phase comprised the four steps described below.

Key Factors and Barriers Definition

Six main categories were identified, namely, urban, environmental, social, legal, technological/architectural, and economic barriers and opportunities (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2016; Specht and Sanyé-Mengual, 2017; Nadal et al., 2018).

Participants' Definition

Experts involved in UA, including project developers, public administration, academics, and citizen initiatives from Barcelona, Berlin, Bologna, and Paris, were identified and invited to participate in the survey.

Data Collection

Data collection was carried out from November to December 2017. The survey was designed to evaluate stakeholder perceptions through Likert scales that provided a range of responses to a series of statements. Five categories of responses were included (Croasmun and Ostrom, 2011), ranging from 5 to 1. The survey was structured into six sections: (1) survey description and context, (2) stakeholder information, (3) key issues for integrating RUA, (4) factors that hinder or promote RUA, (5) public policies to promote RUA, and (6) barriers to integrating RUA. Participants indicated their degree of agreement with a specific statement regarding the environmental, urban, social, legal, technological, architectural, and economic dimensions. Survey sections are further described in **Supplementary Material 1**.

Data Analysis

A quantitative analysis of the survey results was performed, enabling us to define local and global trends in the responses and overall perceptions of the stakeholders.

RESULTS

Phase 1 Workshop

The workshop was attended by 34 stakeholders, grouped by project developers (3), public administrators (6), academics (23), and those involved in citizen initiatives (2).

International Experiences of Urban Agriculture: Berlin, Bologna, Paris, and Barcelona

Figure 2 shows a summary of the results (see complete data in **Supplementary Material 2**, **Supplementary Table 1**). *Increased biodiversity, generation of green spaces, educational, research and social purposes, environmental CO_2 reduction, building energy optimization, new business generation, and new technology development* were identified as potential key factors for integrating RUA. *Urban planning, building laws, tax reduction, subsides, educational policies,* and local policies, e.g., the *Paris Climate Action Plan, Parisculteurs, and Plan Local d'Urbanisme de Paris* (Paris Local Urban Plan) from Paris and the *Primer Concurs de Cobertes Verdes* (First Green Roof Contest) from Barcelona, were identified as policies that potentially "promote" and are related to RUA. Potential barriers identified included *legal gaps, lack of a specific legal framework, building codes, administrative processes, restrictions on food sales, urban codes, health risks, historical building codes, rooftop accessibility difficulties, building designs, building structural features (overloading), high costs of infrastructure, climatic conditions, residents opposed to agricultural roofs on their buildings, lack of economic benefits, cost of water, firemen codes, food-free distribution, economic crisis, and a lack of interest by society*.

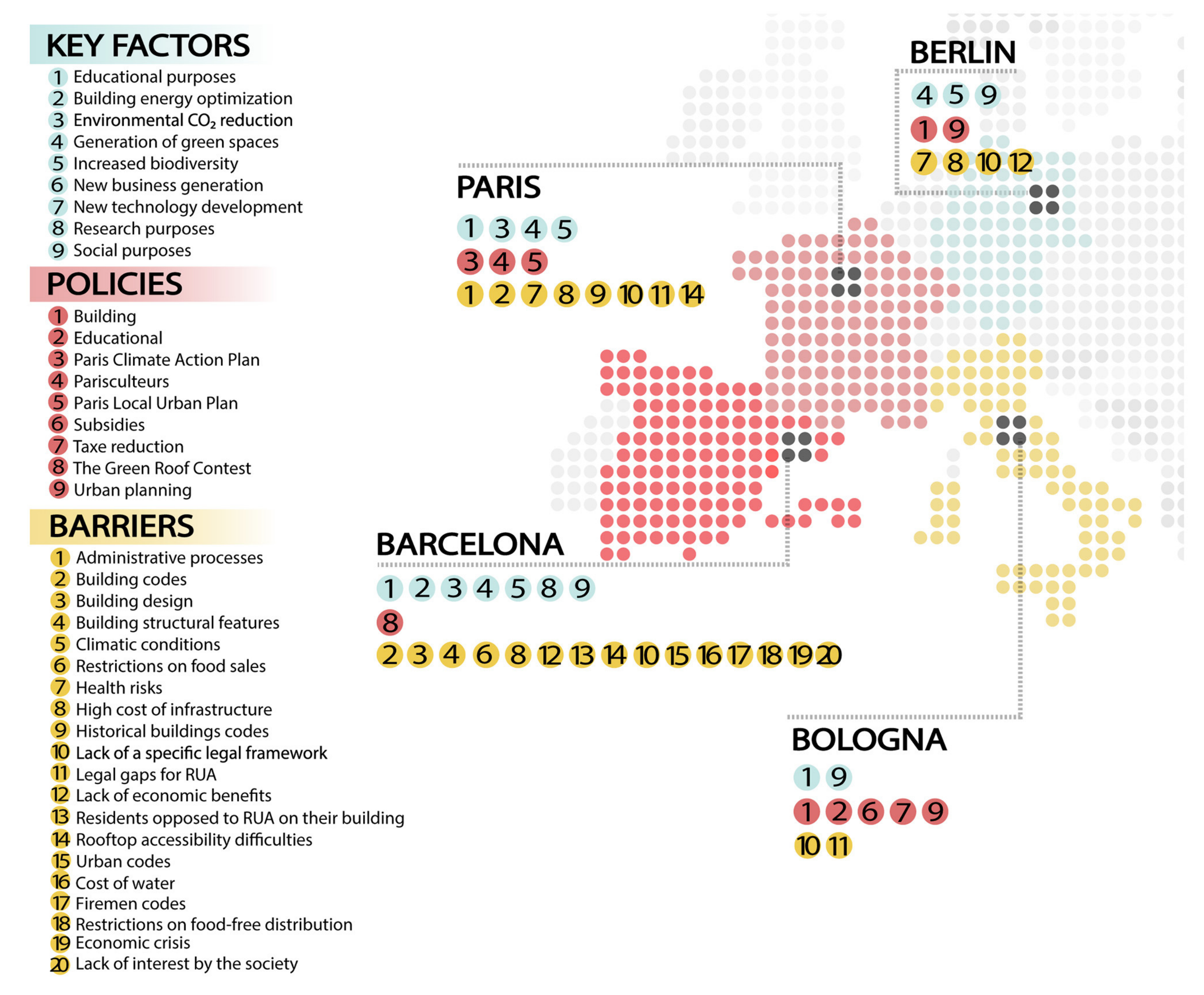

FIGURE 2 | Key factors, policies, and barriers regarding RUA projects according to stakeholder perceptions in four European cities.

Phase 2 Survey

Survey to Identify Potential Key RUA Factors and Barriers

Thirty stakeholders responded to the survey. **Figure 3** shows the distribution of participants and their field of expertise regarding UA, made up of five participants from Barcelona, seven from Bologna, six from Berlin, and twelve from Paris. Fifty percent of the respondents were academics and researchers, 40% of stakeholders were project developers, and 10% were public administrators.

Potential Key Factors for Integrating RUA

Figure 4 summarizes the key factors identified by more than 50% of participants (see all information in **Supplementary Figures**). Two factors—*educational* and *environmental*—were unanimously perceived as "relevant" by participants from Barcelona and Berlin. *Educational* factors refer to the integration of RUA as a tool for developing educational activities. *Environmental* factors include functions such as increasing biodiversity, generating green areas, reducing CO_2, and mitigating urban heat islands. *Research* from a multidisciplinary approach, including agriculture, environmental sciences, urban planning, architecture and social sciences, *technological innovation* related to new forms of UA, *food production* within city limits, and *social* functions are key factors perceived as "relevant" for integrating RUA.

Context Factors and Their Perceived Effects on RUA Diffusion

Figure 5 summarizes the contextual factors and global and local trends that hinder or promote RUA that were identified by more than 50% of the stakeholders (see all information in **Supplementary Figures**). Globally, *pollution* was the only factor identified as a condition that "hinders" RUA. Those

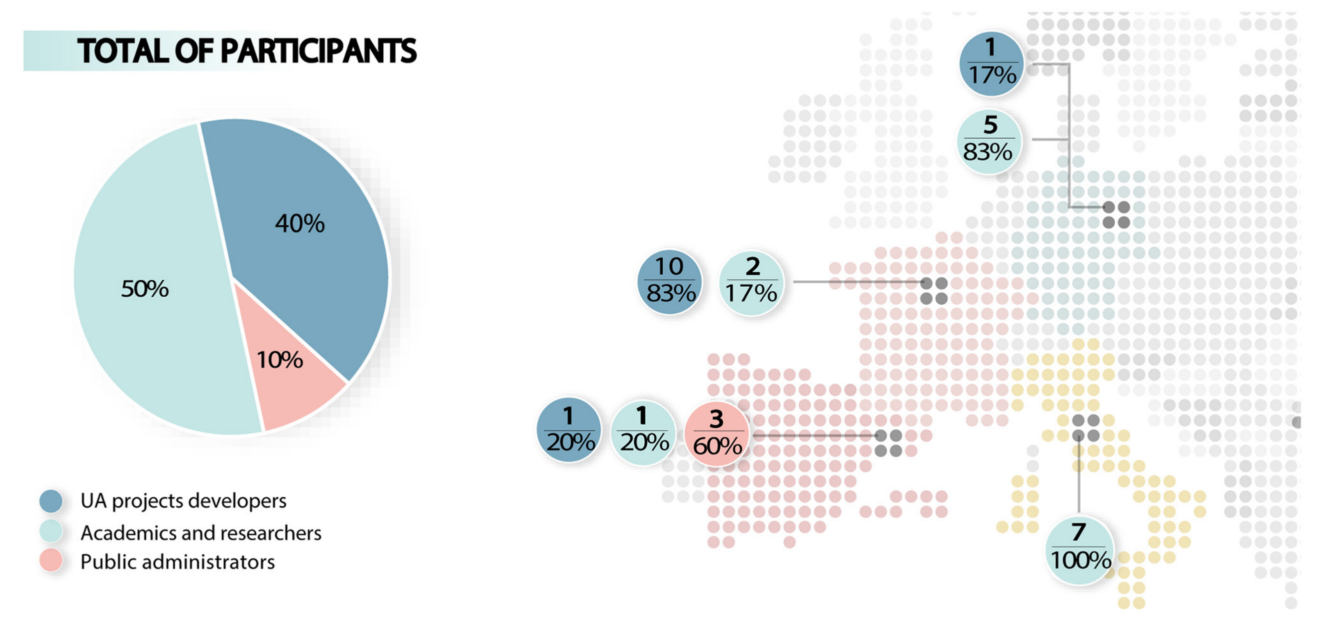

FIGURE 3 | RUA survey participants and their sectors.

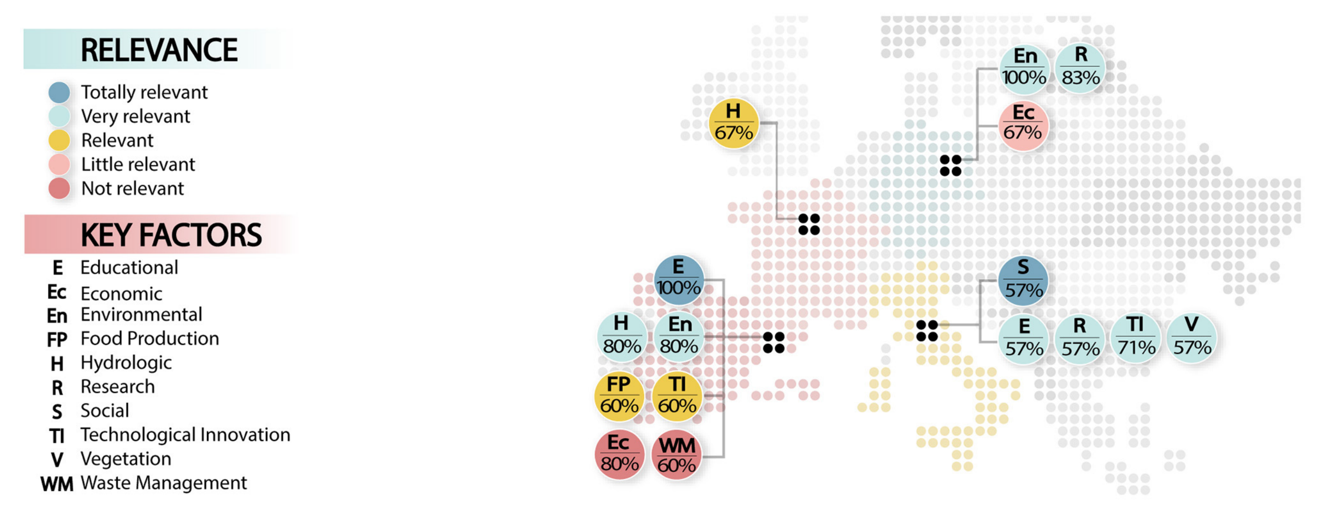

FIGURE 4 | Perceived relevance of key factors in four European cities for integrating RUA.

factors that "promote" RUA with the highest agreement (66%) among stakeholders were *cultural values* and *social rural-urban links*. Local trends showed five context factors perceived as "promoting" RUA: *productive spaces*, *cultural values*, *social cohesion*, *social rural-urban links*, and the *high cost of urban land*. The *cost of water* was perceived as a "hindering" factor to a similar degree both in Barcelona (75%) and Bologna (71%). There was some disagreement on the *pollution* factor; participants from Bologna (71%) identified it as a "promoting" factor, while participants from Barcelona and more than half from Paris (71%) identified it as a "hindering" factor.

Policies and Their Perceived Effects on RUA Diffusion

Figure 6 presents a summary of policies selected by more than 50% of participants, both globally and by city (see all information in **Supplementary Figures**). Five policies were identified in the target cities as "promoting" RUA. The *sustainability policy* obtained greater agreement (79%) among participants from all cities, followed by the *Milan Food Policy Pact* (62%). According to local trends, six policies were identified as "promoting" RUA. One was found to be common in all cities: policies targeting *sustainability*. The remaining five policies targeting *financial incentives*, the *development of new technologies*, *education*, and

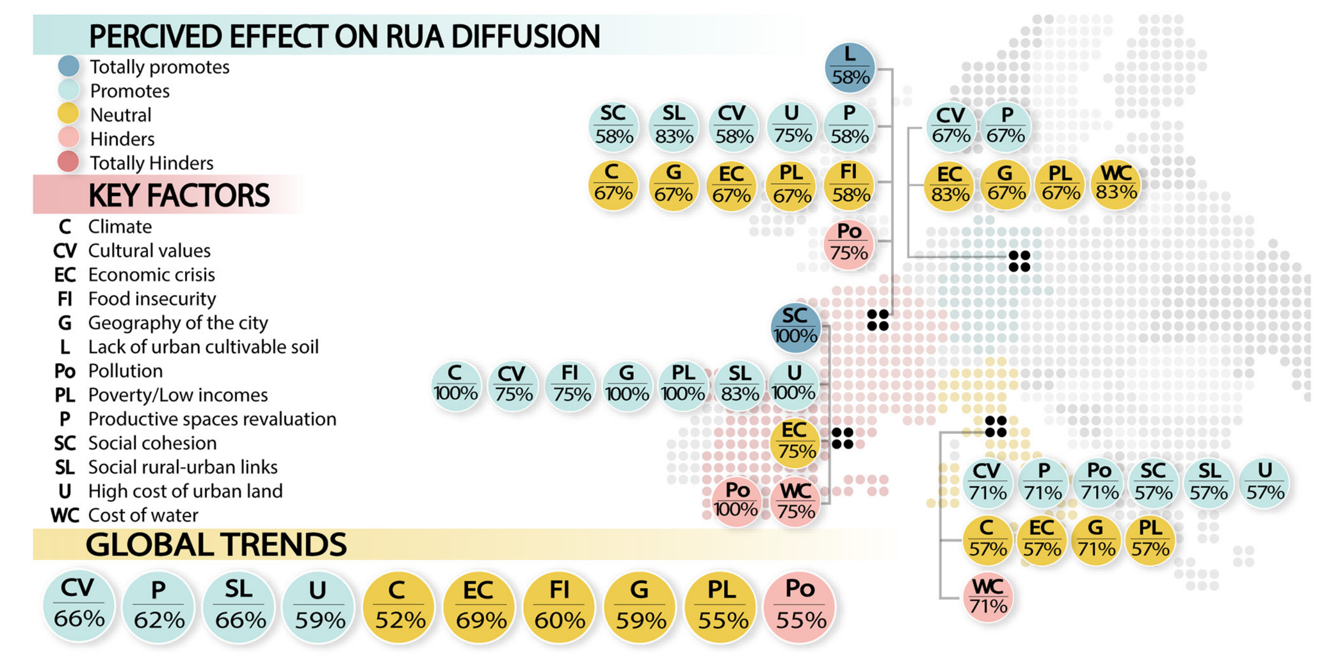

FIGURE 5 | Context factors and perceived effect on RUA diffusion in four European cities.

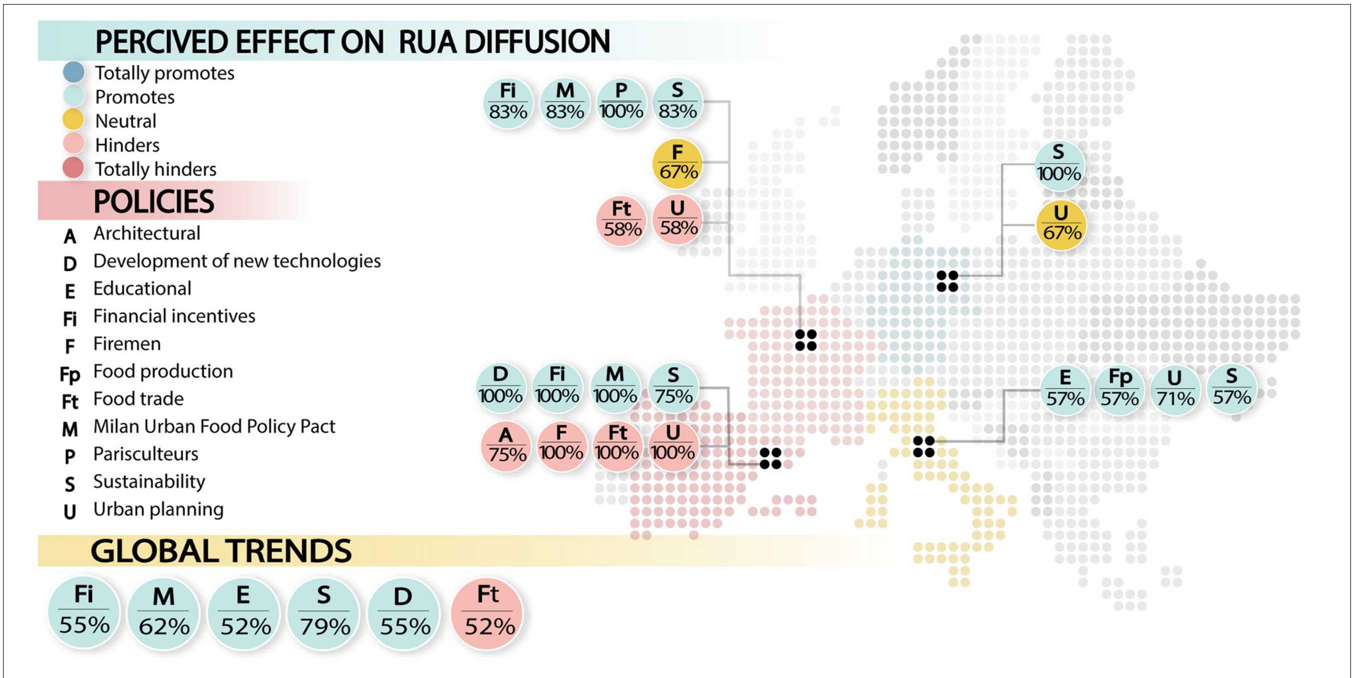

FIGURE 6 | Policies and perceived effect on RUA diffusion in four European cities.

food production, as well as the *Milan urban food policy pact* and the *Parisculteurs* program, were identified as "promoting" RUA. Policies related to *food trade* were considered to "hinder" RUA by all the participants from Barcelona and, to a lesser extent, by the participants from Paris. Policies related to *urban planning* were perceived by participants from Barcelona and Paris as "hindering" RUA and by those from Bologna as a "promoting" factor, while those from Berlin were "neutral."

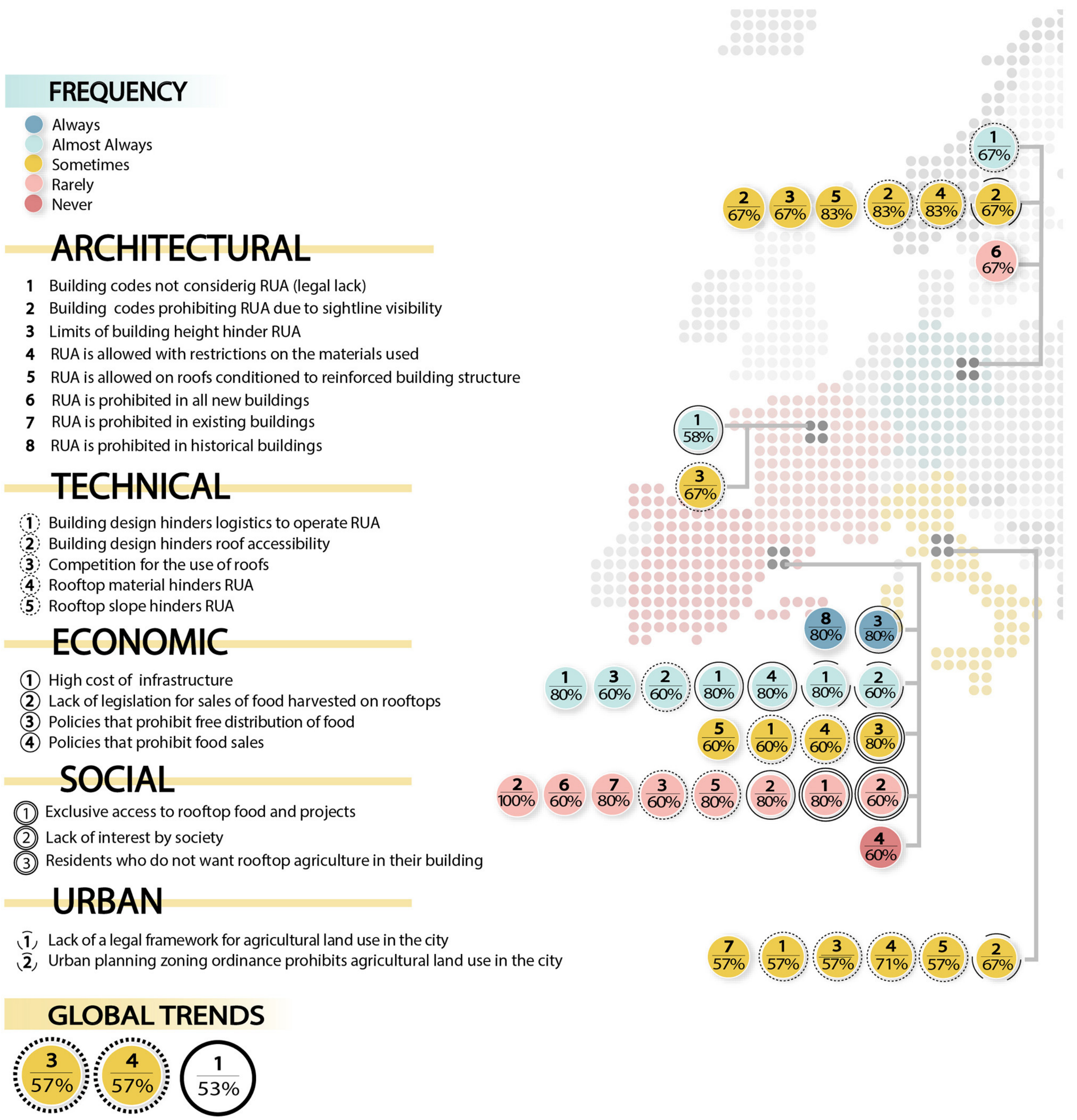

FIGURE 7 | Barriers and perceived frequency with which they appear for integrating RUA in four European cities.

Barriers for Integrating RUA

Figure 7 summarizes the barriers, and the frequency of their presence, to integrating RUA, both globally and by city. Only those barriers identified by more than 50% of participants are shown (see all information in **Supplementary Figures**). The following section presents the barriers, by category.

Architectural Barriers

There was no common architectural barrier for any of the cities studied. Three barriers were identified by stakeholders from Barcelona as factors that "always" and "almost always" hinder RUA: *prohibition in historical buildings*, *building codes that do not consider RUA* and *building height*. On the other hand, four architectural barriers were perceived as "rarely" or "never" hindering RUA by participants from Barcelona and Berlin: that *RUA is prohibited in all new buildings*, *RUA is prohibited in existing buildings*, *RUA is allowed with restrictions on the materials used*, and *building codes that prohibited RUA due to sightline visibility* (from the rooftop to other building).

Technical Barriers

As was the case with architectural barriers, no common technical barrier was found in any of the cities. *Building design hinders logistics to operate RUA* and *building design hinders roof accessibility* were identified as "almost always" occurring by stakeholders from Berlin and Barcelona. *Sloping rooftop hinder RUA* was identified as "rarely" appearing by stakeholders from Barcelona. *Competition for the use of roofs* was identified by Paris (67%) and Bologna (57%) stakeholders as a barrier that "sometimes" appears and by participants from Barcelona (60%) as only "rarely" appearing.

Economic Barriers

The results showed that there was no economic barrier found by all cities; however, the *high cost of infrastructure* was reported as a barrier that is "almost always" present by participants from Barcelona (80%) and Paris (58%). *Policies that prohibit food sales* were reported by participants from Barcelona as a barrier that "almost always" occurs. In addition, Barcelona was the only city that identified barriers as "always" present—*policies that prohibit the free distribution of food*—and "rarely" present—the *lack of legislation for sales of food harvested on rooftops*.

Social Barriers

As in previous barrier categories, no common social barrier was found in the target cities. In this group, *exclusive access to rooftop food and projects* and *lack of interest by society* were identified as social barriers that are "rarely" present; the presence of *residents who do not want rooftop agriculture in their building* was identified by respondents from Barcelona as a barrier that "sometimes" appears.

Urban Planning Barriers

Again, in this category, no common barrier was found among all cities. However, the results showed that the *lack of a legal framework for agricultural land use in the city* was identified by stakeholders from Barcelona and Berlin as "almost always" and "sometimes" present, respectively. An *urban planning zoning ordinance that prohibits agricultural land use in the city* was perceived as "almost always" an issue by stakeholders from Barcelona.

DISCUSSION

This study has provided an exploratory overview of key factors, contextual factors, policies, and barriers associated with the integration of RUA based on stakeholders' perceptions in four European cities. It contributes to the literature on stakeholders' perceptions of RUA using a framework that can be applied extensively in EU cities. These perceptions likely shape the development of RUA agriculture practices and projects. One of the contributions was the identification of differences and similarities of four European cities. In the following sections, the most relevant factors, policies, and barriers that may promote or hinder the integration of RUA are discussed.

Potential Key Factors for Integrating RUA

Technological innovation, *food production* and *research* were factors identified in this study as relevant for integrating RUA that had not been previously reported (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2016; Specht et al., 2016a; Specht and Sanyé-Mengual, 2017). This is likely due to the increasing relevance of RUA in the cities involved in the study, thanks to recent supporting policies and the development of new RUA projects, allowing stakeholders to identify both existing and new key factors. The *research* factor, scarcely addressed in the previous literature, was repeatedly mentioned, possibly as a result of the involvement of academics in the study. RUA, therefore, seems to be an opportunity for developing research projects. Other factors identified in the study that have also been previously mentioned in the literature include *environmental purpose*, *social community building* and *educational functions* of RUA (Sanyé-Mengual et al., 2016; Specht et al., 2016a). A relevant contribution concerns the perception about the *economic* factor perceived as "little relevant" (67%) by the stakeholders from Berlin and "not relevant" (80%) by participants from Barcelona, despite the proven evidence on the crucial role that economic considerations may play in the viability of RUA initiatives (Cerón-Palma et al., 2012; Specht et al., 2016a; Specht and Sanyé-Mengual, 2017).

Context Factors and Their Perceived Degree of Hindering or Promoting RUA

A relevant contribution is a perspective concerning *high urban land costs* which are perceived as a "promoting" factor of RUA. This posture is the opposite of the study conducted by Orsini et al. (2020) about urban agriculture and was not identified in previous RUA studies (Cerón-Palma et al., 2012; Specht et al., 2015, 2016a; Sanyé-Mengual et al., 2016). This finding could be due to the expansion of UA experiences in recent years. *Cultural values*, *social cohesion*, the creation of wasted areas into *productive spaces in urban areas*, and the interaction of *rural activities taking place in urban areas* rather than looking separately, showed correspondence with previous works where similar factors had been identified as opportunities for integrating UA (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2016, 2018a). One difference to highlight was regarding *pollution*, perceived as both a "hindering" (Barcelona and Paris) and a "promoting" (Bologna) factor. Previous studies in Barcelona and Berlin had reported pollution as a barrier for RUA development (Sanyé-Mengual et al., 2016; Specht et al., 2016a). These differences could be associated with the field of expertise of the participants; however, this hypothesis was not addressed in this study, and a more in-depth analysis is required for its validation. The perception of RUA has been associated with health risks related to pollution, although the perceived risks have been partly negated by the results of scientific analyses (Antisari et al., 2015). According to a recent study, heavy metal concentrations in lettuce growing in open-air systems located in high-traffic areas of Barcelona are below the EU-legislated level (Ercilla-Montserrat et al., 2018). However, research on this issue is still recent, and further empirical evidence is necessary to validate the findings in different contexts. This study further revealed that stakeholders perceived the *cost of water* as a "hindering" factor, which had not been identified previously (Cerón-Palma et al., 2012; Specht et al., 2015, 2016a; Sanyé-Mengual et al., 2016; Specht and Sanyé-Mengual, 2017; Zambrano-Prado et al., 2021). Water for irrigation of crops can be expensive in urban areas. In addition, water is an increasingly scarce resource. Different systems can be implemented to optimize water use, for example, leachate recirculation or the integration of rainwater harvesting systems. Thus, special attention and exploration of possible alternatives are needed.

Policies and Their Perceived Effects on Hindering or Promoting RUA

Policies related to *food trade* are a constraint for developing RUA. As other cities have already identified, restrictions on the sale of products from urban farms may limit products grown locally. Some cities (e.g., New York City, Chicago, Toronto) have addressed this restriction by changing policies and the zoning code (Fletcher et al., 2012). Barriers regarding *architectural* and *urban codes* were identified in this work. These findings are not new and still represent legal constraints for RUA, even in cases where UA is highly compatible with urban development strategies. A lack of consistency in various legal fields, such as hygiene and food processing laws, was reported in the previous literature. Nevertheless, major concerns refer to building laws, which are considered too strict and difficult to understand. In this sense, stakeholders perceived various uncertainties and regulatory gaps (Specht et al., 2016a). In the case of Paris, the city council has made some changes in the Paris Local Urban Plan (Paris City Council, 2018) to be more "friendly" to RUA projects. However, according to the results from this study, there is still a perception that *architecture* and *urban planning laws* "hinder" RUA development. In addition, *financial incentives*, the *development of new technologies*, *education*, *food production* and local policies such as the *Milan urban food policy pact* and *Parisculteurs* program were identified in this study as "promoting" RUA. Policies targeting the *development of new technology* not found in the previous literature (Cerón-Palma et al., 2012; Specht et al., 2015, 2016a; Sanyé-Mengual et al., 2016; Specht and Sanyé-Mengual, 2017; Zambrano-Prado et al., 2021) were also identified by the stakeholders in this study, possibly due to the involvement of academics. This finding is relevant for exploring techniques, procedures, and resource efficiencies for RUA. The importance of *educational* benefits has already been determined in the international literature (Cerón-Palma et al., 2012; Specht et al., 2015, 2016a). RUA could be integrated as an educational strategy for promoting environmental education, considering that many schools currently have meal services (Nadal et al., 2018) and, according to the main goal of The Global Education 2030, for developing sustainability competencies as a core of Education for Sustainable Development (Leicht et al., 2018). *Sustainable* benefits have also been extensively recognized (Cerón-Palma et al., 2012; Specht et al., 2015, 2016a; Sanyé-Mengual et al., 2016), although their frequency varies across cities. Contrary to a few years ago, currently in Barcelona, local environmental policies such as Barcelona's Climate Plan 2018–2030 integrate the inclusion of RUA, with the ambitious objective of reaching 34,100 m^2 of green roofs, walls, and facades by 2030. The Climate Plan 2018–2030 also includes drawing up bylaws to promote productive roofs and consolidate an annual green roof contest. In addition to developing the winning projects, which are not restricted to ornamental plants, projects could also integrate food production (Barcelona City Council, 2017). Additionally, the Paris Climate Action Plan (City of Paris, 2018) includes part of the "Objective 100 Hectares" initiative, one-third of which will be devoted to UA located on green roofs and walls (City of Paris, 2018). Differences between cities were found. This is especially true for the perceived effect of *urban policies* on RUA expansion. Assumptions for these differences could be due to the fields of expertise and personal experience with RUA. However, to confirm this hypothesis, a broader analysis is required.

Barriers for Integrating RUA

Architectural Barriers

Constraints for integrating RUA in historical buildings and the *limits on the height of buildings* according to building codes were identified in this study as barriers to RUA development but had not been reported before (Cerón-Palma et al., 2012; Specht et al., 2015; Sanyé-Mengual et al., 2016), perhaps due to the recent growth of RUA experiences. Regarding the limits on the height of buildings, since the implementation of the Parisculteurs program (Paris), the city council has changed urban regulations to allow farming on rooftops even when the building exceeds height limits (Brin et al., 2016). Nevertheless, according to stakeholders' perceptions, this barrier still applies. In Barcelona, RTGs cannot be built on some rooftops due to height/volume restrictions (Metropolitan Area of Barcelona, 2018). Among the constraints for RUA integration, it was mentioned that *building codes did not consider RUAs* and the *need for building structure reinforcement*. Indeed, building overloading and the need for reinforcement (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2016) are still major barriers. Currently, many buildings may not have a suitable structure or load-bearing capacity for RUA (Toporova, 2018), which may also have economic repercussions due to the cost of building reinforcement and the need for professionals to develop and execute such projects.

Technical Barriers

Building designs to operate RUA and the *difficulties of roof access* were mentioned as factors that "constrain" RUA development. Cerón-Palma et al. (2012) also identified the complexity of adapting or renovating existing buildings; in this sense, it is essential to identify how users would access the roof spaces considering safety norms. In general, the technical adaptations necessary to operate RUA can lead to extra costs and limit the economic feasibility of projects. *Competition for integrating other systems and/or functions on roofs* is still present, as reported in previous works (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2016). However, current practice demonstrates that the integration of multiple systems/functionalities can also take place in parallel. In Barcelona, the RTG Lab Fertilecity integrates a rainwater harvesting system (RWHS) for crop irrigation, reaching 100% water self-sufficiency (Sanyé-Mengual et al., 2014). Five RUA projects recently built integrate RWHS and photovoltaic (PV) systems (Barcelona City Council, 2017). Thus, RUA, RWHS, and PV systems can coexist, providing significant benefits (Benis et al., 2018; Toboso-Chavero et al., 2018; Corcelli et al., 2019).

Economic Barriers

Regarding economic categories, stakeholders perceived that the *high cost of infrastructure* is a major barrier; previous studies also reported this constraint (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2016). Such barriers can be addressed with the support of financial policies and incentives, such as those already implemented in Barcelona and Paris. However, the initial investment goes beyond the financial cost, since maintenance of this kind of infrastructure is also expensive and constitutes an additional barrier during the operation stage (Zambrano-Prado et al., 2021). Therefore, for RUA that are successful and do not turn into short-lived projects, maintenance costs beyond the initial costs must be studied and considered. *Food sales policies* are related to urban land zoning ordinances, and together with the perception of *high-cost infrastructure*, can lead investors with commercial interests to easily lose interest. If there is no specific legislation for the trade of products grown within the city, it is difficult to integrate large-scale RUA projects. Fletcher et al. (2012) recognized restrictions by municipalities on sales of locally grown products in cities. To address this barrier, some cities have made policy changes, especially in North America. In 2012, the Berkeley Planning Commission adopted the definition of "Non-Processed Edibles," which allowed the production of different kinds of food products within urban areas and their sale in residential districts (Fletcher et al., 2012).

Social Barriers

As in previous barrier categories, no common social barrier was found in the target cities. Compared to other barriers, social aspects were associated with fewer constraints. The survey revealed that *exclusive access to food growing on rooftops*, *exclusive access to developing RUA*, a *lack of interest by society in RUA projects* and *limited acceptance by residents of RUA on their building* are not frequent. However, during the workshop, stakeholders manifested their concerns about these social barriers. A risk that large companies may transform RUA into an exclusively profit-oriented (Specht et al., 2016a) initiative and, thus, aggravating social disparities in accessing systems and products (Sanyé-Mengual et al., 2016) have been identified by stakeholders in the previous literature. These risks could also be drivers of green gentrification in neighborhoods. Currently, however, this risk does not seem to be a major concern among stakeholders.

Economic Barriers

Urban planning codes that do not contemplate urban agricultural land use are still barriers. Castillo et al. (2013) identified barriers related to zoning codes, such as a lack of clear ordinances that are friendly to agriculture. In Singapore, urban planners included rooftop farms in the definition of urban green spaces and diversified the classification of agricultural land use, allowing this activity in urban areas (Diehl et al., 2020). Additionally, cities in the U.S., such as New York and Chicago, were included (The New York City Council, 2010; Urban Sustainability Exchange, 2011; City of Chicago, 2020). Of the cities involved in this study, in Barcelona, the General Metropolitan Plan does not allow agricultural activities inside the city, effectively making the commercialization of food produced in the city illegal. In the case of Paris, programs to encourage UA have been launched, which may allow agricultural activities in the city, while in Bologna, the workshop findings indicate that agricultural activities are not allowed in the city.

CONCLUSIONS

This paper explores the perceived key factors, contextual factors, policies, and barriers to integrating RUA by ranking their relevance and the frequency with which they are presented. It also revisits the concepts associated with environmental, architectural, technological, social, legal, economic, and urban planning from the perspective of stakeholders from four European cities (Barcelona, Berlin, Bologna, and Paris).

In all cities involved in the workshop, policies exist to support UA, often resulting in RUA experiences implemented by or involving local government. However, an explicit and singular public policy for RUA practices is still missing.

Major key factors that promote the development of RUA, not previously reported, include technological innovation, growing local food, research activities, and the high cost of urban land in cities. Major factors that hinder RUA were identified as the cost of water and pollution (Barcelona and Paris). The cost of water appears as a new barrier, and thus is a relevant topic for future studies and for efforts to find ways to respond to this constraint, including technological innovation, research, and policy creation. Regarding pollution, the need for disseminating proper information and conducting a deeper study on perceptions of the effects of pollution, as well as establishing quality management and quality control for crop production, are highlighted.

Policies targeting sustainability were found to be common in all cities as "promoting" factors. Currently, and contrary to some years ago, there are already policies that promote RUA for environmental purposes, such as Barcelona's Climate Plan 2018-2030 and Paris Action Climate Plan 2019. However, there is still a lack of urban, architectural, and product sales regulations for this kind of infrastructure, which continues to make the integration of RUAs difficult. Policies related to financial incentives that are generally included in city policies, the development of new technologies for crop production systems and buildings, educational programs, policies for food production within the city, such as the Milan urban food policy pact and Parisculteurs program were all identified as "promoting" RUA development. Limitations on marketing products grown within the city, as well as urban policies, continue to restrict the integration of the RUA. The inclusion of RUA in policies focused on climate change is insufficient. For the expansion and success of RUA projects, it is necessary to consider these infrastructures in the different related codes. The creation of new legislation or modifications to support RUA is necessary, especially in the South European cities studied—Barcelona and Bologna. A flexible land use policy that allows UA in cities must be considered by urban planners as well as sales of products with production and distribution regulations. Changing regulatory barriers is a potential opportunity to create laws and programs to promote and expand RUA.

RUA faces several architectural, economic, and urban challenges that need to be addressed. The following architectural factors stand out as impediments: construction licenses in historic buildings, building codes that do not contemplate this type of infrastructure and the height limits of buildings stipulated in construction regulations, usually exceeded by RUA infrastructure. Two technical barriers were identified as major constraints: building designs that pose logistical difficulties in operating RUA and problems with roof access. In the economic category, the high cost of infrastructure and policies that prohibit food sales are major constraints. The lack of legislation regarding agricultural land use and urban zoning ordinances that prohibit agricultural activities also limit RUA integration.

Architectural and technical barriers can represent higher investment costs. Both financial incentives and business plans are needed to develop economically self-sufficient RUA projects. It was noted that access or exclusivity in projects is not a major concern. However, it is necessary to consider risks such as gentrification or commercial purposes and to study and anticipate these potential risks through legislation. The integration of urban agriculture must consider the social, educational, environmental, technological innovation and research functions that have been described as key factors for its integration in cities.

Although some differences were found between the targeted cities, these should be confirmed through more extensive research. To this end, the framework and set of statements elaborated here could be used for further data collection, allowing to analyze and characterize more stakeholder perceptions. Future research should be conducted on a larger sample of participants to confirm the empirical differences between cities.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PZ-P: conceptualization, method design, investigation, data collection, formal data analysis, writing original draft, writing review and editing, and visualizations. FO: writing review and editing. JR: conceptualization, method design, supervision, and review the manuscript. AJ: review the manuscript. XG: conceptualization, method design, project administration, funding acquisition, and review the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.733040/full#supplementary-material

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"We Have Been Part of the Response": The Effects of COVID-19 on Community and Allotment Gardens in the Global North

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Throughout history, urban agriculture practitioners have adapted to various challenges by continuing to provide food and social benefits. Urban gardens and farms have also responded to sudden political, economic, ecological, and social crises: wartime food shortages; urban disinvestment and property abandonment; earthquakes and floods; climate-change induced weather events; and global economic disruptions. This paper examines the effects on, and responses by, urban farms and gardens to the COVID-19 pandemic. The paper is based on data collected in the summer of 2020 at the onset of the pandemic when cities were struggling with appropriate responses to curb its spread. It builds on an international research project (FEW-meter) that developed a methodology to measure material and social benefits of urban agriculture (UA) in five countries (France, Germany, Poland, UK and USA) over two growing seasons, from a Food-Energy-Water nexus perspective. We surveyed project partners to ascertain the effects of COVID-19 on those gardens and farms and we interviewed policy stakeholders in each country to investigate the wider impacts of the pandemic on UA. We report the results with respect to five key areas: (1) garden accessibility and service provision during the pandemic; (2) adjustments to operational arrangements; (3) effects on production; (4) support for urban farms and gardens through the pandemic; and (5) thoughts about the future of urban agriculture in the recovery period and beyond. The paper shows that the pandemic resulted in multiple challenges to gardens and farms including the loss of ability to provide support services, lost income, and reductions in output because of reduced labor supply. But COVID-19 also created several opportunities: new markets to sell food locally; more time available to gardeners to work in their allotments; and increased community cohesion as neighboring gardeners looked out for one another. By illustrating the range of challenges faced by the pandemic, and strategies to address challenges used by different farms and gardens, the paper illustrates how gardens in this pandemic have adapted to become more resilient and suggests lessons for pandemic recovery and longer-term planning to enable UA to respond to future public health and other crises.

Keywords: community garden, allotment garden, COVID-19, resilience, response

INTRODUCTION

The value of urban and rural green spaces to human health and well-being has long been recognized in the literature (Rui et al., 2014; Schmutz et al., 2014; James et al., 2015; Buck, 2016; Federation of City, Farms and Community Gardens, 2016; Bragg and Leck, 2017; Barry and Blythe, 2018; Ambrose et al., 2020). The importance of access to nature in everyday life (Bell et al., 2016; Chalmin-Pui et al., 2021) became clearer during the COVID-19 pandemic, as stay-at-home and social distancing requirements led to a dramatic increase in the use of parks and gardens (Armstrong et al., 2021; RHS Lindley Library RHS Communities Team, 2021). Given the wide recognition of the value of parks and green spaces in cities (e.g., Swanwick et al., 2003; White et al., 2013; Brown et al., 2014; University of Leeds, 2015; WHO Regional Office for Europe, 2016) they have the potential to play a substantial role not only in recovery from COVID-19 but also in the resilience of communities to future environmental, health, or economic challenges (Honey-Rosés et al., 2020; Ugolini et al., 2020; Pouso et al., 2021).

This paper focuses on green spaces used for food production, specifically community gardens and allotment gardens. Urban farming and growing has taken many forms through time and space varying from quite large commercial farms to small individual plots to backyard gardens and even pots on windows or balconies. While they vary in physical and operational characteristics, and have varied goals and objectives, and benefits (Kirby et al., 2021), their common feature is that they enable individuals in cities to cultivate vegetables and fruits and are spaces in which people can engage in varied social activities.[1] The role of such spaces in the current COVID-19 crisis is investigated here.

LITERATURE REVIEW

Whilst the current paper researches, and draws lessons from, the response of urban farms and gardens to the COVID-19 pandemic, there are well-documented examples from recent history (Bell et al., 2016), of urban agriculture making an important contribution during crises as well as in post-crisis recovery. Times of conflict have been an incentive for the resurgence of gardening, for example during the First World War with food shortages appearing in the USA and Europe. The foundation of the National War Garden Commission in 1917 encouraged citizens and schools to contribute to the war effort through gardening in the USA (Herrmann, 2015) with more than 5.2 million gardens established by 1918. During the Second World War, the US National Victory Garden Program also promoted urban farming for the war effort and cultivation of patriotism, with around 20 million victory gardens by 1944 producing more than 40% of the nation's fresh vegetables. The same initiatives were in place in other nations, including the UK (Smith, 2013) and Russia (Boukharaeva and Marloie, 2015) with a similar expansion observed in urban farming.

Urban food growing is also a reaction to economic crises, both sudden and chronic. During the 1893-1897 depression, gardening was seen as an alternative to charity offerings in Detroit and relief gardens also bloomed during the Great Depression in the 1930s with more than 2.3 million US families participating in urban farming, according to a 1934 report (Lawson, 2004). In Australia and the UK, backyard home gardens and small-scale poultry raising developed during this period (Mok et al., 2014). In 1970s New York City, a fiscal crisis led to housing abandonment and demolition; the city government facilitated the creation of community gardens run by residents as a low-cost means to clear, clean and manage vacant lots. In Poland, during the economic challenges faced under Communism, allotment gardens allowed households to extend their budgets by producing vegetables and fruit for household needs (Bellows, 2004). More recent examples include Cuba's response to the economic crisis caused by the end of Soviet support and an American embargo, with a loss of 67% of incoming supplies in 1993-1994. This marked the start of the "special period" in Cuba where vacant land throughout the country's cities was cultivated to address food shortages. By 1998, Cuba had more than 8,000 urban gardens and farms, with more than 30,000 Havana residents engaged in gardening, resulting in some Havana neighborhoods producing 30% of their food through diverse garden and farm types (Novo and Murphy, 2000; Argaillot, 2014). In South America, Rosario in Argentina provides a good example of civil society and local government responding to poverty by creating community gardens for hundreds of families (Santandreu et al., 2009). In Europe, increased urban farming and gardening was a response to the global financial crisis of 2008, with countries hard hit by the crisis, such as Portugal (Delgado, 2015, 2017), Greece (Partalidou and Anthopoulou, 2017) and Spain (Seguí et al., 2017) allocating vacant land to low-income households to enable them to grow food.

The COVID-19 pandemic is the latest crisis to have resulted in a resurgence of urban gardening and farming. Local food production increased in response to varied consequences of the pandemic: supermarket shortages in the early days of the pandemic (Busby, 2020; Evans and Davies, 2020; Molteno, 2020);

[1] A community garden is one where the land is cared for collectively by local volunteers with shared harvest; an allotment garden is one where small parcels of land are made available for individual non-commercial gardening or growing of fruit and vegetables, and other leisure activities. Unless otherwise specified, the term "gardens" in the paper includes both forms of urban agriculture.

perceived risks to commercial food systems (Vittuari et al., 2021); free time due to furloughs and working from home (Sams, 2020); and even the desire for physical activity to address obesity, a co-morbidity for COVID-19 (BBC News, 2020).

A major motivation for engaging in urban agriculture was the potential for gardens to support health and well-being. Some embraced gardening to relieve stress and support mental health (Cockburn, 2020). Gardens have certainly proved to be beneficial to mental health during the lockdowns, relieving social isolation and improving mood and sense of community. Lades et al. (2020) found that time spent outdoors for a sample in Ireland in March 2020 was associated with markedly raised positive emotional effects and reduced negative emotions. Gardening was one of five outdoor activities associated with the greatest benefits. Bu et al. (2020) found that gardening led to improvements in mental health and well-being during the March–May lockdown period in the UK while Corley et al. (2021) and Sunga and Advincula (2021) found spending time in a garden boosted physical, emotional, and mental health. Pouso et al. (2021), using an online survey in nine countries, found that the lockdown significantly affected mental health and access to outdoor space helped people to cope with these impacts. In China, Wang et al. (2020) report on an online indoor micro-gardening programme that provided social and emotional support for participants through the pandemic.

Another important motivation for gardening and farming was the ability to grow fresh food for household use. Before COVID-19, cities were struggling to cope with increased demand from burgeoning urban populations (Khan et al., 2020), and the pandemic illustrated the fragility of supply chains and the impact of labor shortages on harvests and food processing (Lal, 2020). It reinforced the notion that urban growing with shorter supply chains for fresh produce may be able to contribute to a more resilient and sustainable domestic supply (Altieri and Nicholls, 2020; Pulighe and Lupia, 2020). To individual households, the availability of vegetables and fruits was a way to mitigate food shortages caused by consumer hoarding early in the pandemic. Growing food was also seen as assisting the increasing number of households facing food insecurity due to the economic fallout of the pandemic. Gardeners from ethnically and racially diverse communities used their growing spaces during lockdown to produce culturally appropriate foods that were limited by supply chain disruptions, while the community gardens provided common space for diverse individuals to socialize (Mejia et al., 2020).

Historically, urban agriculture has responded in varying ways to different crises because of differing socio-political situations and specific needs. This paper aims to explain how diverse urban agriculture projects in five countries adapted to the pandemic, and how in their adaptation they attempted to address the challenges of the pandemic. We report the results of surveys with two groups of stakeholders, practitioners (i.e., gardeners) and policymakers, to explain how they perceived urban gardens and farms to contribute to pandemic resilience. By illustrating the range of challenges faced by gardens due to the pandemic and strategies to address challenges used by different farms and gardens, we suggest lessons for municipal food planning relevant to future crises.

For the study, we explored the literature regarding the linkage of urban agriculture to previous crises and the contribution of urban agriculture to resilience in cities and we refer back to this in the Discussion: given the *ad hoc* nature of the fieldwork element, completed in extreme circumstances, we chose an empirical approach to explore the impact of the pandemic rather than embedding the research within a theoretical framework.

MATERIALS AND METHODS

The data informing this paper was drawn from research carried out in the summer and early autumn of 2020 in the context of a three-year international research project, called "FEW-meter," funded under the Sustainable Urbanization Global Initiative (SUGI), a collaboration between the Joint Program Initiative (JPI) Urban Europe and the Belmont Forum. The research aims were to measure urban agriculture's Food- Energy- and Water- (FEW) nexus and social dimensions in five countries (Poland, France, Germany, UK and the US) (Caputo et al., 2021; Kirby et al., 2021) over two growing seasons, and through analysis of this data to identify opportunities to improve the performance of urban farms and gardens. The project also included interviews with urban agriculture policy experts and other stakeholders to understand the effects of different policy environments on the success and growth of urban agriculture.

The FEW-meter project was launched in 2018 with recruitment of participating allotment gardens, community gardens and community farms. As the FEW-meter project followed a longitudinal citizen-science approach with farmers and gardeners willing to record data over two cropping periods and because not all forms of urban agriculture are equally represented in all participating countries, and much fewer have organizations that have facilitated access, it was determined early on in the project that each participating country would work with a specific type of garden: in the UK, this was to be community gardens and allotments; in France, micro-farms and allotment gardens; in Poland and Germany, allotment gardens; and in the USA, community farms. Numbers recruited to FEW-meter within each country varied: the data collection request over two growing seasons was significant, certainly for community gardens that are largely dependent on volunteer labor. This explains the low number of respondents in the UK where predominantly community gardens and allotments were the allocated urban agriculture type.

During the Spring to Fall 2019 growing season we measured operations and production and surveyed gardeners and farmers about their motivations for gardening and the effects of gardening on their well-being. The pandemic emerged by March 2020, just prior to preparation and planting of the second growing season, prompting governments in the UK, the EU, and the US to adopt social distancing, stay-at-home, and other non-pharmaceutical interventions to stop the spread of the virus. We decided to investigate the effects of COVID-19 on urban agriculture operations because we expected significant

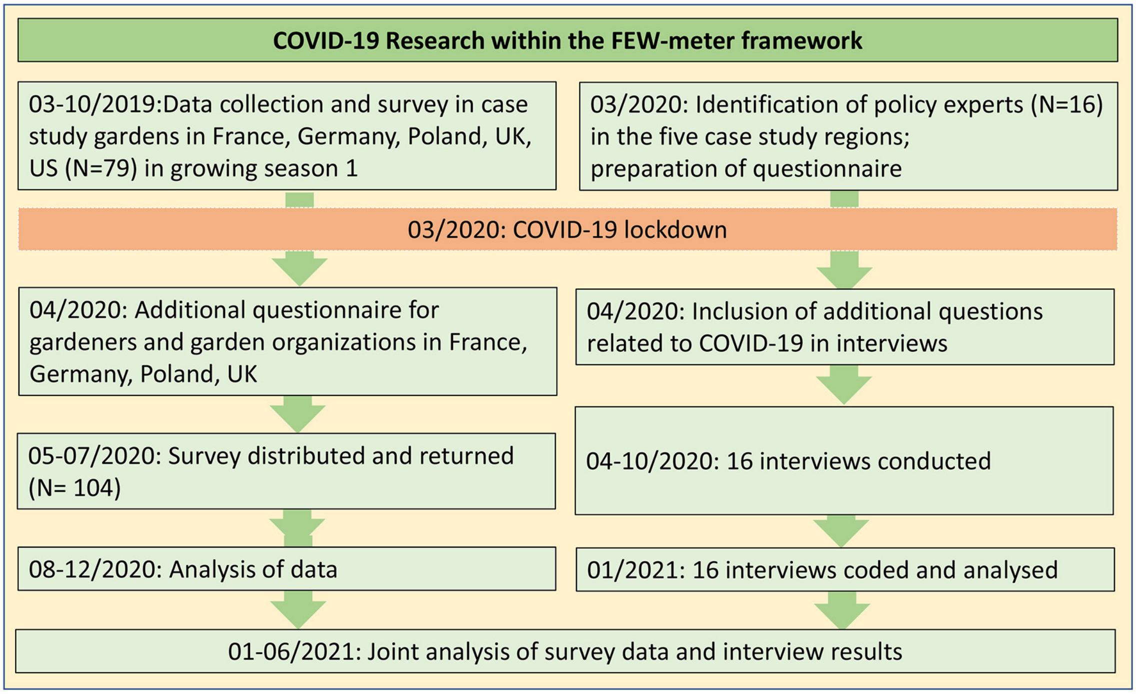

FIGURE 1 | Timetable of research process.

changes that would alter farm productivity and social impacts of the gardens and farms during the second season in our study, and therefore alter the results of our analyses of the FEW nexus. The timetable explaining the timeframe of the research for this and the full FEW-meter study is given in **Figure 1**.

In Spring 2020, in each of the five countries, we added questions to the interview guides for policy stakeholders about the general effects of the COVID-19 pandemic on urban agriculture activities in their projects. To elicit information from gardeners and farmers about their experiences during the pandemic, we also surveyed those who already participated in the FEW-meter project about the impacts of COVID-19 on their individual gardening activities. The survey was adapted to community and allotment gardening and its administration was tailored to social distancing and research constraints in each of the participating countries.

Ethics approval was sought for both aspects of this research. The German team had overall responsibility for the interviews with policy stakeholders, and prior to each interview, the respondent was asked to read and sign a consent form as prepared by ILS. Consent for the garden survey was included in the initial ethics approval obtained by each country academic institution for FEW-meter as this survey was an extension of ongoing work. Where gardens were not already a part of the FEW-meter project, they were asked to read and consent to the same form that signatories to FEW-meter were asked to agree or an early section was added to the questionnaire for respondents to sign before completing the survey.

The findings from the policy interviews and garden survey are analyzed in the Results section below in tandem as the questions followed broadly the same lines of enquiry. More detail on each of the primary sources is provided below.

Guided Interviews With Policy Stakeholders

A significant part of the FEW-meter project is to investigate policies toward urban agriculture in each of the five countries, especially to review the policy enablers and barriers to upscaling of urban growing in the case study locations. The methodology for this aspect of the FEW-meter project employs qualitative interviews with key stakeholders (considered to be well-informed, influential, food policy figures) in each of the five countries, as suggested by our local academic teams. We chose diverse types of stakeholders that we considered to be relevant for the strategic development of UA.

To understand the wider impact of the COVID-19 pandemic on urban agriculture, as part of the larger 19-question interview protocol (primarily dealing with the strategic development of resource efficient UA and its embeddedness in policies) the following three questions specifically related to the effects of the COVID-19 pandemic were included:

1. How is the current crisis affecting UA in your city/region?;
2. Is any local authority supporting urban gardening/farming in light of the COVID-19 pandemic? If yes, what kind of support is provided?; and

TABLE 1 | Number of questionnaires completed by garden type in each of four FEW-meter project countries.

	Community garden representatives	Allotment association representatives	Allotment plot holders	Rationale for respondent numbers
UK	8	1	1	Questionnaire was distributed to the seven original FEW-meter case study community gardens and the one allotment association. Of these, six community gardens responded, as did the allotment association and the one plot holder within that allotment garden. In addition, the questionnaire was sent to the community garden at the University of Kent where two of the authors are employed (Schoen and Caputo) as well as one other community garden that had expressed an interest in joining FEW-meter but that did not continue to supply input and harvest data.
Germany	–	38	10	Questionnaire was distributed to allotment gardeners involved in the FEW-meter project but also, using a pre-established contact, it was possible to distribute the questionnaire to allotment association representatives of the Westphalia and Lippe Association of Allotment Gardeners (LWL). This greatly enhanced the number of German respondents.
Poland	–	–	29	Poland started the FEW-meter project with more allotment volunteers than other study countries and so had a wider base for distributing the survey.
France	2	5	10	Questionnaire was administered to the gardeners involved in the FEW-meter project and, using pre-established contacts, to the National Family Garden Federation and to 14 additional allotment garden associations.
TOTAL	10	44	50	

3. Do you believe that urban gardening/farming can increase resilience locally and city-wide in the light of this pandemic? If yes, how?

If interviewees referred to some effects of the COVID-19 pandemic in other parts of the interview, their responses were also coded accordingly and considered in the analysis. Given the exploratory nature of this research, the questions to policy stakeholders were deliberately open-ended allowing respondents to elaborate on those areas where they had knowledge and information and to provide shorter answers where they were less informed. Given the severity of the global pandemic at the time the interviews were completed, it would have been surprising if answers to other questions on the interview schedule did not allude to COVID-19. Again, due to the baseline nature of this research, we felt it added to the value of the findings if we were to report reference to the pandemic if this occurred outside of the three specific COVID-19 questions.

Three or four stakeholders were interviewed in each country, varying according to availability, leading to a total of 16 policy interviews being completed. These interviews were undertaken via online-conference tools between April and October 2020 in the five countries involved in the FEW-meter project. Interviewees included stakeholders from municipal governments (5), NGOs (7), academia (3) and one consultant. The interviews were transcribed, coded via MaxQDA (a software package for qualitative data analysis) and pseudonymized. To organize and analyse the survey data we applied the principles of qualitative content analysis (Mayring, 2000). We recognize that the completion of 16 interviews does not enable the application of our findings to a city or country level, but these results do give an indication of the issues considered relevant and important at a very difficult time.

Survey of Gardeners and Allotment Plot Holders

The survey of allotment and community gardeners was completed with FEW-meter project gardens in France, UK, Germany and Poland, as well as additional gardens where the researchers had pre-established contacts. The urban agriculture project in New York City was farmed by cohorts of young adults, but during COVID-19, the organization running the farms delayed hiring a new cohort of farmers, so it was not possible to implement the garden survey. **Table 1** shows the number and type of respondents by garden type and country.

Numbers of questionnaires completed and type of garden respondent vary by country. This was partly due to the difficulties of engaging with garden staff and volunteers (particularly those with whom a relationship had not already been established via FEW-meter) during the pandemic but also because of the need to complete the survey in a time limited window whilst the questions regarding garden response remained relevant. The initial aim was to distribute the survey to all gardens participating in FEW-meter, but in some cases, an opportunity arose to distribute this to a wider number of relevant respondents. An explanation behind the number of questionnaire responses received by country and garden type is also given in **Table 1**.

The survey was administered in early June 2020. It asked about garden response to the pandemic at the time of completing the survey, but also asked respondents to consider conditions four months prior to the survey when the pandemic emerged

FIGURE 2 | Photographs to show examples of gardens included in the study. **(A)** Allotment garden, France (Credit: IRSTV). **(B)** Allotment garden, Germany (Credit: ILS). **(C)** Allotment garden, Poland (Credit: AMU). **(D)** Community garden, UK (Credit: KSAP). **(E)** Urban farm, USA (Credit: CUNY).

and policies to reduce its spread were initially implemented. The questionnaire investigated the impact of COVID-19 on the farms and gardens in terms of: (1) accessibility and service provision; (2) changes in operational arrangements; (3) impacts on production; and (4) future outlook. Moreover, the survey had an open-ended question that invited insights on related issues that gardeners believed to be relevant and important.

The garden survey was designed at a time when the reality of the pandemic was beginning to unfold and, this being an unprecedented event, it was difficult to know exactly what the immediate effects would be on urban growing sites and hence what the most pertinent closed questions were to ask. From our in-house knowledge as a result of working with practitioners on the FEW-meter team, we had sufficient awareness of the types of effect being experienced to put together the questionnaire but the originality of the situation in devising a survey for an unprecedented event meant that the value of the open-ended question was much greater than we had anticipated. In fact it is probably the answers received on this last point that gave the greatest insights into how the pandemic had affected the operation and perceived future of the gardens in the sample.

Questionnaire results, both closed-ended and open-ended responses, were coded and organized into key themes, reported below. Quotations are included in the results to illustrate the responses and to provide additional context. By way of illustration of the range of gardens included in our FEW-meter and specific COVID-19 research, we include a photo from each country included in the study at **Figure 2**.

RESULTS

Many insights were offered ranging from the practical effects of social distancing requirements and restrictions on gathering in the gardens to the longer-term effects of the pandemic on individual gardens. Several themes emerged relevant to these spaces over the course of the pandemic across the different groups of interviewees and across countries. These included attitudes toward local food production, the ability to operate the sites during the pandemic and future opportunities and challenges. Quotes taken from the policy interviews are followed below by brackets showing the country of the policy stakeholder. Quotes from the survey of community and allotment gardens are shown with a text reference to their origin.

Challenges and Opportunities of Food Production

One of the debates referred to in the policy interviews and survey was the role of local food production during the pandemic and implications post-COVID-19. Responses focused on the potential for locally grown food to meet increased demand, the loss of former out-of-home catering markets and discovery or expansion of alternative markets and the development of new projects.

Food Access and Demand for Local Food

In general, the interviewees agreed that the crisis has shown how fragile the food system can be and that cities are not self-sufficient in their food provision. The policy stakeholders stated that the pandemic has made people think more about food security and food access and they stressed the importance of local food production, including urban agriculture. As one interviewee explained, "The idea of food access and food security is now at the forefront of a lot of people's minds which I think inclusively leads to people thinking about urban farming and urban gardening and resilience of neighborhoods" (US01).

There was agreement over the generally important role of local food during the pandemic, but the policy stakeholders had different views concerning its potential contribution to food security and self-sufficiency at a wider scale. While some interviewees believed that at city level up to 75% self-sufficiency could be reached through local food supply, other stakeholders questioned the feasibility of food self-sufficiency: "You're never gonna feed 8.5 million New Yorkers with urban farms. I think we all recognize this" (US01). A stakeholder from London explained that, while the COVID-19 crisis has highlighted how insecure people are with the food system, urban agriculture is not usually the solution that decision-makers are falling back on. Given the reference to limited space or limited markets for specialized UA production, another interviewee assumed that it would be very dangerous to suggest that urban agriculture could feed the city "unless it was suddenly established in food policy" and became "a reliable, consistent, affordable, accessible culturally specific source of food" (UK02).

Policy interviewees observed that concerns about food access in the early days of the pandemic led to a sudden increased demand for locally or self-produced food. Some peri-urban farms found themselves in a situation where they could sell a large share of their produce locally through direct sale more easily, so that they had less produce available to supply the city. One interviewee from Nantes explained that some producers even stopped supplying the city because "there was a lot of consumer demand near their farm and they did not have enough additional produce to deliver in the city" (FR03). A Polish stakeholder explained that the rising demand for food caused price increases, which created an advantage for small-scale urban farmers and gardeners who could consume their own produce: "The COVID crisis manifested itself in higher prices of fruit and vegetables. Those involved in urban farming with their own food resources [...] were not as heavily affected by this crisis as people who are not agricultural producers" (PL02).

Stakeholders shared the view that farms and gardens will increasingly gain importance as suppliers of food for their communities over the long term. One explained that demand for urban grown food will increase because, "people began to see the relationship between values and wanting their [money] to stay local, to support their local economy" (US03).

Loss of Previous Markets and Expansion of Others

Some policy interviewees reported that as a result of COVID-19, a number of farms lost their institutional markets as school meals were suspended and public canteens were closed. While some farms were unable to adjust to this challenge, others reported that sales from farmers' markets or vegetable boxes or vegetable starts for home gardening more than made up for the revenue loss due to increased demand as consumers avoided crowded supermarkets and instead sought urban grown produce.

The pandemic also affected food distribution with a shift in demand from institutions to households and new market opportunities opening up where restaurants and onsite cafés were forced to close. Interviewees reported that the community gardens and farms were able to cope with the pandemic after some period of adjustment to new social distancing and hygiene rules. Those engaged in direct marketing for distribution were most easily able to continue their activities. As one stakeholder noted: "Our supply chains were never disrupted and so I think that our markets demonstrated that this direct consumer model is flexible and resilient" (US03).

Other gardens had to adapt their strategy and diversify their activities. One of the UK community gardens started to deliver food to local residents who were self-isolating; one stopped supplying restaurants and diverted all its produce to vegetable boxes for delivery. Community gardens in the UK as well as in the US started to run their own food banks for vulnerable or food insecure households. Others donated their produce to food banks rather than distributing directly to local residents, as this stakeholder explained: "We decided to stop selling to the public during lockdown to restrict exposure between gardeners and the public. We made an exception for donations to those in need of fresh produce, and we have been making infrequent donations as requests are made."

Importantly, the gardeners felt that they could improve the situation during the COVID-19 lockdown and provide help to people in need. One gardener explained, "We have been part of the response, I suppose" (UK04). Although initially the pandemic did bring challenges for some community gardens as previous outlets closed, over time, opportunities opened up in terms of increased sales via home deliveries and philanthropic donations to those in most need.

Support for New Urban Agriculture Projects

In response to the crisis, cities opened up their own new funding schemes for urban agriculture. One innovative project that targeted the establishment of new food growing spaces in low-income neighborhoods was reported from the city of Nantes: "... They put in place a policy, that they called "Paysages nourriciers" [*Nourishing landscapes*] where 100 places in the conurbation [...] were transformed into food gardens, [...], often not very big, [...] to ensure a supply to the more fragile populations... " (FR03). Another practical approach was reported by a policy stakeholder from New York where the City Parks' GreenThumb program delivered "110,000 vegetable "starts" to about 300 gardens throughout the city" to help them plant their first crops (US01).

Maintenance of Sites and Services: Challenges and Opportunities

The pandemic inevitably led to difficulties in maintaining pre-COVID-19 levels of accessibility and service, more notably for community gardens than for allotment gardens. Community gardens by their very nature bring groups of people together to work and socialize whereas allotment plots are tended individually. The stakeholder interviews and the garden survey revealed what measures were put in place to allow gardens to continue to operate, how changes to gardener numbers affected their ability to function and what they were still able to offer in terms of services.

Measures to Allow Gardens to Continue Operations

Community gardens and allotment gardens were affected differently by COVID-19 restrictions. In the UK survey, the five community gardens that continued to operate did so with reduced numbers of gardeners to allow for social distancing. In France, at the peak of the pandemic, the two community gardens in the study had to close but by the time of completing the survey, one had partially, and the other had fully reopened.

All community gardens employed some kind of COVID-19 precaution measures during the peak of the pandemic, canceling all events, limiting numbers in the garden and strictly regulating operations. One UK garden stated that "Clean tools are provided in the morning on a table and have to be put back on another table after use. Taking any tool from the dirty table is strictly forbidden." These precautions continued throughout the pandemic. One gardener explained that "strict measures are carried out" to allow the garden activities to continue.

The allotment garden managers in France and Germany reported that site maintenance on the individual plots continued throughout the pandemic. Plot holders were allowed into the allotment but could work only with their own tools and had to abide by national COVID-19 restrictions regarding, for example, the number of different households and total number of persons allowed on each plot at one time. Allotment gardens were often among the only (green) spaces that were left open in cities, which partly called for measures to direct the growing flow of visitors to ensure social distancing by finding "some kind of one-way street regulations [...] to regulate the crowd of visitors in some way" (GE02).

Reasons for and Effects of COVID-19 on Gardener Participation

The pandemic reduced participation in gardening as many people remained at home and avoided public spaces. Those gardeners who lived further from the garden were prevented from gardening either because of travel regulations or their own fear of public transit. In some community gardens, due to the absence of active gardeners "the ability to steward the gardens has been very limited" (US01). Transport to the gardens was a main limiting factor. One garden in the UK restricted access to those volunteers able to attend by foot, bicycle or private car. In Poland, "the low frequency of the bus made traveling difficult" for gardeners, while in France the legal limit for non-essential travel was 1 km, so for gardeners who lived more than 1 km away, the visit was impossible.

The interviews further revealed that the mix of gardeners changed during the pandemic as older gardeners tended to be more cautious and stayed home, in some cases disadvantaging younger gardeners who relied on their expertise. According to one UK respondent: "[Fewer] gardeners are coming (a) because of fear of exposure to the virus, (b) because our usual Saturday Gardening Club isn't running. Less experienced members relied on this to learn from more experienced members."

In contrast, some gardeners spent even more time in the garden because it was viewed as a safer outdoor space offering access to nature and physical activity. For the allotment gardens in Germany, for example, the pandemic had less of an impact on the attendance of individual plot holders. The majority reported all allotment holders were visiting as normal, albeit with social distancing measures in place. Allotment gardeners from Germany and Poland reported that even the "number of visits to the plot during the pandemic increased" and they were spending more time at the garden due to reduced work or alternative social commitments:

"Since we worked from home and had more time due to [not commuting] we spent more time in the garden than usual, especially at the beginning of the pandemic. Therefore, we also had more time to take care of the cultivation of vegetables, so we grew more vegetables. Social contacts have increased, because the other allotment gardeners were also more often in the garden and conversations over the garden fence were very possible."

Changes in Service Offers to the Communities

Being aware that community gardens fulfill many social functions, the policy stakeholders expressed some concerns about the effects of missing support for vulnerable or isolated people who regularly would have visited community gardens. In all gardens, community and educational events had to be canceled, resulting in fewer opportunities for socializing and addressing organizational issues. The interviewees shared some concerns that it might be difficult to rebuild these lost connections to volunteers. Community gardens are often providers of a programme of social and educational activities and for the majority of gardens responding to the survey, this would normally be a major role and in some cases, a source of funds for the garden.

Another effect observed included suspended urban farm-based school nutrition education programs: "Some schools had nutrition education programs and some of those programs also included urban agricultural education and obviously that was discontinued" (US02). The challenge of reduced services in some cases opened opportunities for innovation to maintain links with the vulnerable populations that the gardens served. For example, a UK community garden started a "growing at home" group, sending seeds with garden volunteers to help them to grow vegetables at home.

Other Specific Opportunities and Challenges

Opportunities for the Environment

Respondents noted that the pandemic's reduction in the use of garden sites had potential unrecognized benefits. One French community garden respondent noted the multiplication of flora, insects, birds and animals as a result of the reduced footfall through the garden, commenting on this as an increase in "wild gardening" visible to those who ventured out around the garden. A policy interviewee acknowledged the contribution of allotments and other gardens as key pollination sites and for the city's water cycle: "[...]I think it [UA] can have a small but important impact in making our cities and neighborhoods more resilient" (US01).

Opportunities for Allotments

Allotment gardens appear to have been easier to keep open during the pandemic because of the nature of the work that happens on individual plots, although for some, communal areas and facilities were closed. In contrast, according to one UK stakeholder, some of the UK allotment sites chose to close the garden to facilitate social distancing. Most allotment gardens in France, Germany and Poland remained accessible, at least for the plot-holders. During the second lockdown in France, for example, special authorization was given to all gardeners so that they could travel to their plots. Consequently, our interviewees observed that plot-holders spent much more time in the gardens than before the pandemic: "they were spending like 20 h in the gardens, they couldn't—they didn't want to—go home, they didn't want to be locked in again" (PL03).

A German policy interviewee confirmed that the role of allotment gardens has been strengthened during the pandemic which has been reflected in the increased demand for allotment plots. The majority of German survey respondents also acknowledged the increased interest in gardening through the pandemic with a resultant increase in intention to grow fruit and vegetables for self-supply. Demonstrating again the perceived value of allotments at this time, one respondent from Germany wrote: "many citizens have been looking for allotments. Everyone is asking about growing fruit and vegetables. There are fewer flower beds and more vegetable beds."

Opportunities for Policy

Interviewees observed that in the early weeks of the pandemic, local authority priorities were to secure the food supply in general. As one noted: "What we've seen is a huge local authority response around food provision and their priority has been feeding people and getting hold of food" (UK04).

Public authorities chose different ways to support urban agriculture, for instance, by changing land-use policies in favor of UA, reducing bureaucratic hurdles or through material or financial support. A policy stakeholder from London reported that as a result of a local conference "[the City is] opening up land for projects [. . .] making London more productive food-wise" (UK03). An interviewee from NYC acknowledged the administrative support by the city's food policy director who "funded our work, ensured we could get the permits that we needed, got us equipment [. . .], her office was instrumental in helping us operate all of our sites. And to launch a new emergency food operation" (US03). The interviewee's appreciation was extended to the entire municipality, which "[. . .] worked with us to expand our permits [. . .] let us take on new sites [. . .] closed streets for us. And these are five agencies working together who normally don't even speak to one another to help make this out within a week's time. So COVID has really expedited processes" (US03).

In contrast, for the allotment garden sites, interviewees did not observe any support from local authorities. They also believed that public authorities were too busy trying to tackle and survive the pandemic: "[. . .] there was no support [for allotment holders] as they did not suffer any significant losses" (PL02).

Future Opportunities and Challenges

Increased Demand

The survey distributed to UK community gardens asked for views on what might happen to demand for their services once lockdown ended. At the time of the survey's administration there was a feeling that more volunteers would want to use the garden after lockdown: many were working from home or not working and had more time to learn new skills. Many had started gardening at home and were interested in learning more about it or to practice with other people. One garden expected "Volunteering services [. . .] to be high in demand, especially for vulnerable groups" although another recognized the challenge of trying to meet this demand. A third stated: "I have been getting an increased number of requests to join the garden during lockdown [. . .] I think because people have more time on their hands, and because gardening is a peaceful and therapeutic activity." Other opportunities included the mental health benefits of community gardening and the increased demand for mental health support post lockdown from people "[. . .] seeking support after the lockdown/loss of loved ones etc."

Several respondents noted greater demand for vegetable boxes through lockdown in many community gardens across the UK and hoped the higher demand would be maintained: "We are hoping increased demand will continue, as it will be a while before customers go back to supermarkets and "normal" shopping. [. . .] Restaurant sales won't be back to normal for a while." In Germany, the majority of respondents acknowledged the increased interest in gardening through the pandemic with a resultant increase in intention to grow fruit and vegetables for self-supply. One thought that higher prices will lead to greater home harvests. One thought that 2020 might see an increase in harvests as gardeners had more time to spend in the garden and less alternative options available for leisure.

Decreased Revenues

Eight of the German allotment garden managers referred to the financial losses caused by the pandemic, largely by the closure of the allotment's clubhouse and resulting short term loss of rental income. The community suffered as formal and informal events were canceled. It was impossible to carry out valuations on allotment plots so no exchanges could take place allowing new leases to begin. This was particularly important because many of the allotment gardeners at one garden were over 80 and hence more prone to social isolation as they were less likely to be able to visit the garden. Allotment associations in France and Germany were asked whether they thought the current crisis would have a longer-term effect on local food production. In France, one respondent thought that greater time spent on the plot will lead to better production and yet another thought that a lack of rain in 2020 combined with the difficulties of coping with the crisis will lead to reduced yields.

DISCUSSION

This section elaborates on the interview and survey results and identifies some key points that emerged through their analysis.

It is organized with the same thematic areas with which results were presented, and it aims at identifying slight divergences in the views of policy stakeholders and gardeners or key points worth highlighting. It suggests lessons learned as a result of the challenges and opportunities for local food production that COVID-19 has brought to the fore as well as the new situation facing community and allotment gardens post-pandemic. It also considers the role of local policy in assisting community and allotment gardens with a post COVID-19 recovery.

Challenges and Opportunities Regarding Food Production

There is an ongoing debate over the potential of local food to expand and increase its contribution to local self-sufficiency, the saliency of which has been reinforced as a result of the pandemic. During the World Wars, food gardens were valued for their contribution to resilience through food security. Today, the contribution of food gardens to improve resilience within the current crisis is multi-dimensional. It is also worth noting that many gardens distributed food to groups that needed it, thereby increasing food security not merely by increased production but by targeted and effective distribution. Indeed, measuring food gardens with productivity metrics may undermine their capability to endow resilience at several levels and for those who are more vulnerable.

There were commonalities between the views of policy stakeholders and those of gardeners regarding COVID-19-induced challenges and opportunities for food production and sales. One main point of divergence was that, in line with the literature (Vittuari et al., 2021), policy stakeholders in some of the case study countries focused on the importance locally produced food has gained in the pandemic and at the relevance of strengthening local markets, while gardeners‘ and farmers‘ views focused more on the direct impact the pandemic caused, pointing at changed distribution strategies or effects of the lockdown on the participation of volunteers. The latter also focused more on the gardens' important role in mental well-being and socialization. The rise in mental illnesses recorded in many nations during the pandemic (Xiong et al., 2020) shows how, during this particular crisis, mental well-being is a key factor in increasing the resilience of societies. This agrees with the literature which has described the effects of engaging in urban agriculture for mental and physical well-being (Bu et al., 2020; Lades et al., 2020; Pouso et al., 2021).

In terms of how policy has been used to ameliorate the effects of the crisis within community and allotment gardens, the responses suggest that some municipalities have been more supportive than others, with Nantes a case in point (see FR03). Other food gardens had to resort to their creativity in order to survive. For example, some were able to sell the produce typically bought by restaurants through vegetable box schemes, which have been high in demand. It may be challenging for these food gardens to retain this new customer base as the current crisis subsides. Supporting these gardens and their local supply chains with targeted policies would help build a diversified, more resilient supply system, breaking away from current long-supply chains that have proved to be vulnerable (Yu et al., 2021).

Challenges and Opportunities Regarding Maintenance of Sites and Services

Being outdoors and working in a garden has been shown to have positive mental and physical health benefits (Corley et al., 2021; Sunga and Advincula, 2021) and just at the time when these were most in need, the gardens faced challenges in being able to continue operation. Policy stakeholders gave their opinion on a more abstract level pointing at limited operationality due to the general absence of volunteers in the gardens due to lockdowns and other restrictions and questioned whether the disrupted relationship with groups of volunteers could be revived post-pandemic.

According to the statements of the gardeners in terms of accessibility, many managed to remain open for large parts of the lockdown, the allotment gardens more so than community gardens. Where gardens remained open, transport issues were a barrier to access for some, often those most vulnerable because of their reliance on public transport. Those who were still able to get to a garden were appreciative of its benefits and often stayed longer as competing demands on their time had been reduced by workplace closures or opportunities to work from home.

Where allotment gardens have remained open, they have been well-attended, with a greater sense of community achieved. In line with the pulling together of communities seen in other crises, increased cooperation between plot-holders has been observed with some looking out for the plots of those unable to attend. The current crisis has also offered some community gardens the opportunity to achieve more philanthropic objectives, supplying fresh produce to food banks and delivering to those in need and those isolating.

Community gardens, by their very nature, are normally able to provide for those struggling with mental health difficulties. They offer social and educational programs that engage all sectors of society and cross the age divide. Outside of the pandemic, such gardens might be one of the few opportunities for social engagement that some gardeners experience during the week. During lockdown, where gardens remained open, they were able to continue to provide an outdoor space for people to get away from the lockdown confines of their own homes. An increased demand for allotment plots was also noted by some and an increase in the numbers wanting to visit the community gardens. This is in line with the literature in which the relationship between crises and the raised interest for engaging in urban agriculture has been explored for different periods and different regions of the world (e.g., Novo and Murphy, 2000; Delgado, 2015, 2017; Bell et al., 2016).

Where gardens were forced to close or provide a reduced service, they were absent just at the time when their normal service provision was more needed. Their educational programs ceased, which could impact childrens' relationship with the outdoors and their consumption of a healthy diet long term. Social events were also canceled, having an impact on the mental health of those who would normally attend, as well as on the finances of the gardens. As some respondents noted, having stopped all activities during 2020, it might be more difficult to get these started again post-pandemic and it will certainly be very demanding to return such events to their pre-COVID levels.

This problem is worsened by the fact that the garden leaders or managers frequently tend to be older and more experienced gardeners who have often been the most reluctant to return to the gardens due to health fears around the pandemic.

Interestingly, through the pandemic, those gardens that normally operate independently of government and grant monies have fared the worst as their commercial operations have been curtailed. Community and allotment gardens that run on-site cafes, supply to the restaurant trade, rent out space and host corporate days have all lost income whereas those that are grant dependent have sometimes fared better due to the emergence of crisis funds that some gardens have tapped into.

It is clear that the allotment gardens have been less impacted by the pandemic than the community gardens. This is largely due to their organizational structure whereby gardeners have their own individual plots and are able to tend those spaces at a distance from other gardeners. Community gardens deliberately encourage cooperation between gardeners. If social distancing requirements continue to be encouraged, gardens may need to continue to modify their operations to resume offering pre-COVID services to their established clientele.

Specific Opportunities and Challenges

Policy stakeholders agreed that the pandemic has strengthened the role of community gardens and allotment gardens. While many other outdoor spaces such as zoos, public playgrounds or even parks were closed, allotment gardens were kept open at least for the plot-holders and community gardens, especially in New York City, received strong support that expedited processes to overcome bureaucratic hurdles to ensure their operation although with limited access for volunteers. This might reflect the iconic meaning of urban agriculture in cities like New York with high levels of food insecurity. It also points to the roles these spaces have played in the view of some municipalities, particularly in the US, in supporting well-being during the pandemic.

The recognition from policy stakeholders of the contribution that urban gardening has made through the pandemic may encourage greater support for the sector post-pandemic as the contribution of urban gardens to health and nutrition becomes clearer. Looking to the future, it is likely that the role of gardens and the value of outdoor spaces in promoting mental health will become more salient as cities emerge from the pandemic with high rates of unemployment and economic dislocation, and grapple with the COVID-19 deaths that have occurred.

On the other hand, while the pandemic solidified support for gardens and farms, post-COVID-19 cities will be facing many fiscal and social challenges, and urban agriculture will be only one of many issues they will need to address. As job creation and economic development, and other strategies to reverse tax revenue losses due to reduced demand for city centre commercial real estate take priority, policies for urban agriculture may be put on the back burner.

Policy Needs to Meet Future Opportunities and Challenges

As noted, policy support to food gardens has been significant, recognizing their contribution to urban resilience in this pandemic. Not surprisingly, those municipalities or countries that distinguished themselves over the last years for their policies promoting UA were more supportive than the others. In particular, New York and Nantes implemented practical initiatives that enabled food gardens to function when other public facilities were closed. In France, support is demonstrated not only in Nantes but also in other municipalities such as the city of Paris (Reynolds and Darly, 2018) and Romainville where the first French farm directly managed by a city was recently opened (la Cite Maraichere de Romainville, 2021). In contrast, in London and the UK generally, during the pandemic, general policy support did not translate into tangible help other than refraining from a total closure of the gardens. That said, there was substantial pandemic response financial support available from many of the grant giving trusts, both locally and nationally. Generally, the lack of policy support could be said of Germany and Poland, too. In the UK, recovery efforts are encouraged through the government's Green Recovery Challenge Fund (DEFRA, 2020) that offers grants at a minimum of £50,000 for projects that create jobs in nature recovery and conservation. The success of urban growing projects in winning such funds is as yet unclear: although some food related projects have received funding in the first round of this fund, many have not.

The post-war decades saw a decline in interest and policy support in food gardens, reflected in a reduction in the overall land area allocated to urban agriculture and in the face of their contribution to wartime resilience. In Eastern European countries this phenomenon intensified after transition to a free market economy in the 1990s, when rapid building construction began to compete with UA. One of the challenges that policy must face in a post-COVID time is the protection of a sector that in this crisis again has strengthened resilience. Financial support could attract new gardeners through reduced lease costs for allotments for those who cannot afford current allotment rent and help commercial urban gardens contain prices for vegetable boxes schemes, thus becoming competitive with big food retailers.

Limitations of the Study

For the purposes of this study, we wanted to survey the FEW-meter gardens because their involvement with the project meant that they were the most attuned to thinking about the impact of COVID-19 on their gardening and farming efforts. Ultimately the study uses a case study design rather than a random survey and so results cannot be extrapolated to all gardens and farms. Results could have been more robust and generalizable had we planned this as a separate project and surveyed a random selection of urban farmers and gardeners.

Another limitation is the selection of the participants for the interviews. We did our best to identify three to four policy stakeholders in each case study country from different spheres who were willing to be interviewed, but the sample includes a wide range of personal backgrounds that may not be comparable.

We also found the timings of lockdowns and extent of restrictions varied between nations and designing a common questionnaire that would fit all circumstances was challenging. The speed with which the pandemic advanced and social distancing restrictions became the norm in each country also meant that findings that might have been novel in mid-2020 became less interesting as time went on.

CONCLUSION

In conclusion, the COVID-19 pandemic came as a shock to all countries in the study and many contingency plans were made as events unfolded at the national, regional and local levels. Within allotment and community gardens efforts were made to keep the sites open for as long, and for as many volunteers and gardeners, as possible, where restrictions allowed. Just as national governments did, so did urban growing spaces adapt to the changing situation. Our surveys, too, had to develop as the pandemic grew and these were adapted to the extent we could to fit the evolving circumstances in five different nations. Undertaking research in such challenging times was not without issue but the results do present important learning points for gardeners and policy makers alike. Urban community gardens at their best provide both food and, perhaps more importantly, social activities for those at various points on the mental health spectrum and just at the point when these services were required more than ever, they were forced to curtail their provision. Allotment gardens offered an important contribution to city resilience, especially during the lockdowns for those without gardens, when these spaces were often the only option for parents to find outdoor space for their children. Despite all of this, the gardens, particularly the community gardens, grew and adapted to whatever obstacles they encountered, finding alternative means to meet their regular and newly acquired objectives.

The message to policy makers at this time, drawing on lessons from the response of urban gardens to the pandemic, is that UA is a healthy and meaningful way to support post-COVID recovery as it brings together a myriad of additional benefits beyond just the production of food. Going forwards, policy needs to recognize the contribution that such spaces made to resilience during the pandemic and the contribution that they can continue to offer if financial and regulatory circumstances allow.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

VS, RF-K, and KS: conceptualization, methodology, formal analysis, investigation, data curation, writing—original draft, and review and editing. CB and SC: conceptualization, methodology, writing—original draft, and review and editing. AF-L: investigation, data curation, and writing—original draft. NC: writing—review and editing. LP: investigation. KF: investigation and data curation. All authors contributed to the article and approved the submitted version.

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Growing-Service Systems: New Business Models for Modular Urban-Vertical Farming

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To secure sustainable and resilient food systems, new approaches, innovations, techniques, and processes are needed. In recent years, urban farming firms have been developing and experimenting with innovative approaches to expand their offerings and connect with consumers in new ways. New business models are being developed to provide functions and services instead of traditional products to meet demands from consumers, retailers, and users. As such, modular growing systems are increasing in popularity to provide fresh produce, visual appeal, transparency, and other tailor-made functions and services in so-called "growing-service systems" (GSS). Using GSS approaches, firms are developing and providing modular and small-scale farms in restaurants, residential spaces, supermarkets, and other commercial spaces, often including a large degree of automation and optimization of digital solutions to remotely control their operation. Using qualitative methods, the aim of this study is to explore and analyze the development of these novel GSS systems, highlighting different strategies, business models, motivations, and challenges. The results illustrate the divergence in approaches to GSSs for vertical farming. This includes different scales of modular units and varying business models for capturing value from the combination of products and services. All of the systems include varying degrees of automation and digitalized solutions to ensure the services are monitored, which is done to improve growing conditions and improve the experience for the users. Business-to-business systems are being developed as both market expansion and awareness-building strategies, where modular units are provided as a rental or subscription model that includes a number of services. Business-to-consumer systems are being introduced as an alternative for consumers, particularly in urban areas, to have greater control and access over growing their own fresh produce. The modules are purchased by consumers, which includes a number of ongoing services from the GSS firms. By categorizing and exploring these systems, this article offers novel insights and a first endeavor to distinguish these new GSS systems in the growing segment of urban agriculture, controlled-environment agriculture, and product-service system literature.

Keywords: vertical farming (VF), product-service system (PSS), business model, in-store, urban agriculture, modular farming, hydroponic agriculture

INTRODUCTION

In order to secure sustainable and resilient food systems, new approaches, innovations, techniques, and processes are needed for both food production and consumption. In recent years, agriculture has seen dramatic innovations and development to bring food production systems closer to consumers (Klerkx and Rose, 2020). There has been an increasing interest in urban agricultural systems and alternative food systems focusing on shorter supply chains (Eigenbrod and Gruda, 2015; Benke and Tomkins, 2017; Pulighe and Lupia, 2020). As such, urban farming has been identified as a promising solution to secure food supplies and reduce pressure on agricultural land; (see e.g., Despommier, 2009; O'Sullivan et al., 2020). There are many examples and methods for urban farming, although approaches such as vertical and hydroponic farming have been popular options worldwide in urban environments; (see e.g., Kozai, 2013; Kozai and Niu, 2016; Weidner et al., 2019). In particular, vertical farming[1] has seen extensive expansion, technical innovations, prolific growth, and upscaling taking place worldwide (Specht et al., 2014; Armanda et al., 2019; Appolloni et al., 2020).

Beyond the many prevalent large-scale vertical farming systems available worldwide, also called "plant factories," which have met critique in recent years (Banerjee and Adenaeuer, 2014; Cox, 2016; Pinstrup-Andersen, 2018; Bryce, 2019; McDougall et al., 2019), urban farming companies have been developing and experimenting with new approaches. These have spawned from the need to expand their offerings, business models, and connect with consumers in different ways. In recent years, small-scale modular, in-store growing systems are also increasing in popularity and number in connection to residential, commercial, and retail spaces; see also (Bustamante, 2020; Butturini and Marcelis, 2020). These new systems employ new business models for ensuring that customers are provided with fresh plants or tailor-made functions. Worldwide, several flagship systems have received extensive investments and expansion, (see e.g., Jürkenbeck et al., 2019; Butturini and Marcelis, 2020; InFarm, 2021; Renmark, 2021). Often these systems provide fresh plants, while the vertical farming company retains ownership and control of the infrastructure. Using these new business models, alternatives to traditional sales of products in conventional retail supply chains from centralized production locations, e.g., from plant factories, are increasingly being explored (Tukker, 2004; Mont et al., 2014; Geissdoerfer et al., 2018). As such, the operation and farming are provided as a service, i.e., "growing as a service." In this study, we refer to these developing modular systems as ***growing-service systems (GSS)***, as they are inherently linked to the concept of product-service systems (PSS).

PSS refers to an approach where a company (or provider) sells a service, function, or a result, instead of a traditional product, placing value on designing for durability and remanufacturing (Tukker, 2004). There are different types of PSS offerings, depending on how the product is used, the business models employed, and what is to be the result of the contract. The literature categorizes different approaches to this to include product-oriented services, the most common being product, use, and result-oriented services; see a more thorough description in Tukker (2004). Integrating product and service offerings has been outlined to improve efficiency, which can lead to positive economic and environmental effects for industry and society (Mont and Tukker, 2006; Reim et al., 2015; Lingegård, 2020). Thus, PSS examples can be framed as sustainable business models which can help providers with approaches for a transition to the circular economy and provide differentiation from competitors (Amaya et al., 2014; Michelini et al., 2017). However, while such PSS systems and circular use of products are promoted as sustainable alternatives to conventional sales, their sustainability implications are rarely accounted for and are often confined to qualitative reviews of their potential (Lindahl et al., 2014; Salazar et al., 2015; Bocken et al., 2018). Furthermore, PSS research has tended to focus on the use of electronic equipment and manufacturing, with no studies related to food production systems, or services related to plant production. Despite the expansion of the field, insights on the implementation, adoption, and reasons for PSS business models are still very limited (Baines et al., 2007; Gaiardelli et al., 2014; Reim et al., 2015; Annarelli et al., 2016). Furthermore, as outlined by several authors, consumer-oriented products have received little attention, despite their potential (Skjelvik et al., 2017; Bocken et al., 2018; Martin et al., 2019a, 2021).

The aim of this study is to explore and analyze the development of these novel GSS systems in order to highlight their divergence in methods, business models, motivations, challenges, and of their implementation contexts. As such the article offers novel insights and the first of its kind to distinguish these new GSS systems in this growing segment to connect the urban agriculture, controlled-environment agriculture, sustainable business model, and product-service system literature for an emerging business-to-business (B2B) and business-to-consumer (B2C) service.

In the following sections, we outline the methodology employed to collect information on these systems (Section Methodology), highlight results from our qualitative review (Section Results), and provide a discussion on the results, including limitations and future research opportunities (Section Discussion). This is followed by a concluding discussion (Section Conclusions).

METHODOLOGY

Research Design and Data Collection

This study used an exploratory case study design to identify and characterize GSS firms[2] and solutions. Due to the focus on how and why GSS solutions are being introduced along with the relative novelty of the phenomenon, case study methodology was deemed appropriate, which enables rich data collection despite a small number of cases (Eisenhardt, 1989; Voss et al., 2002). Multiple cases were selected in order to prevent researcher

[1] In this study we define vertical farming as the vertical production of edible plants and vegetables through controlled-environment agriculture (CEA) techniques.

[2] Hereafter, we refer to farming companies as simply "firms," while reference to specific sites as "farms."

bias and increase the external validity of generalized findings (Voss et al., 2002). Qualitative research methods that enabled an in-depth investigation of the GSS systems were utilized (Denscombe, 2007).

To identify cases, we made use of an exploratory approach to identify firms implementing GSS solutions. An initial set of firms were identified from previous research conducted by the researchers. This list was expanded through information found in vertical farming newsletters and other industry news sources. Furthermore, we conducted online searches using keywords such as "growing-as-a-service," "farming-as-a-service," with a combination of terms such as modular, in-store, and vertical farming. To be included in the study, the firms needed to have a business model that went beyond the sale of plants to include a service component, typically realized through the combination of hardware and software systems. In addition, an effort was made to include firms with a business-to-business focus and ones with a business-to-consumer focus in order to capture the full spectrum of GSS solutions on the market.

The data was collected between February and September 2021. Questionnaires and interviews with firms made up the primary data sources. Due to the start-up environments of the firms, the researchers decided to give a choice between completing open-ended questions via an online survey tool or a video-based interview format so that firms could respond in the manner they deemed best because of often busy schedules. The questionnaire and interviews were developed and focused on seven key areas: (1) Company background and motivations, (2) Overview of how the modular unit/system work, (3) General business model (product and services), (4) Customer experience/training, (5) Benefits of the modular systems, (6) Barriers for modular systems, and (7) Sustainability aspects of the systems. The open-ended questions in the survey and structured interview questions were aligned to enable analysis of the qualitative information whether gathered in written or spoken form. The questionnaire and interview guide employed for the data collection are provided in the **Supplementary Material** for further information.

Questionnaires and interview requests were sent to 16 firms through the online questionnaire system Typeform. Survey responses were received from seven firms. Two of these were determined to be invalid for the study due to insufficient information or outside the case study criteria. Two firms elected to conduct a structured qualitative interview instead of participating in the survey. Primary data provided by the questionnaires and interviews were supplemented with secondary data sources, including online media articles, videos, and podcasts in order to enhance the reliability of the study through triangulation of data (Yin, 2014). This resulted in seven cases built on primary and secondary data. In addition, despite not having answered questionnaires or being interviewed, further cases were added through the sole use of secondary materials due to the richness of online sources (Yin, 2014; Salmons, 2015). Some of the largest firms providing GSS solutions had ample information in online interviews, podcasts, and their respective websites that enabled the researchers to answer questions in the questionnaire and interview protocol outlined above. Thus, a total of 11 firms from six countries in North America, Europe, and the Middle East were included in the study. See **Table 1** for a summary of the data collection and firms analyzed for the study.

Data Analysis

As the first step in data analysis, the results of the questionnaires and interviews were compiled and reviewed as individual cases. The two interviews were recorded and transcribed to enable the compilation of data and analysis. During this initial phase of analysis, research memos were written to capture emerging themes (Saldaña, 2013). The researchers were also inspired by themes from the PSS literature (e.g., based on business models and value creation), thus an iterative process between data and literature began, which resulted in the construction of a data matrix encompassing these themes: system characteristics, general business model, benefits/drivers, barriers, and sustainability. The data collection and analysis process is illustrated in **Figure 1**. The matrix was used to plot information from both primary and secondary sources for all cases and enabled a systematic cross-case analysis and comparison during the second phase of analysis. The goal during this phase was to identify similarities and differences across cases (Miles and Huberman, 1994) as well as convergent or divergent views about the benefits and future needs of GSS solutions. The data matrix is not provided in the **Supplementary Materials** due to proprietary information and requests from the firms involved. However, anonymized information and data can be provided upon request to the corresponding authors.

RESULTS

In this section, we present the findings of the analysis of the firms employing GSS systems. Five key areas were observed when analyzing the data, including (1) drivers and perceived benefits, (2) key characteristics of the systems, (3) business models, (4) sustainability, and (5) barriers and challenges.

Key Characteristics of the Systems

All firms employ principles of controlled environment agriculture in their modular farms, including closed environment, sensors, LED lighting, and circulating water systems. While most firms boast a simple "plug-and-play" system, behind the hardware of the modules are complex software components, with remote monitoring of the systems for both business-to-business and consumer options. This happens through a wifi connection and is often accompanied by an App for the customer to also track and monitor the status of the plant growth and environment. Analytics technology is typically applied from the data gathered in order to improve conditions within the modules and promote "self-learning farms." This enables optimization of the plant environment, with little knowledge or action needed from the user of the module.

Automation is a priority for the providers of the systems in order to minimize manual labor and ensure the systems are easy to use. Most firms include automation of key aspects, including lighting, climate controls, and pumps. Aspects that

TABLE 1 | Overview of firms analyzed.

Firm	Country	Founded	Data (primary/secondary sources)
Swegreen	SE	2019	Primary: qualitative online survey Secondary: website, media articles
Vegger	NL	2016	Primary: qualitative online survey Secondary: website, media articles
Hollbium	SE	2018	Primary: qualitative online survey Secondary: website
Grönska	SE	2016	Primary: qualitative online survey Secondary: website, media articles
FutuFarm	SE	2016	Primary: qualitative online survey Secondary: website, media articles
Natufia	SA	2014	Primary: structured interview Secondary: website, media articles, videos
Yasai	CH	2020	Primary: structured interview Secondary: website, blogs, media articles
Smallhold	US	2017	Secondary: podcasts, videos, website, media articles
InFarm	GE	2013	Secondary: white papers, websites, media articles
Farmshelf	US	2014	Secondary: website, media articles
Agrilution	GE	2013	Secondary: website, media articles, videos

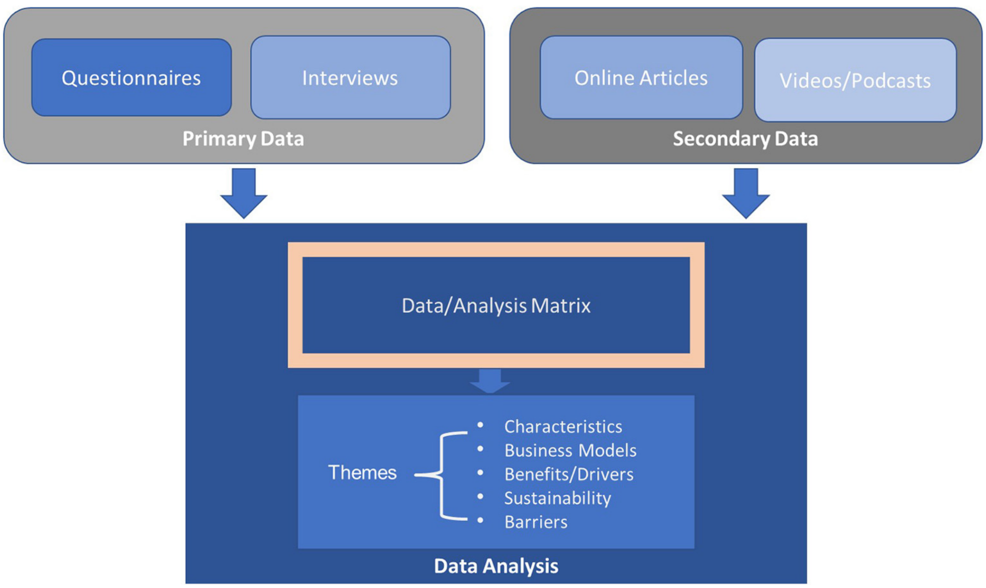

FIGURE 1 | Methodology employed for data collection and analysis.

require human intervention, such as harvesting and cleaning, are handled through push notifications in accompanying Apps in order to minimize planning and time spent on the module. All systems require the initial placement of seedlings or seed pods in the system, and some also separate a "nursery chamber" for young plants that requires movement to a different shelf in the system until the plants are ready for harvest. The systems themselves range from small cube-like structures to shipping containers, with many likened to a large refrigerator unit found either in a home or retail location. The main products grown in the modular systems to date include leafy greens, herbs, and microgreens, with a few offering tomatoes and one focused exclusively on mushrooms.

Drivers and Perceived Benefits

The results highlight that many of the firms point to undesirable aspects of the current food system, e.g., long transport needs, unpredictability, and pesticide use as drivers to develop new ways to produce and distribute food. These drivers also translate into the perceived benefits of the systems. The ability for hyper-local production is believed to reduce transportation but also give more people the opportunity to be growers, whether that means

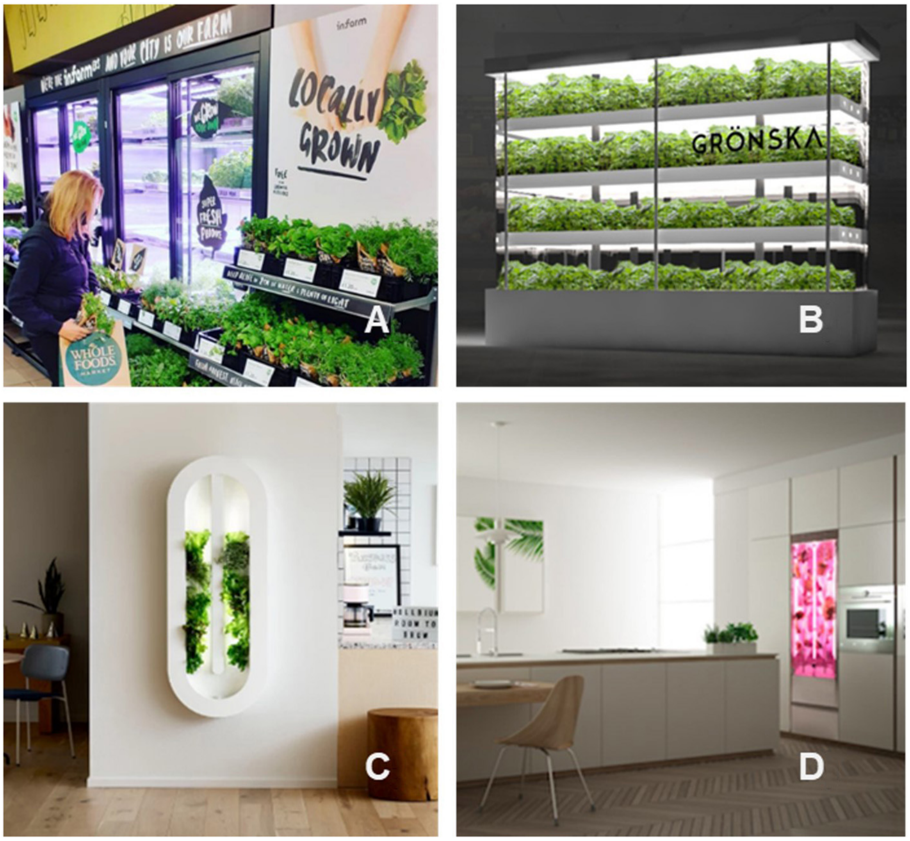

FIGURE 2 | Depiction of different types of GSS systems analyzed in the study, with **(A)** showing an in-store farm by InFarm (2021), **(B)** showing an in-store/in-restaurant farm by Grönska (2021), **(C)** depicting a growing unit in an office environment by Hollbium (2021), and **(D)** showing a B2C example by Natufia (2021).

in a retail location, restaurant, office, or at home. Some firms point to the desire to expose more people to the health benefits of a green environment, especially in cities, despite the fact that the systems themselves are not limited to use in urban areas. Contributing to food resiliency and helping to increase the local food supply are also mentioned by multiple firms as motivations for developing such modular systems.

Beyond these systematic ambitions are also business-specific drivers and benefits. As identified by several firms, the size of the systems opens up possibilities, both for location and revenue diversification. The size of the module systems also enables firms to distribute growing across locations and avoid the strict zoning and building needs of larger farming systems. But aside from these benefits, the systems also play an important role in marketing the firms and their technology. From a firm level, several firms identified that the systems bring visibility to the farms and the use of hydroponics and technology in food production. For business-to-business clients, the firms providing the GSS systems believe there are benefits to the visual appeal of the systems in stores and restaurants. In fact, one of the firms in the study initially envisioned the systems being placed in the back of the house in restaurants. However, the restaurant owners themselves began to demand well-designed systems that could be used in the front of the restaurant as a kind of art installation. This is also apparent in consumer models, where design is a key element of the systems to ensure its integration into the home where space is limited. See **Figure 2** for a depiction of different types of GSS modular farms.

Business Models

Seven of the firms in this study focus exclusively on the business-to-business (B2B) market, though the users of the systems vary from food retailers, restaurants, offices, and public institutions such as elderly care homes. Two of the firms focus exclusively on the consumer market, i.e., business-to-consumer (B2C), while the remaining two have deployed both B2B and B2C models. One of these firms had plans to launch a B2C module and accelerated those plans when the Covid-19 pandemic hit. The remaining firm remains focused chiefly on B2B customers but launched a B2C solution during the pandemic as a pivot when many restaurants in its area were shut down due to restrictions.

Value Creation

The input from firms suggests that the value created by the systems is largely connected to the idea that consumers want better access to fresh, local food products. The characteristics of the systems outlined above provide a compelling experience to provide hyper-local production. From a B2C perspective, this value is expressed as the ability to grow your own fresh produce and increased access to nutrition-dense leafy greens and herbs. Some system providers are able to show a cost comparison between the long-term use of their systems vs. buying (and in many cases wasting) produce at the store. This is translated into clear value from a consumer perspective. The end-consumer is compelled to purchase a system due to a desire to grow their own produce at home in an easy, low-maintenance manner.

The value creation from a B2B perspective includes the proposition of fresh, local produce but is also driven by intangible assets such as technology, innovation, intellectual property, customer relations, and branding (both for the firms and users). These aspects are harder to quantify in economic terms, especially in a retail environment where space for modules is limited and often expensive. So while there is value being created, the economic value, specifically the profitability of the systems for the firms (providers) and the revenues generated for the users of the GSSs, is unclear at this stage, pointing to the general novelty of the systems.

Value Delivery

While the specific technology and services offered by the firms, as well as the locations of the farms can vary, all firms were found to use an operational model built on the integration of hardware and software to deliver value. This is typically realized through a type of platform for digital interaction between providers and users of the system. This requires a combination of people, processes, and technology in order to deliver value. **Figure 3** depicts a generalized system and value delivery model for GSS systems.

From a people perspective, there is a combination of resources inside the system providers and people in the customer organization needed in order to maximize the value. Though, as pointed out in the section on characteristics of the systems, the firms look to minimize the need for human intervention from the customer, thus hoping to reduce the demand for new skill sets or a reorganization of job responsibilities. The process is largely automatic and continues to be optimized through business intelligence tools such as machine learning and artificial intelligence analytics. Off-site monitoring and proprietary software applications also help streamline the process for the end-user. The technology includes the hardware of the modules and needed input materials. There is a mix of proprietary hardware solutions and the use of third-party inputs. To deliver consumables and other materials, a number of suppliers and partners are needed, including seed providers, substrate materials, and delivery, which usually occurs through regular mail.

From a B2B perspective, scalability remains a challenge of the modular system, particularly in the retail sector. While some firms focus solely on modular solutions, others are combining the approach of both modules and their larger-scale centralized vertical farms, also called "mega farms," in order to deliver desired volumes of local, fresh produce. Many times these are different technical set-ups, however, in one of the cases, the firm is building mega farm solutions built on its modular technology, which can easily be scaled up or down based on customer needs. Others are taking the principles of the "growing-as-a-service" model, but integrating it into partnerships in mega farm facilities, where retailers or real estate owners invest in a modular farm, and the firm takes care of the growing for them.

Value Capture

While surveys, interviews, and secondary sources provide some insights into the revenue models of these systems, there is a mix of strategies at this stage and it is unclear if the modular systems offer a sustainable profit model over time. This also points to a relatively young phenomenon. Though specifics vary, the customers of these systems are paying for the bundling of both products and services. The majority of the B2B module systems are either leased or rented, with some firms requiring longer-term contracts.

Using a subscription-based model, many firms offer a service package that includes a number of features such as access to remote monitoring and a software application and certain services, including maintenance, training, system servicing, etc. Inputs such as nutrient solutions and seeds/plugs are sometimes included in a monthly subscription fee, while others require users to purchase them on demand. Other services that may require a separate fee or are included in package pricing include installation and a customized product mix plan for the units. Some of the firms do require the B2B customers to purchase the systems, which include the hardware and software components. Customers must then pay either monthly or on-demand costs for needed supplies and inputs.

Not all firms surveyed have developed their own technology behind the systems. All but one use a mix of proprietary and purchased components in order to package the products and services into a unique offering. One of the firms is using a more standard white label strategy, where it resells the hardware/software bundle developed by another farm in a different market under its own brand in its region.

Unlike the majority of B2B offerings, the B2C modules are purchased by the end-consumer. Prices of the consumer GSS systems place them in a luxury category, with the current in-home units offered by the firms in our study ranging from US$4,000–US$8,000. The purchase price typically includes a starter kit of seeds and nutrient solutions, as well as access to a software application and remote monitoring support. From there, some firms offer a monthly subscription option to cover supplies, while others use an on-demand purchase model.

Sustainability

The majority of the firms suggested that their GSSs are, or are becoming, more sustainable. This is often related to environmental sustainability, where many of the firms suggest that the modular farms offer resource-efficiency advantages, primarily through reduced water and fertilizer consumption in the horticultural production methods employed.

As mentioned previously, location was identified as a key benefit of these systems. The production of hyper-local foods is often recognized by the different firms as a sustainable advantage, providing reduced transportation through shorter distances in

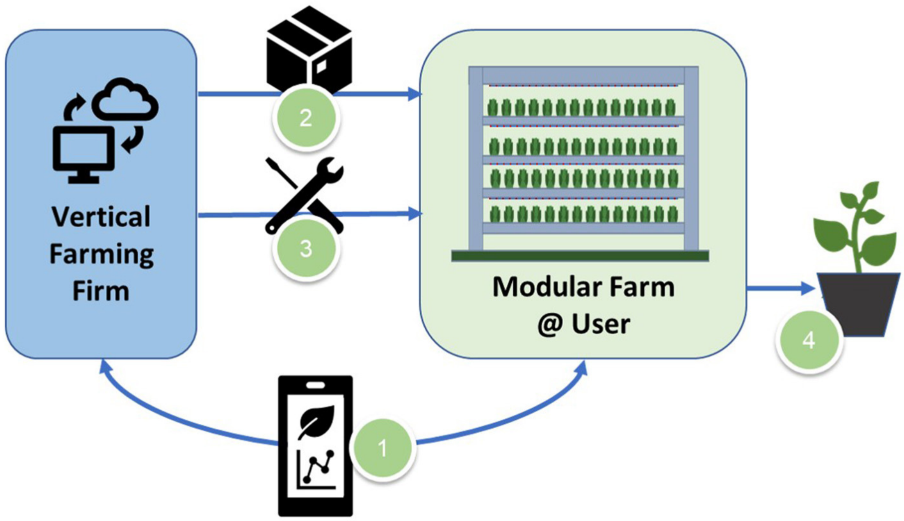

FIGURE 3 | Generalized system and value delivery model for GSS systems. The farm and vertical farming firm are connected through (1) cloud-based application to monitor and provide feedback for (2) consumables and other inputs, (3) possible maintenance and optimization, and finally (4) information about the cultivation and final harvesting periods.

their supply chain, and bringing the crops closer to the consumer. Connected to this are the many suggestions of increased freshness and shelf-life, which in turn are suggested to add to the quality of the product. Furthermore, this proximity to the end-users is suggested to reduce waste along the supply chain by a number of firms.

Sustainability was also suggested by many firms to be a priority in their work. Some firms are looking into reducing supply chain sustainability impacts by reducing shipping distances for consumables needed in the modular farms. Several firms also addressed the sustainability of their packaging materials, suggesting they are moving away from conventional plastics, and have been using, or experimenting with new materials. Furthermore, circularity was also discussed, as several firms are taking steps to include more circular approaches in their production. This includes reusing materials, developing new fertilizers, and improving the integration with urban environments and their building hosts. Nearly all firms were aware of the impacts of energy use, mentioning electricity and its negative environmental impacts. As such many of the studied cases highlight their purchasing of renewable energy or optimization developments to reduce energy consumption; see also discussions above on key characteristics.

Barriers and Challenges

The barriers and challenges outlined by the firms can be categorized into broader industry barriers and firm-specific challenges. From an industry perspective, the cost of technology is considered a current barrier, though many admit the costs are decreasing. The variety of products grown in the systems is also seen as a challenge for long-term growth and demand generation. Overall, the efficiency and sustainability factors of the systems are noted as an area that needs to be improved. In addition, one firm also identified the need for better business models in order to achieve economic sustainability of the modular offering. This includes aspects of the contracts and ensuring the long-term use of the systems so they are not seen as just marketing or display tools that are frequently changed out for other product displays, as floor space is often limited and/or expensive. Due to the novelty of the systems and hydroponic growing in general, supply and demand management is also difficult for most firms at this stage.

From a firm-specific perspective, the cases seem to be at different stages of development or concentrating on different concerns. In general, most of the firms are focused on bringing greater efficiency to the hardware/software interaction in order to further decrease the work required by the customer. As noted by one B2B-focused firm, the customers do not want to be farmers, so improving automation and services are seen as vital. Others are focused on increasing the variety of plants that can be grown in the systems and/or the mix within one unit. For B2C-focused firms, the initial costs of the units are seen as a barrier, as they may be considered luxury products in the current market. In addition, space is a concern, especially for city apartments. One firm mentioned the development of smaller units and units with less technology included to bring different price options to the consumer segment.

DISCUSSION

This section further elaborates on themes that emerged from the analysis and also presents avenues for future research.

Distributed Modular Systems

While there has been an extensive expansion of larger-scale centralized production systems for vertical farming (Butturini and Marcelis, 2020; Kotsier, 2020), our results highlight an expanding smaller-scale modular system for vertical farming. It was found that the novel approach to food provisioning in urban areas is being conducted worldwide, and encompasses a number of different products and systems. As highlighted in previous studies, there is a growing market for such solutions (Jürkenbeck et al., 2019; Butturini and Marcelis, 2020; Renmark, 2021). Our findings imply that these systems are being offered as novel, or niche, approaches, and in B2B environments, as an expansion of the vertical farming firms' own business portfolio. It was found that several firms are combining modular farms with conventional larger scale vertical farms; either starting directly with modular units or starting from larger farms and exploring the use of modular units. Once again, this approach has been highlighted as a way to differentiate from competitors in the market; aligning with previous studies on vertical farm market development, (e.g., Bustamante, 2020). As such, these tailored systems can create customized products to increase competitiveness and a unique profile in the retail market; (see e.g., Pine and Gilmore, 2014; Charters et al., 2017; Jürkenbeck et al., 2019; Sjölander-Lindqvist et al., 2020). A few of the firms in the study highlighted the ability to increase the types of products grown in the systems as an important area for expansion, which would address previous criticism of vertical farming in general (Cox, 2016; Pinstrup-Andersen, 2018); though others argue this limitation is more about economics than system ability (Banerjee and Adenaeuer, 2014).

Jurkenbeck et al. (2020) also found that the transparency provided by such modular solutions, which are directly visible to consumers, greatly improves their acceptance of such systems. Nonetheless, research has shown that consumers may be reluctant to consume foods from these more "technical" or less "natural" solutions (Siegrist, 2008; Coyle and Ellison, 2017; Grebitus et al., 2020), due in part to the lack of knowledge of these systems (Coyle and Ellison, 2017; Jürkenbeck et al., 2019; Yano et al., 2021). As such, by providing a visual element, the GSS providing firms are attempting to break down barriers by providing further transparency to how food is produced in vertical farming environments and engage with consumers. The firms in our study also pointed to this important aspect of the distributed model, which enables consumers to understand hydroponic growing. Placed in the retailers, the module systems provide a unique experience and educational opportunity. Located in homes, consumers are given the power over the product decisions, harvesting and availability. Such effects expand previous PSS research which have highlighted how consumer awareness of PSS systems challenges conventional product ownership, especially in urban areas, with systems for rental, sharing, and services (Acquier et al., 2017; Zamani et al., 2017; Hollingsworth et al., 2019; Martin et al., 2019b, 2021). In addition, few previous studies have outlined B2C examples of PSS systems, where the module is included at home. While such examples are available for B2C applications in the home, e.g., printing (McIntyre, 2018), robotic vacuums (Electrolux, 2019), no systems have outlined food production systems.

Business Models and Market Approaches

While the study provides some general insights into the business models of GSS solutions, it was difficult to obtain a detailed view of any one firm's business model. This could be due to a number of factors including the relative recent entrance of GSS solutions in the market, a desire for secrecy about this aspect of the farms and also the limitation of using open-ended surveys, where firms may have felt less inclined to write detailed commentary on this aspect. This was especially difficult in the B2B-focused firms. However, the analyzed information did uncover a number of interesting points.

First, although the long-term sustainability of the business model is unknown, almost all of the firms acknowledged the benefits of the systems in helping to grow awareness of hydroponics and build market acceptance. For the B2B focused firms, the modular-based systems also provided an opportunity to further develop relationships with retailers and restaurants by providing a unique experience for their end customers. Thus, by introducing the modular systems, even as the business model may be in flux, the GSS providers are able to explore the market and grow a network; which has been acknowledged as instrumental for technology entrepreneurs and a key function of business models (Doganova and Eyquem-Renault, 2009). This ability to extend the current offering beyond the delivery of plants and build relationships with their customers also aligns with key factors for the success of PSS offerings (Annarelli et al., 2016).

Second, while specifics vary, the customers of these systems are paying for a bundling of both products and services. B2C models require the purchase of the system, which also includes access to a number of software applications. The majority of the B2B systems are either leased or rented, and contracts include a number of services, which may or may not include performance indicators around the number of plants harvested and sold. From our results, it was difficult to suggest which conventional PSS model was employed and there does not seem to be one dominant model at this stage (i.e., product-oriented, use-oriented and results-oriented per Tukker, 2004). The B2C models align with a product-oriented model, as the main offering is still the product, which in this case could be considered both the plants and the physical module. B2B solutions, however, are harder to categorize. Some systems seem to align best with the use-oriented model, especially those found in restaurants or offices, as the systems are rented and largely run by the customer. However, retailer-focused solutions are harder to categorize. Some seem to be use-oriented, but others are also based on the number of plants harvested, aligning more with a results-oriented model. This difficulty in categorization points to the difference in our study vs. past PSS studies, which have generally focused on the manufacturing sector. Many times, in those cases, services were added to a long-term use product, where in GSS systems, a plant is the original product. Thus, the GSS system is introducing both a new product (the module) and services to a product that is consumed and used in a relatively short period of time, making it more difficult to fit into the established categories of PSS models. As highlighted, more information is needed for GSS firms to improve upon their business models in order to achieve economic viability of the offering. As such, further design developments and business model iterations may be necessary. Similar assertions are also highlighted in Kambanou and Lindahl (2016) and Bocken et al. (2018).

Last, our study uncovered some insights into business model innovation in the food industry. Vertical farming systems are constantly improving and expanding. As suggested in Klerkx and Rose (2020), vertical farming innovations are potentially game-changing, affecting the way in which food is produced, processed, traded, and consumed. The visibility and benefits of hydroponic growing enables customers to make decisions based on new characteristics of food, such as environmental effects, or by taking into account intangible benefits such as eating a product closer to harvest. The ability to differentiate products based on intangible and tangible benefits, along with "turning ordinary products into extraordinary experiences" have been identified as key PSS benefits (Annarelli et al., 2016). These developments are also in line with consumer demand for more locally produced food, especially in wake of the Covid-19 pandemics (Toler et al., 2009; Granvik et al., 2017; Pulighe and Lupia, 2020). In particular, the B2C modules are challenging the dominant business model in the food industry, where typically an individual buying a product from a store supports the business model of the food retailer (Kaplan, 2012). B2C modules enable the GSS firms to capture the value directly from the end-consumer. Some firms argue that giving the consumers the control over production is an intangible value consumers are willing to pay for. As all of the firms in the study point to a desirability to improve the environmental performance of the current food system, the experimentation of business models that support sustainable innovation is an important and ongoing endeavor, as it is difficult to simply transplant business models from one economy to another if sustainable development is a goal (Boons and Lüdeke-Freund, 2013).

Benefits and Sustainability

The results suggest that most firms highlight a number of benefits of modular systems. Owing to their proximity to consumers, the location was highlighted as a beneficial aspect of these systems, where the freshness and nutritional aspects of the products were suggested to be superior in these systems. This is especially important for leafy greens, which can begin to lose nutritional value as soon as they are harvested. Indeed, previous studies have suggested that vertical farms can control the genetics, quality, and sensory experience of different croups through optimized conditions during growth and pre-harvest, (see e.g., Selma et al., 2012; Nicole et al., 2019; Sharathkumar et al., 2020). Furthermore, many firms also suggest location is important for sustainability, e.g., by reducing transportation along the supply chain. However, previous studies have shown that the transportation of foods has a relatively minor impact on the overall impact (Edwards-Jones et al., 2008; Coley et al., 2009), and specifically for urban-vertical farms (Martin and Molin, 2019). Nonetheless, an important benefit also highlighted for vertical farms in close proximity to consumers is also related to variety of crops which can be produced, which can be chosen for flavor and taste, thus providing differentiation, which is not always possible in conventional varieties found in retail which may be optimized for transportation resistance (Bogomolova et al., 2018; Harada and Whitlow, 2020; Renmark, 2021).

Beyond transportation, many of the firms outline the advantages the GSS systems provide for environmental sustainability, primarily relating to resource efficiency improvements and reduced toxicity from the lack of pesticides employed. Such motivations are common amongst urban agricultural systems, see e.g., assertions in Specht et al. (2014), and have been found to be a major driver in consumer acceptance of such systems for different vertical farming systems (Coyle and Ellison, 2017; Jürkenbeck et al., 2019). However, no firms highlighted other sustainability pillars, e.g., social or economic sustainability. There are a limited number of studies reviewing sustainability or specific case studies of urban farms in different scales beyond plant factories and rooftop farms (Kulak et al., 2013; Romeo et al., 2018; Martin et al., 2019b) and thus more research could focus on the implication of GSS systems in comparison to their larger counterparts. Furthermore, while such PSS systems are promoted as sustainable alternatives, their economic, social, and environmental implications are rarely accounted for and are often confined to qualitative reviews of the potential of these systems (Lindahl et al., 2014; Salazar et al., 2015; Kambanou and Lindahl, 2016; Bocken et al., 2018). It is important that further developments, case studies, and assessments are explored and tested to ensure they achieve the desired intentions and provide value to both provider and users of the systems (Kambanou and Lindahl, 2016; Bocken et al., 2018; Martin et al., 2021).

A further benefit outlined by most firms is the potential to control the systems to allow for learning and ease of use by the consumers. This is often included in PSS offerings, allowing for the provider to control the system and maintenance and reduce risks for the user (Tukker and Tischner, 2006; Lingegård, 2020), although its influence on the sustainability of the systems are not well-known (Martin et al., 2021).

Limitations and Future Research

Our analysis of GSS could be improved in a number of ways. First, the study sought to understand the nature of the activities and technical functions surrounding GSS solutions but did not evaluate their effectiveness in any one area, e.g., market development, sustainability, innovation management. Future studies of GSS systems could include further information and questions relating to the business models employed. As many of the firms suggested that they are designing the systems with the users and consumers in mind, in the future, research could focus on user and consumer perception and perspectives of these systems. Furthermore, while the questionnaire and interviews did not address the lifetime of the modular units, the lifetime, and design for durability are important for the PSS systems. Our study also highlighted a limited geographical selection of such cases, which has examples worldwide, but has a more European focus. Further work can be done to develop knowledge from a broader set of GSS solutions worldwide, especially as they are becoming increasingly apparent. Finally, as the study is focused on a novel method for vertical farming, a more longitudinal approach could be employed to study the change in these systems over time to study their development. Further studies could also focus on the complexity of business ecosystems for GSS solutions.

CONCLUSIONS

Using a product-service system approach, the results of this study highlighted examples and characteristics in the development of technology and software systems in vertical farming, referred to as growing-service systems (GSS) in this paper. It was found that this novel method is employed by a number of firms as a new business model. This was used to extend and improve their markets, either as an additional approach to their larger centralized farms, or as their exclusive approach. The value created by these systems rests largely on intangibles such as fresher products, local production, and automated control over growing aspects. In order to deliver this value, all firms are developing a combination of hardware and software applications that provide a number of automated services to achieve the desired output. We found that the value capture strategies for the systems varies between the B2C and B2B contexts. While the modular units are often provided with a subscription service for B2B contexts, they are generally purchased in B2C contexts; though both concepts included a number of services to complement the hardware system.

The key motivations for these systems were the ease of use and the perceived benefits of hyper-local production, including improved product quality and building more resiliency in local food systems. Many of the firms also found the modular systems to be beneficial in their marketing by increasing transparency and awareness for vertical farming methods and products. Nearly all firms motivated the development and use of these systems to contribute to more sustainable food provisioning. Location was found to be a key aspect in both the sustainability and quality of the products, e.g., linked to the proximity to users and "freshness" of the product. However, the study also highlights some barriers to their development. These include improving the business models to allow for more economic viability, reducing costs, improving the efficiency of the systems, and technology for increased automation in limited space.

The results and knowledge produced contribute to the emerging literature on sustainable business models, urban-vertical farming, and PSS through empirical evidence from a novel segment of PSS in the food industry; once again referred to in this study as GSS. The results of this study can be useful for GSS firms, in addition to retailers and direct users, to further develop and improve the GSS offerings and modular vertical farming systems for different contexts. Future research should also be placed on understanding the implications of these modular systems in comparison to their larger-centralized counterparts, in addition to studying the role of technology and user perception/acceptance of these systems to add to the understanding of the opportunities and challenges of deploying sustainable business models.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MM and MB equally contributed to the concept of the study, its data collection, analysis, and writing of the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.787281/full#supplementary-material

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COVID-19 Driven Adaptations in the Provision of School Meals in the Baltic Sea Region

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The instability, rapid changes, and restrictions generated by the COVID-19 pandemic tested the provision of school meals in the Baltic Sea Region (BSR). School meal services were affected by factors such as full or partial lockdowns, strict hygiene regimes, lay-offs or staff shortages, stressful working environments, supply shortages, and changes to storing, cooking, and serving models. However, the responses to the COVID-19 crisis were highlighted by innovation, new opportunities, and cooperation. This paper reviews several examples of COVID-19 crisis management at school canteens in five BSR countries [Estonia, Finland, Poland, Russia (Saint Petersburg), and Sweden] between March 2020 and March 2021. The paper reveals the significant operational, logistical, and systemic problems that appeared because of the pandemic; the solutions and adaptations that were developed are also identified. The preparatory processes, logistics, and services that were adapted during the COVID-19 pandemic resulted in a new school meal provision model—a takeaway model; that includes similar features and unique characteristics across the different countries. Overall, the provision of school meals was carried out successfully in the BSR during the pandemic. Responsible, competent, and innovative professionals used their organizational skills, flexibility, and responsiveness to feed school pupils in a highly restricted and rapidly changing environment. It is expected that several of the COVID-19-driven innovations will remain in use following the pandemic.

Keywords: school meal, COVID-19 pandemic, Baltic Sea Region, takeaway meal, social innovation, crisis management, school closure, distance learning

INTRODUCTION

School meals play an essential role in society by providing food and shaping healthy lifestyles and eating habits. The content and design of school meals have an impact on children's health and well-being, and they can support better learning (Anderson et al., 2017; Schwartz and Rothbart, 2019). For children from deprived families, a school lunch may be their only proper meal during the day; thus, school meals can contribute to achieving food security in society (Van Lancker and Parolin, 2020).

The provision of school meals requires numerous preparatory as well as logistical processes. In selected Baltic Sea Region (BSR) countries, namely Estonia, Finland, Sweden, Poland, and Russia

(Saint-Petersburg) (**Figure 1**), an ordinary school lunch is a hot meal with regulated nutritional values. School meal frameworks depend on national and local government regulations that control factors such as full or partial meal subsidies, in-house food preparation vs. procurement from external catering companies, and on-site kitchens vs. centralized facilities with delivery services.

The recent Coronavirus (COVID-19) pandemic has put school food provision under severe pressure worldwide. While there have been fewer cases of COVID-19 among children, national responses to the pandemic have had significant effects on child nutrition and educational outcomes (WFP et al., 2020). A US study covering all US jurisdictions analyzed the child nutrition administrative agencies' responses to meal service provision during COVID-19–related school closures; the study concluded that understanding the initial approaches of the jurisdictions are critical to emergency planning in order to better address food insecurity (McLoughlin et al., 2020a). Research by Parnham et al. (2020) revealed that up to half of the children entitled to free school meals in the UK did not have access to the scheme during the COVID-19 lockdown, and this has increased the discussion of food insecurity. Kinsey et al. (2020) reached similar conclusions in a study of free-of-charge or subsidized meals that were disrupted because of long-term COVID-19-related school closures in the US: both the nutrient intake of students and household food security were potentially decreased during the pandemic period. However, the majority of scholars have taken a different approach to researching food provision and well-being during the pandemic; instead, they have addressed the impact of COVID-19 on general eating behavior (Janssen et al., 2021; Jia et al., 2021; Philippe et al., 2021) or stress-related, emotional eating (Cecchetto et al., 2021; Jansen et al., 2021; McAtamney et al., 2021). Therefore, the exact adaptations of school meals during the crisis, particularly in transnational studies, are yet to be analyzed.

School closures and the introduction of distance learning were widely implemented as pandemic-related restrictions between spring 2020 and spring 2021. The aim of this article is to discuss how schools adapted their school meal provision during the changing phases of the COVID-19 pandemic and address how this has affected the primary stakeholders. This article reviews regional approaches to providing school meals during the COVID-19 pandemic in selected BSR countries. This paper focused primarily on the service providers' point of view, as this presented a unique opportunity to evaluate the front-line of school meal provision during the crisis. How did the COVID-19 pandemic influence the provision of school meals in practice? What were the most significant challenges, and what solutions were implemented while providing school meals during the COVID-19 pandemic? In line with the results reported by Kinsey et al. (2020), this study identified a set of COVID-19-related innovations in school catering services and public authorities.

The paper first provides the theoretical background regarding the regulatory frameworks and organizational models of school meal provision in the studied countries. This is followed by a description of how the COVID-19 pandemic affected schools between spring 2020 and spring 2021. Finally, the paper analyzes how the provision of school meals was adapted and the responses to the rapidly changing situations are identified. This research has established how the theoretical operational models were altered during the pandemic, resulting in the emergence of a new take-away school meal model that was adapted to the specific conditions of the pandemic in each country.

Regulatory and Organizational Models of School Meal Provision

The overview of the regulatory frameworks and theoretical models of school meal provision are based on the analysis of public meals in the Baltic Sea Region completed in the StratKIT project (StratKIT, 2019). School meals are served under several different cost-sharing, organizational, and manufacturing models (**Table 1**). Some of the models are strictly regulated by national or local laws; other models involve freedom of choice, including at an individual school level.

Cost-Sharing Models of Catering Services

From the perspective of the consumer, there are different cost-sharing models of school meals (StratKIT, 2019). School meals can be (1) fully subsidized by public institutions, (2) partially subsidized (a share of the cost is covered by the consumer), or (3) not subsidized (the consumer must pay the total cost of the meal). There is also the option of a (4) mixed model that applies all of the previous models. All of the studied countries offer partially subsidized school meals, at least to selected groups. For example, all school levels in Finland and Sweden provide a fully subsidized (free-of-charge) daily meal. In Estonia, the state provides a subsidy of 1 euro per meal. The remaining cost is covered by the municipality (fully subsidizing the meal) or the child's guardians, or both. Similarly in Poland, primary schools are partially subsidized—parents pay for the food and, in most cases, the local governments cover all other costs (e.g., labor and facilities). In Saint-Petersburg, Russia, school meals are either fully subsidized (for children from specific social categories that are determined by the Social Code of Saint-Petersburg) or partly subsidized; however, the free-choice menu that is regulated by Rospotrebnadzor and the Department of Social Nutrition (DSN) is not subsidized.

Organizational Models of Catering Services

The preparation of school meals can be divided into two main organizational categories: (1) in-house—meals are prepared and catered by the schools themselves, and (2) contract catering—meals are procured from private companies that organize the catering. The school (or municipality) is responsible for procuring the food in the in-house operational model and the service is also provided by the schools. In contract catering, the service is tendered by public procurement and provided by a selected commercial enterprise according to the procurement criteria.

The studied countries tend to use a contract catering model that generally employs a private catering company to provide the catering services. In Estonia, this service covers the supply of goods and food products, cooking, recruitment, and quality control. In Saint-Petersburg, Russia, the catering model is the

FIGURE 1 | Map of the study area.

TABLE 1 | The school meal framework in selected BSR countries.

Framework model	Estonia	Finland	Poland	Russia, Saint-Petersburg	Sweden
Cost-sharing models of catering services	Subsidized by the state up to 1 euro per meal, the rest fully or partially subsidized	Fully subsidized	Partially subsidized	Mixed model (from full to no subsidies)	Fully subsidized until 9th grade.
Main organizational models of catering services	Mainly contract catering	In-house by schools Contract catering	In-house by schools	Contract catering	In-house by schools Contract catering
Main manufacturing and delivery models	On-site kitchen, *Cook and serve*	Central kitchen, *Cook and serve, Cook and chill, Cook cold*	On-site kitchen, *Cook and serve*	On-site kitchen, *Cook and serve, Cook and chill*	On-site kitchen, *Cook and serve*

Source: StratKIT (2019) and own research.

only organizational model that is available for educational institutions. In Finland, catering services can either be managed by the education provider, such as the municipality or the school, or procured from a company that is owned by the municipality or a private business. Primary schools in Poland traditionally use the in-house model for providing meals—schools are equipped with kitchens and employ cooking staff (usually municipal workers) to procure and process food at an individual unit level; this system is most popular in the bigger cities. In Sweden, most primary schools operate their own food service; in-house catering by public bodies accounts for 87% of public catering and contract catering accounts for 13%. Almost three-quarters of the Swedish municipalities have a single organization that manages all public meal activities (school, pre-school, elderly care, etc.). In contrast, 20% of the meal provision is divided over several administrative bodies.

Manufacturing Models for Preparing and Distributing Public Meals

Traditionally, educational institutions have had kitchens on their premises. Therefore, food is prepared *in situ* ["On-site" model (1)] and provided as ready-to-eat, hot meals (*cook and serve*). This model is common in Estonia, Poland, and Russia. In Sweden, almost 60% of public primary schools have an on-site kitchen that is connected to their school restaurant. The central kitchen model (2) is an emerging trend, particularly in Finland; central kitchens follow sanitary rules and prepare meals, either partially or entirely, that are then transported to schools. In Finland, there has been a continuous increase in the number of modernized central manufacturing kitchens. On-site kitchens that were previously used for food manufacturing now often operate as satellite or service kitchens that have food delivered to them from a central kitchen. The decision for a central manufacturing kitchen is often made when old premises require refurbishment; Finnish municipalities make significant long-term investments to establish new premises, equipment, and even cooking methods. Central kitchens in Finland operate mainly by cook and serve and cook and chill manufacturing methods. The less frequent method of cooking cold is also being used more often. In Poland, Estonia, and Russia, the meals are rarely cooked in central kitchens.

The COVID-19 Pandemic in BSR Countries

The outbreak of COVID-19 was caused by the spread of the SARS-COV-2 virus, and was first discovered on December 31, 2019 in Wuhan, China. COVID-19 was detected in Europe on January 24, 2020 in France[1], and a global pandemic was declared on March 11, 2020. In all the studied BSR countries, the first COVID-19 cases were confirmed within a five-week period, starting in Finland on January 30, 2020 and ending on March 4 in Poland[2]. A state of emergency was declared in Estonia, Poland, and Finland. The BSR countries often followed a similar pattern during the period under review (March 2020 to March 2021), with a first wave of COVID-19 during spring 2020, a rapid increase in the number of cases through March and April, and then a second wave in autumn 2021 or March 2021 (see **Figure 2**). The lengths and severity of these waves and the measures undertaken to control the spread of the virus varied in each country. Full or partial national lockdowns were imposed during the first months of the pandemic in Estonia, Finland, Poland, and Russia; schools and school canteens were closed as part of the restrictions. Sweden was a worldwide exception in terms of its response to the COVID-19 pandemic, as schools were kept operating, with several modifications, throughout the whole period.

Figure 2 shows the monthly averages of the reported COVID-19 cases per 100,000 population for a 14-day period between March 2020 and March 2021 in five BSR countries: Estonia, Finland, Poland, Russia, and Sweden. **Figure 2** clearly shows the timeline of the two or, in some cases, three surges in COVID-19 cases, often referred to as COVID-19 waves; the first waves started in March 2020 in all of the studied countries. The second waves began in autumn and winter 2020; cases increased sharply in October and November in Poland and in November and December in Sweden. Estonia had the longest and strongest increase in COVID-19 cases and had the maximum average of new reported cases in March 2021—over 1,400 cases per

[1]https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020 (accessed June 15, 2021).
[2]https://www.ecdc.europa.eu/en/publications-data/download-todays-data-geographic-distribution-covid-19-cases-worldwide (accessed July 26, 2021).

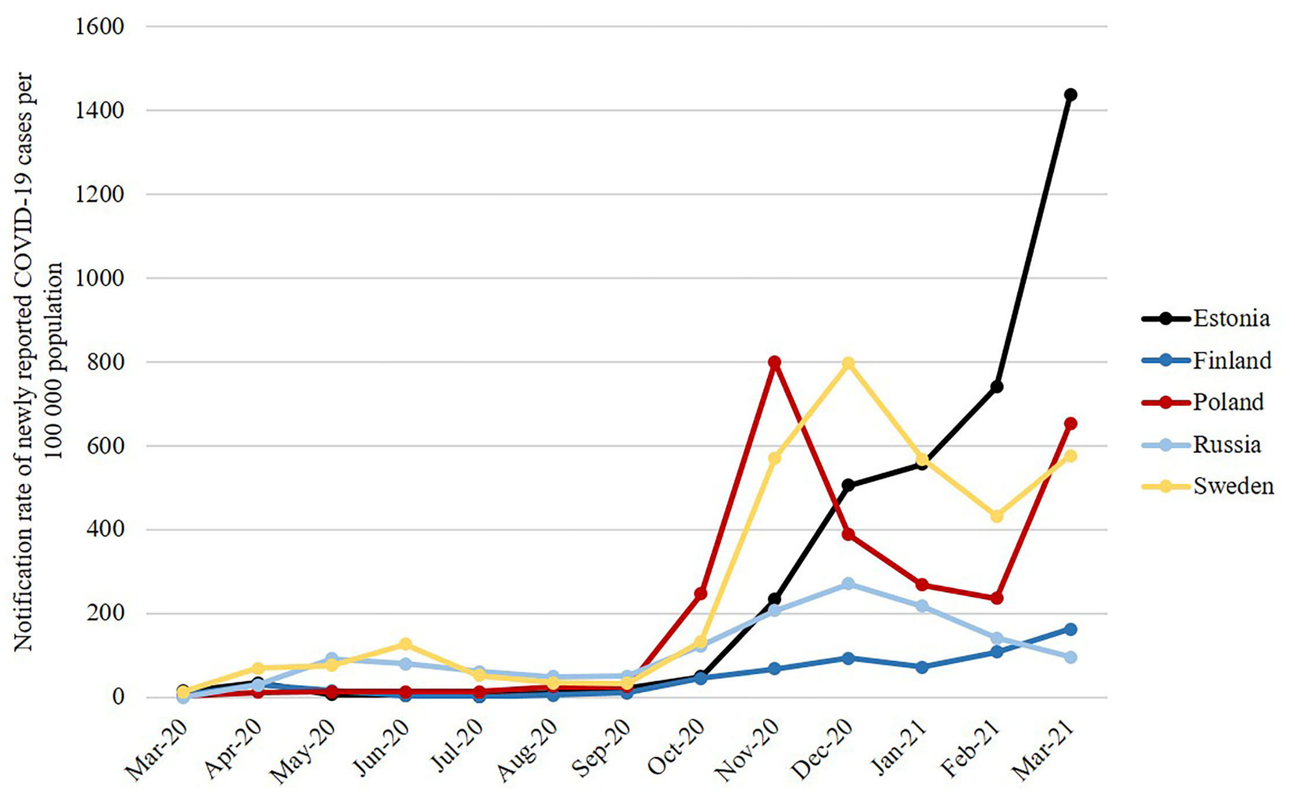

FIGURE 2 | Monthly averages of the 14-day notification rate of newly reported COVID-19 cases per 100 000 population between March 2020 and March 2021. Source: own calculation based on ECDC.

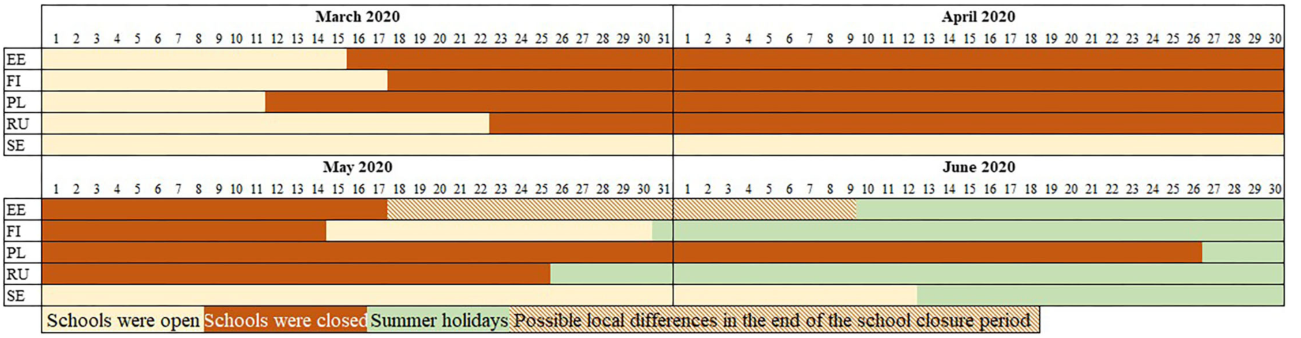

FIGURE 3 | School lockdowns in studied BSR countries in spring 2020. Source: based on ECDC data.

100,000 population in a 14-day notification rate. Russia was the only country among the five to show a decrease in rates after December 2020. In comparison to the other BSR countries, Finland had a very mild second wave that started in 2021.

In response to the first wave of the pandemic in March 2020, the studied BSR countries either closed schools or kept schools open (shown in **Figure 3**). Furthermore, the gap between the first confirmed COVID-19 case per country (data published by the European Center for Disease Prevention and Control) and the closure of schools and the introduction of distance learning can be counted in days: the number varied from 9 days in Poland to 52 days in Russia. Sweden was an exception, as schools were not closed at any point following their first COVID-19 case on February 5, 2020. In contrast, Poland maintained the longest lockdown for schools, which ceased at the end of the school semester after 106 days. Schools in Saint-Petersburg, Russia, also ended a 63-day lockdown at the start of the summer holidays. In spring 2020, Finland kept its school closed for 58 days and Estonia for 62 days; both countries then resumed contact learning for at least 2 weeks before the summer break.

TABLE 2 | Data collection method summary.

Country	Study case(s)	Selected methods and additional information
Estonia	City of Tallinn, City of Tartu, Baltic Restaurants Estonia	Telephone interviews with stakeholders followed a general list of nine questions (**Annex 1**) and included an open discussion.
Finland	Municipality of Seinäjoki, Municipality of Tuusula, Saimaa Support Services	Online interviews with stakeholders following a **Annex 1** questions as well as an open discussion. The conclusions drawn from the discussions were sent to the stakeholders for verification.
Poland	Municipality of Rybnik, Municipality of Izabelin	A questionnaire consisting of eight questions (**Annex 2**) was sent *via* email to the headmasters of all the primary schools in Rybnik and several schools in Izabelin. Twenty-four responses came from Rybnik and four from Rybnik. Additional telephone interviews were conducted with six schools and covered information on opportunities and positive developments.
Russia (Saint-Petersburg)	School No. 126, School No. 249, Private school "Shamir"	Three stakeholder interviews were conducted: one on-site and two telephone interviews. The on-site visit allowed a participatory and observatory research experience. All three interviewees were initially asked the same questions: 1) How was the school meal provision organized in each school, and how did it change in response to COVID-19-related restrictions and new regulations? 2) Were there any additional challenges? If yes, how were they solved? 3) Will any positive developments be retained in the future?
Sweden	City of Gothenburg	In order to gain an overall picture of the national situation, the Swedish input was primarily based on the National Food Agency's country-wide report (Livsmedelsverket, 2021). The city of Gothenburg was used as a case study, and an interview with Gothenburg's municipal food services was conducted. The interview lasted 45 min and addressed the questions in **Annex 1**. In addition, e-mail correspondence with five food service managers was used to gain a more detailed picture. The interviews and e-mail responses were compiled, and categories were created based on the relevant data. The report from the National Food Agency was used as a supplement.

Source: own research.

However, some municipalities in Estonia, including Tallinn, kept schools closed until the end of the school year in 2020. The regional examples described in section Results also show that in autumn 2021 additional preventive measures were introduced, as a second wave was expected (e.g., obligatory face masks, restocking of cleaning equipment, changes to dining order, and physical distancing).

The school year of 2020/2021 started with contact learning in all of the studied countries. The school lockdowns that followed differed nationally and regionally because of the regional COVID-19 case ratios and the speed of local transmission.

MATERIALS AND METHODS

The paper is based on a mixed-method approach, combining a literature review and case studies to review the unfolding COVID-19 situation and examine how the five selected countries adapted to the crisis; a total of 12 regional examples are provided.

Representatives from each country selected a suitable method for their regional data collection; however, baseline questions were constructed for comparative purposes (see **Annex 1**). Each country contributed between one and three different cases. The selection was based on availability and convenience, as well as national organizational schemes when the data concerned a municipality as a whole or a particular school. The study identified other national variations in the management of school meals during the pandemic; therefore, the collected data does not provide a complete representation of the studied BSR countries. In order to provide a full description of the different cases, the data were collected in three different ways: (i) stakeholder interviews, (ii) stakeholder questionnaires, and (iii) a literature review and web-based searches to identify the national and local emergency regulations that were implemented during the COVID-19-related school closures between March 2020 and March 202. **Table 2** summarizes the data collection and selected methodology per country.

Based on the results, a comparative textual analysis summarized the joint findings. Additionally, a word cloud algorithm was generated to identify the challenges and opportunities that were reported most frequently.

RESULTS

School Meal Provision During the COVID-19 Pandemic in Reported Case Studies

Estonia

Schools in Estonia were affected by two official COVID-19 waves, the first in spring 2020 and the second in spring 2021. Schools were fully closed throughout Estonia from mid-March until mid-May 2020 and from early March until May 2021. Most of the municipalities, including Tallinn, kept schools closed until the end of the 2020 school year. From autumn 2020 until March 2021, schools tried to minimize the contact between pupils. Thus, many schools combined contact learning with distance learning. For example, classes could attend school on different weekdays or on alternate weeks. These timetable shifts were not usually applied to the younger pupils in grades 1–4. Between March 2020 and June 2021, whole classes were frequently instructed to stay in quarantine because of a close contact with a classmate or teacher who had tested positive for COVID-19. Distance learning was practiced during the quarantine period. If a pupil had individual contact with a COVID-19 infected person, the pupil remained in mandatory individual quarantine for 10–14 days.

During the COVID-19 pandemic, hot school meals were provided throughout the periods of in-school teaching. Measures were taken to minimize the contact between children in the canteens. For example, pupils could eat in their classrooms or meal breaks were extended (while shortening the lessons) to allow only one class at a time in the canteen. Extra attention was also given to hygiene and sanitary requirements (e.g., cleaning tables and common surfaces thoroughly and more often, frequent handwashing).

Hot school meals were not provided during the periods of distance learning. Instead, children were generally supplied with food packages. The contents of the food packages adhered to the requirements of the sub-regulation of the Public Health Act: Health protection requirements applicable to catering in pre-school childcare institutions and schools. The food package usually included ingredients for making meals at home, such as pasta, rice, or buckwheat, a can of soup, cereals, fresh fruit and vegetables, milk, yogurt or other dairy products, bread, and meat products (e.g., sausages and meatballs). The kitchens distributed the packages once a week, and the contents of the package varied from week to week.

In spring 2020, some municipalities only provided the food packages to pupils from deprived families (e.g., Tartu); other municipalities supplied food to any pupil who signed up to the meal program. However, in spring 2020, the number of pupils receiving the food packages was relatively small. From autumn 2020 onwards, all distance learning pupils who signed up for the food packages could pick them up once a week; the packages could also be collected by the parents. Children in individual quarantine could only receive food packages following a special request.

The municipalities managed the contents of the food packages differently. The system was similar in spring 2020 and spring 2021, although the details and organization were refined in spring 2021. Initially, there was significant confusion; therefore, the city of Tartu developed a guide for caterers that outlined the type and quantity of food each package should contain. The guide followed the Ministry of Education and Science regulation that sets the requirements for school catering.

The food package content in Tallinn differed during the full and partial distance learning. When individual classes were distance learning, the school caterer assembled the food package in cooperation with the school. During the nation-wide period of distance learning, the content of food packages was managed centrally by the Tallinn Education Department. The aim was to include a wide variety of products (cereals, fruit and vegetables, milk and dairy products, meat or eggs, etc.) while also considering the limiting factors of shelf-life, storage conditions, and price. The Education Department provided school caterers with a list of product groups; however, they did not specifically define the products, as it was thought that this could create problems with supply. To maintain a diverse selection, the content of the food packages varied from week to week. During the complete lockdown, the budget for a food package was increased to allow for more fruit and vegetables. Allergies and special diet requirements were considered at the school level.

A significant number of takeaway packages were not picked up, and this put pressure on the management of food waste. Therefore, caterers tried to find solutions to avoid food waste. For example, the perishable food products were distributed among kitchen staff and teachers, and products with a longer shelf-life were reused in packages in the following weeks. **Table 3** lists the key COVID-19 related problems in Estonia and the reported solutions.

TABLE 3 | Challenges and positive developments during COVID-19 in Estonia.

COVID-19 driven reported main challenges and problems
Communication between schools and parents or schools and caterers was not well-organized even though it depended greatly on school.
The generation of food waste increased due to takeaway packages not being picked up.
Organizing social distancing when eating at school (separating classes, eating in classes, etc.)
Communication between municipalities and parents increased tremendously and consumed a lot of time for municipality officers.
Parents' views of the food package content varied considerably. Therefore, getting consent on the issue among the parents, municipalities and/or caterers was difficult.
It was challenging to manage kitchen/canteen staff, who did not have full-time work anymore but at the same time might unexpectedly stay in quarantine due to COVID-19 close contacts, and the replacement was needed.
Agreeing on the cost of food packages between municipalities and caterers was problematic at times or in some municipalities.
Introduced solutions and other positive developments
The food ordering system became particularly useful in pandemic times (Tartu).
Parents donated the unneeded food from the package to the Foodbank on their initiation or the school (or municipality) organized it.
Hygiene standards and behavior improved considerably.

Source: conducted interviews.

Finland

In Finland, schools continued to operate, at least at a minimal level, throughout the COVID-19 pandemic. From late March 2020 to mid-May 2020, most pupils in Finland were moved to distance learning. Children requiring special assistance continued to attend classes with contact learning. At the beginning of the pandemic outbreak, the obligation to provide school meals did not extend to pupils involved in distance learning. As a result, municipalities could decide whether, when, and how they offered school meals to children studying at home. The various initial approaches included not supplying a meal, distributing food vouchers, or providing industrial food packages; however, the most common option was the supply of prepared takeaway meals. In summer 2020, the Ministry of Education made school meals for distance learning pupils obligatory and unified the rules for the main dish, stating that the school meal must include good quality ingredients and have a high nutrition value. In addition, special diets had to be considered when distributing meals. During autumn 2020, Finland removed the requirement for distance learning (except when pupils were in quarantine). For 3 weeks in March 2021, schools were asked to organize distance learning; however, the need to implement distance learning was based on the infection rate in each region. The Municipality of Seinäjoki in South Ostrobothnia is an example of a region that was not required to lockdown in March 2021.

When the first COVID-19 restrictions, including school lockdown, were implemented in March 2020, Seinäjoki municipality only provided meals for children in contact learning. A month later in mid-April and prior to the national regulations, the school meal provision was extended to include a hot takeaway meal for pupils in distance learning. During March 2020, ready-made industrial meals were not used. However, an updated crisis management plan accepted the introduction of industrial foods if future lockdowns were required. The cost of a school meal during the lockdown, despite its bigger size, was estimated to be the same as a standard in-school meal. Several reasons for this consistency were that side products, such as salads and milk, were not included, and staff costs did not change.

During the first COVID-19 wave, schools in Tuusula (a Helsinki sub-region) were operating with only ∼20 pupils per school requiring special assistance. Following the introduction of distance learning, within 1 week the municipality had introduced a drive-through that provided a once-a-week pick-up point for meals for the whole week. The cooked cold meals were usually prepared in the central kitchen, where they were cooked, chilled, and then distributed frozen. Acquiring adequate space for the chilling phase was a technical issue; however, no infrastructure investments had to be made. At the pick-up point (first from the central kitchen and then also from schools), pupils were served without the need to sign up or apply in advance. Approximately 60% of meals were picked up, and the remaining frozen meals were distributed during the next round. The menu list was modified to support the changes to the preparation processes. During the COVID-19 pandemic, the cost of the school meals in Tuusula doubled because of higher staff costs, packaging, and the large, unified portion sizes. In spring 2020, the municipality of Tuusula introduced an additional set of modified practices. To avoid lay-offs, municipal workers were reallocated to different units and tasks, such as cleaning. Unpaid holiday leave was also granted at the employee's request. A new practice, which is likely to remain permanent, was the introduction of an extra summer meal served to pupils at a park. The outdoor dining in 2020 was very popular and greatly appreciated. Each working day in summer, pupils with their own food containers and cutlery were given a hot meal (soup and pasta from the school menu list).

At the Eastern borders in Lappeenranta and Imatra (operated by Saimaa's Support Services), a takeaway school meal was introduced in late April 2020. The takeaway system was first based on an application list; however, pupils were removed from the list if they failed to pick up the food twice in a row. This requirement was no longer in practice in spring 2021. The takeaway food was delivered to schools twice a week, although pupils with a right to communication support (e.g., living in remote areas) had the food delivered to their homes. This hybrid arrangement (in-school meals for pupils requiring special assistance, takeaway meals, home delivery) in spring 2020 and spring 2021 required significant changes to the food manufacturing processes. Initially, when the meals were only required for about 10% of pupils, 350 employees were temporarily laid off. On the other hand, the preparation and delivery of meals for pupils in distance learning required an extra labor force because of weekend and evening shifts. Another major change was the significant need for packaging materials and equipment. As a result, the cost of these modified school meals was calculated as 1.5 times the original price.

Throughout the COVID-19 pandemic, pupils in contact learning were served food under very strict hygiene rules. For example, schools in Lappeenranta, Imatra (Lpr), and Seinäjoki (Sjk) extended the duration of the lunch period (from 10 a.m. to 1 p.m.). Pupils were instructed to dine in class groups and eating in classrooms was also recommended. In addition, the serving cutlery was replaced, and the tables were wiped clean after each group. From autumn 2020, visitors to the canteens were asked to wear face masks. The Tuusula (Tuu) municipality held a series of planning meetings with school principals to organize school dining once the schools reopened. The general rule was to not allow the classes to mix. However, each school could decide if pupils ate in their classrooms or at different times in the school canteen.

Table 4 lists the main reported challenges in the Finnish municipalities from March 2020 to March 2021; the positive developments are also listed.

Poland

In Poland, the implementation of the required tasks for each school was determined by the degree of risk related to the COVID-19 pandemic. Therefore, schools followed the recommendations of the Ministry of Education and the Ministry of Health and only conducted distance or hybrid learning in the more severe periods of the pandemic. All schools were closed from mid-March 2020 to the end of the school year (end of June 2020), and pupils were taught by distance learning. The following school year began with contact learning, but most schools reintroduced distance learning from November 2020 to the end of the first semester (January 31, 2021). In the second semester (February 1, 2021–June 25, 2021), lessons were again being carried out in schools; however, between March and April 2021, schools were required to teach remotely or use hybrid methods. Contact learning resumed at the beginning of May.

During the pandemic, school canteens usually only served meals while schools were operating normally. However, some schools continued to serve meals to pupils who remained at school because they did not have the required conditions for distance learning at home. Some schools provided takeaway meals when they were closed. A number of canteens also prepared meals for specific groups, such as children requiring

TABLE 4 | Challenges and positive developments during COVID-19 in Finnish municipalities.

COVID-19 driven reported main challenges and problems
The amount of communication between parents and the kitchen increased tremendously during the takeaway period (Sjk).
Receiving up-to-date and accurate information on pupils in distance learning and their special food requirements (Lpr).
Adjusting to modified cooking methods supporting takeaway meals (Lpr, Tuu).
Stressful and heavy time for the staff in general (Tuu).
Usually, the food that was to be wasted was collected by the local church food bank. However, during the COVID-19 lockdown period, their activities were also quite limited, and they could not successfully further use the meals. The unpicked meals were therefore regarded as biowaste (Sjk).
Higher packaging waste (Lpr, Tuu, Sjk).
Introduced solutions and other positive developments
Both the importance and the appreciation of school meals have increased during the COVID-19 pandemic (Sjk).
The staff has been healthier than normal because people have taken good care of distances, protection and hand hygiene (Sjk, Lpr).
The cooperation between the central kitchen and the schools has been strengthened (Sjk).
The staff has been very committed to their work, and there has been little reluctance to work (Lpr). The circulation of the staff raised up team spirits (Tuu).
In general, the amount of food waste generated in schools has decreased, strengthening collaboration with a third sector organization that would further distribute the un-picked takeaway meals for those in need. (Lpr), (Tuu).
Developed a new summer outdoor meal service for children (Tuu).

Source: conducted interviews.

TABLE 5 | Challenges and positive developments during COVID-19 in two Polish municipalities.

COVID-19 driven reported main challenges and problems
The problem with scheduling work for the canteen staff, limited by sickness and quarantines (Izabelin).
Uncertainty of the school opening times and work hours followed by an unpredictable number of pupils and lunches (Izabelin, Rybnik).
Strong fear of contamination and worries about keeping a hygienic regime in kitchens and work areas, additional stress for the staff (Izabelin, Rybnik).
Uncertainty of the number of pupils and lunches that have to be served led to organizational issues. It often was indicated as a reason for the higher food waste rate than usual (Rybnik).
The often changing numbers of pupils and times of lunch, as well as new regulations including special dining groups (children supported by social services, children of medical personnel), created logistic and operational complications (Rybnik).
Introduced solutions and other positive developments
Based on the high demand for a school meal that started to include adults, an online application for ordering takeaway lunches and serving food for the whole community—pupils and adults (in different price ranges) was created (Izabelin).
Strengthen communication between pupils' parents and the municipal staff (Izabelin).
Stronger sense of solidarity—during the lockdown the personnel started to make masks and aprons for the local community (Izabelin).
Serving food for smaller groups and diversifying the lunch breaks' hours led to a better atmosphere in the canteen, especially between the youngest pupils, as they more tranquility with less of the waste (Rybnik).
Higher hygienic education within all stakeholder groups, personnel, teachers, and pupils helped prevent disease spreading among many canteen staff members (Rybnik).

Source: conducted interviews.

special education, children and families of medical and social service employees, and law enforcement employees engaged in duties relating to the pandemic to ease the childcare burden on them. During the periods of school closures, the school canteens did not prepare meals. However, the school canteens that prepared meals also for kindergartens were constantly operating, as the daycare was operating normally.

School canteens applied different solutions to the numerous problems that arose during the pandemic (see **Table 5**). The serving times of meals were often changed, and pupils were frequently served in smaller groups to comply with the new sanitary regime and physical distancing requirements. In addition, pre-registration for meals was required to avoid waste. Additional lunch breaks were also organized, meals were served to the tables, and pupils were encouraged to always sit in the same place in the canteen.

Russia (Saint-Petersburg)

In Saint-Petersburg, Russia, schools were closed from mid-March 2020 until the end of the school year (end of May 2020). The spring holiday was then extended from 1 to 3 weeks (from the end of March until mid-April). This was followed by distance learning, which lasted until the end of the school year. Therefore, from March to May, school canteens were closed; however, food packages were supplied to all elementary school pupils (aged 7–10 years) and children from certain social categories (children from low-income families, families with three or more children, orphans, children with disabilities) who were entitled to fully subsidized school meals during the regular school year.

These packages were put together by catering companies and included foodstuffs such as oatmeal, buckwheat, rice, canned meat, chocolates, tea, and jam. School administrators and staff (School No. 126, School No. 249) worked with catering companies to hand out the packages twice a week to parents, who could collect them according to a schedule developed by school staff. If parents were unable to come to the school, the administrators delivered the packages to the pupils' homes (School No. 126). According to the schools' representatives, they received mostly positive feedback from parents; the packages were a significant help for parents who had lost jobs or were struggling financially during the 1st months of the pandemic.

Schools fully reopened in September 2020 and followed the very strict hygiene guidelines and regulations developed by the Federal Service for Surveillance on Consumer Rights Protection and Human Well-being (Rospotrebnadzor). The new regulations required a strict shift schedule, and pupils from each class had

TABLE 6 | Challenges and positive developments during COVID-19 in Saint-Petersburg schools.

COVID-19 driven reported main challenges and problems
Once reopened, schools had to add separate entrances and exits into the canteen, so more classes could get to the canteen during the breaks and not cross each other's paths (all schools).
Sometimes the food got cold while staff had to set a lot of tables during the break.
Menus of the free choice were canceled for the 2020/2021 school year. All elementary school students got the same meals according to 12-days menus developed by the Department of Social Nutrition. It was done in order to prevent long lines and mix-ups in the canteen during the breaks (No. 126).
Canteen staff was exhausted and had to overwork—earlier start, additional shifts, stricter rules, less time for breaks (No. 249, No. 126).
Introduced solutions and other positive developments
Increased hygiene. Pupils became more organized and responsible and washed their hands more carefully (all schools).
More automated process: teacher noted in computer system how many pupils were in class, and canteen staff set the tables based on this information. A No-cash system was further developed to pay for the meals.
The snack buffet was closed during the day and children got only hot and cooked meals, thus a healthier option. Before the COVID-19 times, the school also sold pastry and baked goods (prepared on-site) that children really liked, during the pandemic, the pastry was served only twice a week (No. 249).
Decreased food waste, resulting from fewer meal potions.

Source: conducted interviews.

to have meals at the same time and sit separately in the canteen. This led to extended lunch periods and strict monitoring of the new safety measures, such as sanitizers in the canteens, physical distancing, and a 30-min disinfecting process between the dining shifts. During the 2020/2021 school year, distance learning was only implemented when a whole class went into quarantine. Private schools also had to comply with the general Rospotrebnadzor rules and follow the same safety guidelines.

Canteen staff in elementary schools set the tables for pupils before the pandemic, and this process continued in the 2020/2021 school year. When pupils followed the school schedule and arrived in the canteens, the food was already on the tables, and they were not required to line up to get food or pay for meals. In School No. 126, only non-cash payments were allowed. Students used a special "student card" to enter the school at set times, and parents could load money onto these cards (or the government transferred the money if a student was provided with fully or partly subsidized meals). Teachers recorded how many students were in class and their lunch options; this information was then sent to the canteen staff so that they could accurately set the tables in advance.

Table 6 lists the main reported challenges in the Saint-Petersburg schools from March 2020 to March 2021; the positive developments are also listed.

Sweden

In Sweden, most primary schools were open throughout the pandemic. Some schools occasionally organized distant learning using several different systems: some pupils had 2–3 days of homeschooling per week (and the rest on campus), while others had homeschooling every other week. These measures were taken to reduce the number of pupils on school premises and minimize the risk of spreading COVID-19. By law, pupils have the right to school meals even when their learning is based at home (but not if the school is closed). However, regular homeschooling was primarily only used for pupils in upper secondary school (grades 10–12), although some lower secondary schools (grades 0–9) also implemented homeschooling during winter/spring 2021.

In spring 2020, the Swedish authorities announced that the measures developed to limit the spread of COVID-19 were affecting public meal services. This was primarily due to an increase in staff absenteeism and the rise in questions concerning the requirements for reduced congestion and infection control in public domains. The National Food Administration then mapped the pandemic's influence on the activities of meal services (Livsmedelsverket, 2021). Large scale organizations often need long lead times for meal preparation, and their processes were significantly affected by the expedited decisions from the authorities and management; for example, organizations had to adapt to the rapid changes in the number of people allowed in indoor spaces. Overall, catering services struggled to reorganize their systems at the management levels, and this contributed to a variety of problems, such as increased food waste.

In some Swedish schools, salad buffets were downsized, completely removed, or exchanged for ready-made salad plates; these changes reduced queuing, released time for kitchen staff, and limited the number of occasions when pupils shared serving utensils. To reduce workloads and manage staff absenteeism, menus were often modified to include fewer dishes or simplified recipes. In some schools, menus were made more flexible so that ingredients could be utilized in dishes that were not part of standard meal plans (Livsmedelsverket, 2021).

School canteens strengthened hygiene protocols to address infection control; the additional measures included increased use of disinfectants, control of handwashing, additional cleaning of surfaces, and frequent changes of the serving utensils. Textile cleaning cloths were replaced with spray bottles and paper towels. Schools also began to use additional spaces, such as classrooms, for dining. Moreover, the furniture in dining halls was reduced and markings on the floor were used to remind people to maintain physical distancing. The lunch periods were extended to ensure fewer pupils were in the canteen at the same time.

Food waste increased, especially at the beginning of the pandemic. The number of diners varied daily; therefore, it was difficult to predict the volume of food required. Several school canteens also noted that a large amount of food waste was connected to the introduction of lunch boxes for distance learning pupils, as many boxes were not picked up. During autumn 2020, pupils could collect a takeaway lunch box every day from the school canteen. The pick-up frequency was low; therefore, during spring 2021, kitchen staff reduced food waste by changing the meal program: once a week, pupils could collect a week's worth of chilled meals.

The pandemic response focused on issues related to crisis preparedness and provided an opportunity to review and test contingency plans in a real life situation (**Table 7**). Topics that

TABLE 7 | Challenges and positive developments during COVID-19 in Sweden.

COVID-19 driven reported main challenges and problems
Uncertainty about staffing and the number of meals.
Communication and decision-making were challenging in rapidly changing conditions.
At the beginning of the pandemic, there was a shortage of disinfectants, gloves, and disposable products.
Making pupils keep their distance from each other in food queues and at tables (and in the school as a whole) was an additional burden and challenge to the staff.
It was difficult to interpret the directives from the Swedish Public Health Agency guidelines for school canteens compared to regular restaurants.
Introduced solutions and other positive developments
If the shortage of staff occurred, either re-allocation of own staff or hiring professionals from the private restaurant industry, that suffered extensive lay-offs, took place.
Both sense of community in the kitchen (team-building), and cross-administrational cooperation increased.
Contingency plans were developed or improved if already existing.
Digital competence among the staff increased.
Increased hygiene and hygiene education.

Source: conducted interviews.

have been discussed include food storage, staffing during a crisis, non-delivery of supplies, and prioritization of tasks in the event of a staffing shortage.

The BSR Response to the Crisis

As presented in section School Meal Provision During the COVID-19 Pandemic in Reported Case Studies, all the studied countries, except Sweden, responded to two observable waves with complete or partial (hybrid systems) school closures. Regardless of their vastly different populations or COVID-19 occurrence rates, the studied BSR countries all faced a challenging period. The studied regions adopted similar methods when providing meals for contact learning pupils; the new systems were based around improved hygiene regimes and extended lunch periods. The primary differences were related to meal provisions during school closures, including when and how often a takeaway meal or its equivalent was offered. The studied BSR regions operate under a variety of regulatory and organizational models for food provision, and there were clear structural differences between the adaptations of their school meal programs in response to the COVID-19 crisis. However, this study recorded similar challenges and COVID-19 driven developments.

The key issues reported above were extracted using the word cloud algorithm that analyzes the frequency of words and word phrases. **Figures 4**, **5** visually present the joint findings from the BSR, the regional COVID-19 related problems and challenges, and the positive developments in the provision of school meals in the regions. The problems that were listed most often by the countries included unpredictable staff changes, uncertainty about potential school closures, and constant variation in the number of meals required. The working hours and stress levels of canteen staff were strongly interconnected and often increased. The communication between all of the actors involved in the school meal system—including canteen and kitchen staff and their managers, school officials, municipal authorities, food suppliers, parents, and pupils—were either problematic or caused distractions because challenging issues were amplified. Food waste, especially at the beginning of the lockdown, and packaging waste were common problems in the BSR countries. Furthermore, national regulations changed frequently, and the immediate actions that followed required extraordinary flexibility in terms of structures and processes. Physical distancing was also identified as difficult to organize and monitor.

The adaptations to the COVID-19 pandemic produced novel solutions to significant problems. The responses to the crisis led to a range of innovations and developments concerning people (canteen/kitchen staff, pupils, and community), places (canteens, schools, and kitchens), and products and processes (hygiene, meals, food waste, and food education). An important development was the increased awareness of hygiene, including pupils' hygiene education and behavior. Another key finding was the increased importance of the school meal during the crisis period. The health of canteen staff has generally improved because of the widespread use of hand sanitizers and the high standard of the new hygiene measures. Overall, the spread of many seasonal diseases has been minimized. Schools have reported that the highly organized lunch breaks have led to more pupils finishing their meals, especially younger children. The effort to reduce food waste during the COVID-19 pandemic also required significant attention. Steps were taken to minimize food waste following the unforeseen school closures in March 2020; these measures included redistributing unused meals/food products, collecting attendance data for accurate meal preparation, and establishing cooperative partnerships with third sector organizations. Following the COVID-19 pandemic, a number of innovations and developments are likely to become standard procedures: non-cash payments in canteens (RU), attendance records related to the canteen by class teachers (RU), outdoor meals during the summer (FI), commercialization of the school meal *via* a phone application (PL), digital training and meetings for canteen staff (multiple countries), frequent use of hand sanitizers and adherence to strict hygiene standards (all countries).

Public Procurement and Catering Services Response to the COVID-19 Pandemic

Public procurement and catering services in the BSR have a history of being well-organized and regulated. However, the COVID-19 pandemic presented a range of new challenges; for example, school meal services had to adapt to states of emergency, rapidly changing national regulations and ministerial decisions, and changing requirements of parents and pupils. Section Regulatory and Organizational Models of School Meal Provision presented the regulatory and organizational models of school meal provision while section Results outlined the different effects of the COVID-19 pandemic in the studied BSR countries;

FIGURE 4 | A word cloud for the reported BSR challenges and problems. Source: own analysis based on interviews.

FIGURE 5 | A word cloud for the reported BSR solutions and developments. Source: own analysis based on interviews.

this study also observed that the countries developed similar adaptations (see **Table 8**). Corresponding with the results of the reviewed literature (Kinsey et al., 2020; Parnham et al., 2020), this study observed that the provision of subsidized school meals and access to school meals in general were considered a matter of food security in the BSR region. The cost of a school meal during the COVID-19 pandemic varied; some regions were able to maintain their existing budgets, while for others the cost doubled. The factors that contributed to the rise in costs included packaging materials, additional work shifts that included weekends and evenings, and problems with food suppliers. A new role assigned to both on-site and centralized kitchens during the pandemic

TABLE 8 | COVID-19 pandemic effects on regulatory and organizational models of school meal provision.

Models of school meal provision	Generalized COVID-19 pandemic effect
Cost-sharing: fully subsidized	No changes in the full meal subsidies of school meals were observed. If operating under a fully subsidized model, the obligation to provide meals also for pupils in distance learning occurred (either immediately or after some time). The price of meals for the state or local authority in most cases increased. At the same time, variety of served meals decreased.
Cost-sharing: partially subsidized	From the parents' perspective, partial subsidies were also mainly unaffected, while the cost covered by the state/municipal authority could increase. Partial subsidies, in the case of distance learning, in practice might have resulted in no school meal. In contrast, the variety of served meals decreased.
Cost-sharing: not subsidized	No subsidies, in the case of distance learning, in practice might have resulted in no school meal. The variety of served meals decreased.
Cost-sharing: mixed model	Mixed models, in the certain cases, resulted in specific groups of pupils receiving takeaway meals during the school closure. Provision of meals for pupils in contact learning continued, often with less served options.
Organizational: in-house	In the in-house organizational model, staff circulation was observed in order to avoid lay-offs. Such practice affected better internal communication and understanding of others responsibilities. Increased communication with local authorities and parents.
Organizational: contract catering	Contact catering model was in higher risk of personnel lay-offs, especially at the beginning of the pandemic. Communication with local authorities and parents increased.
Manufacturing and delivery: On-site kitchen	During the school closure, on-site kitchens were either closed or operating in a strongly modified environment to prepare takeaway meals and packages. On-site kitchens were a popular pick-up point for the takeaway meals.
Manufacturing and delivery: Central kitchen	Central kitchens were mainly open through the pandemic. The meals were prepared (often in modified conditions and methods) and then distributed to the schools or picked by parents directly.
Methods: Cook and serve	In open schools, the cook and serve cooking method was used with small modifications such as limited choice, longer lunchtime or meal served on the plate and table instead of a buffet. Cook and serve method was not adequate for takeaway meals.
Methods: Cook and chill	Cook and chill model was used both to prepare meals for contact and distance learning.
Methods: Cook cold	In order to prepare takeaway meals, additional phases had to be added: cooking, chilling and freezing. This extension required a set of modifications in the kitchen, e.g., additional ovens and space for chilling.

Source: own analysis.

was to serve as a pick-up point for takeaway meals. At the same time, staffing issues were also reported, such as temporary lay-offs, redeployment to other municipal services, and additional shifts and cleaning requirements.

The results revealed a strong sense of duty to provide a nutritious meal to children, especially during the COVID-19 pandemic. This finding advocates for the role of public procurement and catering services in addressing food insecurity (McLoughlin et al., 2020b; Borkowski et al., 2021).

The Rise of a Takeaway School Meal Model

In response to the COVID-19 pandemic and the ensuing school lockdowns, school nutrition programs in the BSR countries developed innovative ways to secure safe access to nutritious meals. Based on different national and regional examples, this paper outlines the takeaway model for school meals that evolved under COVID-19 pandemic conditions. Before COVID-19, a takeaway school meal was regarded as an unhealthy fast-food style meal that children obtained independently (Patterson et al., 2012). This paper offers a new definition of a takeaway school meal as an innovative and nutritious meal that supports a community. The takeaway school meal model, presented in **Figure 6**, is described using four main features: meal provision, accessibility, distribution, and the generation of food waste.

The first distinguishing feature of the takeaway school meal concerns the meal itself, whether pupils were offered a ready-made meal (to be re-heated or cooked) or a package of food products to prepare at home. In the latter case, the meal's nutritional value was supported by a greater variety of foodstuffs, which represented all the basic nutritional categories: cereal and bread, dairy, vegetables, fruit, and meat. The package size was adjusted to the times of the weekly pick-ups. When served as a pre-prepared nutritious meal, whether frozen, chilled, or hot, the portion size was also unified, and thus, in general, increased to meet everyone's needs. However, these meals often did not include sides, such as bread or salads. Additionally, the freshness of the food products in the lunch packages was also questioned when the ingredients were used to prepare meals later in the week. During the studied period from March 2020 to March 2021, pupils could not select the types of takeaway meals they received. However, several municipalities are planning to include vegetarian options in the future. Overall, schools were able to account for known and documented special diets in the meal planning (e.g., food allergies).

The second fundamental characteristic of the takeaway school meals was the variable conditions of availability; for example, the provision of meals could be based on socio-economic statuses, a prior application, or a universal distribution without pre-conditions. In the early stages, pupils could be dropped from the application list if, for example, meals were not collected on a number of occasions. In one particular region, the school meal became a commercial meal, offered with a range of prices, that pupils and adults could order *via* a mobile application.

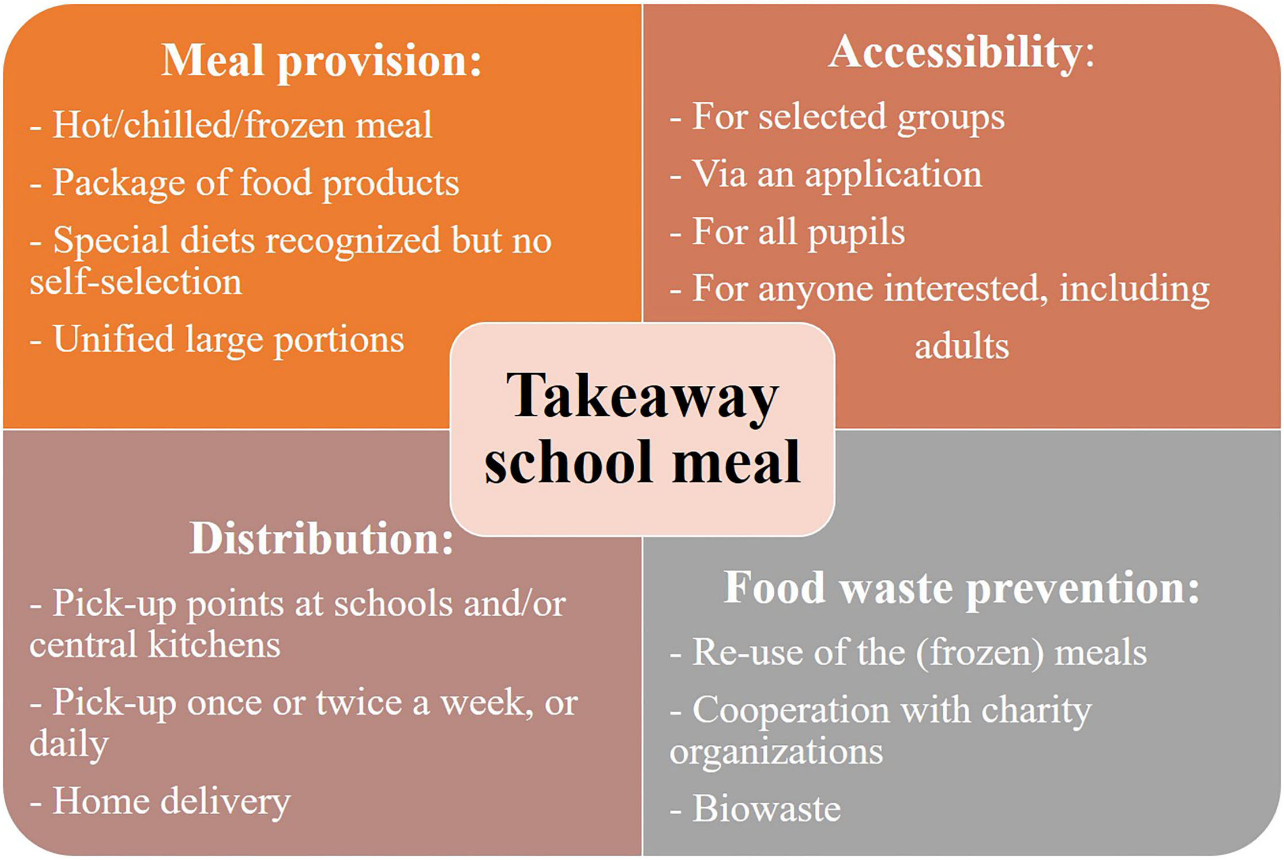

FIGURE 6 | The characteristics of the takeaway school meal model evolved during the COVID-19 pandemic in the BSR countries. Source: own analysis based on interviews and collected data.

The meal distribution was generally organized as a pick-up from school premises, and/or, if available, from a central kitchen. The pick-up frequency varied from daily to weekly. Takeaway school meals were sometimes delivered to pupils' homes; however, this option was only applied under certain conditions and was rarely used.

Finally, food waste generated by the takeaway meals was avoided or decreased *via* two methods. First, unclaimed meals were often donated to charity or, if possible, offered again at the next available pick-up. Meals that were not consumed were then collected separately as biowaste. Second, it was assumed that the large meal portions would be shared with other family members, and at least one region noted that parents had openly complimented the food. However, organizations should record more accurately the volume of food waste that is produced when using the takeaway meal model.

FURTHER DISCUSSION AND CONCLUSIONS

The provision of school meals has a definite impact on the nutritional status of children and adolescents; therefore, there is a requirement to provide healthy and well-balanced meal options. In addition to nutritional value, the provision of school meals can extend pupils' nutritional knowledge and skills (Frobisher et al., 2005). Scholars have analyzed the school meal from the paradigm of multi-level social interaction and social learning, where the satisfaction derived from a meal is a complex process that includes taste, nutritional values, atmosphere, and canteen organization (Lülfs-Baden and Spiller, 2009; Berggren et al., 2020). Further research is required to define how the COVID-19 pandemic has influenced the provision of school meals from the perspective of pupils' satisfaction. During the study period, the provision of school meals, as described in this paper, differed both nationally and regionally and often evolved over time in response to changing conditions and regulations.

This paper has focused on the organizational aspects of school meal provision during the COVID-19 pandemic. More specifically, *why* and *how* pupils received their meals during both the school lockdowns and the periods of contact teaching was analyzed. The national differences originated from high-level ministerial decisions, yet there was also a unified need to apply the restrictions and recommendations in a short time frame. The sustainability adaptations of catering services were supported by the reported actions to prevent food waste and the sense of social responsibility to provide a nutritious meal (Mikkola and Post, 2012; Post and Mikkola, 2012), and this study found that these factors retained their importance during the COVID-19 crisis. The COVID-19 pandemic required numerous rapid adjustments and extensive changes to well-established food services in schools and other educational institutions worldwide. All of the actors within the sector (schools, caterers, and suppliers) had to acquire new skills to manage the rapidly changing conditions and emerging challenges. In several BSR countries, schools provided meals even when it was not legally required (e.g., early in the pandemic in Finland and Poland); this voluntary provision of meals acknowledged the social importance of the public procurement and catering services and their positive impact on well-being. This paper also, indirectly, presents public procurement and catering services (especially those operating in small and centralized units) as dynamic, flexible, and reliable organizations that value pupils' welfare. Finally, the COVID-19 pandemic provided a significant opportunity to acquire new knowledge and skills for the actors involved in the provision of school meals. The experiences gained during this period of rapid change could also lead to future developments that are more flexible, mobile, and innovative. In addition, the open appreciation of school meals has been a positive social impact of the COVID-19 pandemic, and it has directed attention toward the importance of the preparatory processes and primary stakeholders.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

The work was led and directed by UA-K, its foundation was developed during meetings with RG-W, RK, EP, EF, AP, and MM. All authors contributed to the analysis and writing and the data collection in their own country (i.e., *EE*—EP, *FIN*—UA-K and MM, *PL*—RG-W and RK, *RU*—EF and VM, *SE*—AP), contributed to the manuscript editing, and have approved its final form.

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SUPPLEMENTARY MATERIAL

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Corrigendum: COVID-19 Driven Adaptations in the Provision of School Meals in the Baltic Sea Region

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Keywords: school meal, COVID-19 pandemic, Baltic Sea Region, takeaway meal, social innovation, crisis management, school closure, distance learning

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European Food Systems in a Regional Perspective: A Comparative Study of the Effect of COVID-19 on Households and City-Region Food Systems

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The concept of the city-region food system is gaining attention due to the need to improve food availability, quality and environmental benefits, for example through sustainable agri-food strategies. The COVID-19 pandemic has reinforced the importance of coherent and inclusive food governance, especially regarding food resilience, vulnerability and justice. Given that evidence from good practices is relatively sparse, it is important to better understand the role of different types of cities, regions and household characteristics. The paper's aim is to describe, analyze and attempt to explain (sub-national) regional variations of household food behavior before and during the first wave of COVID-19 in 2020 using a city-region food system perspective. Informed by the literature, comprehensive survey data from 12 countries across Europe is used to describe the pre-pandemic landscape of different household food behaviors across comparable regional types. We examine how a specific economic and social shock can disrupt this behavior and the implications for city-region food systems and policies. Conclusions include the huge disruptions imposed on income-weak households and that the small city scale is the most resilient. Proposals are made that can strengthen European city-region food system resilience and sustainability, especially given that future shocks are highly likely.

Keywords: regional analysis, COVID-19, food behavior changes, crisis resilience, city-region food systems, income loss

INTRODUCTION

Context, Research Aim, and Structure of Paper

Given that about 75% of the EU's population now resides in urban areas (Macrotrends, 2021), city-region food systems play a crucial role in meeting the challenges besetting the European food sector. Although integrated city-region food system policies across most of Europe are still scarcely developed, with actors operating outside of local production and consumption spheres and at higher governance levels (Sonnino et al., 2019), the COVID-19 crisis has revealed a need for more local approaches to food governance (Blay-Palmer et al., 2021; Morley and Morgan, 2021; Zollet et al., 2021) and for taking into account the socio-economic determinants of food behaviors, in order to build a more equitable food system (Cohen and Ilieva, 2021).

On the other hand, even though inequalities between population groups within cities and their hinterlands, as well as growing differences between cities themselves (Nijman and Wei, 2020) also related to food provisioning (Keeble et al., 2021), existed before COVID-19, the system shock has further exposed and exacerbated them (Zollet et al., 2021). It has moved actors to take actions starting from a perspective much more grounded in local food systems and the agency of different actors (Lever, 2020; Schoen et al., 2021; Vittuari et al., 2021). Moreover, the pandemic has stimulated a wealth of literature concerned with its effects on food systems and consumer behavior.

The concept of a city-region food system as a system of *"actors, processes and relationships that are involved in food production, processing, distribution and consumption in a given city region"* (FAO, 2016) provides a definition from a socio-economic perspective. This enables their exploration through the lens of the Eurostat classification of territorial typologies, which relies on the assumption that most economic, social and environmental situations and developments have a specific territorial connotation (Eurostat European Commission Statistical Office of the European Union, 2018).

The aim of this paper is to describe, analyze and attempt to explain (sub-national) regional variations of household food behavior before and during the first wave of COVID-19 using a city-region food system perspective. Informed by the literature, comprehensive survey data from 12 countries across Europe is used to describe the pre-pandemic landscape of diverse household food behaviors across comparable regional types, and then how the pandemic has disrupted this behavior and the implications this has for city-region food systems and policies.

The paper examines the issues described above from a regional perspective through the following structure. First, Section Introduction presents the aims of the paper, outlines the context, provides a literature review and proposes a conceptual framework. Section Materials and Methods describes how the survey data was designed, collected and analyzed, the basic definitions and approaches used and the representativeness of the samples. Section Results presents the results of the analysis around four main topics: (1) COVID-19 restrictions on household income and health; (2) Local food environments: where households shop and eating outside the home; (3) Social context: the amount of food, money and stocking up, food preparation at home and food vulnerability; and (4) Food consumption and diet: types of food consumed, special dietary needs and environmental issues. Finally, Section Discussion links these four topics together with existing literature and state-of-the-art knowledge in the context of the conceptual framework to suggest likely explanations of the results obtained. Focus is on the key responses and adaptations needed to external shocks taking account of ongoing trends toward the re-regionalization of European city-region food systems, how they can be made more resilient and sustainable, as well as the role of spatially heterogeneous food policy and governance arrangements within the city-region food system context.

Literature Review

Food Systems, Governance, and Policy

There are numerous recent studies on the policies and governance of food systems especially in a city-region food system context since the outbreak of the pandemic. These include a special issue of the Food Policy journal in August 2021 on "Urban food policies for a sustainable and just future". In the introductory editorial, Moragues-Faus and Battersby (2021) identify three core perspectives in urban food governance scholarship: a shift toward systemic engagement with food systems; increased engagement with scalar complexity; and a growing focus on relational aspects of urban food governance and policy-making dynamics. Their analysis also points out three key aspects that require further focus for the field to be transformative: a stronger conceptualization of the urban; a clearer definition and articulation of the nature of governance and policy; and a more engaged focus on issues of power and inequities. In the same issue, Cohen and Ilieva (2021) show how policy makers are starting to acknowledge that the food system is multidimensional, that social determinants affect diet-related health outcomes, and the need to move away from focusing food programs and policies narrowly only on food access and nutritional health. Thus, the boundaries of food governance are expanding to include a wider range of issues and domains not previously considered within the purview of food policy, like labor, housing, and education policies.

There is clear evidence that households already experiencing some food poverty were pushed to an even greater extent to a reliance on charity and food banks. Capodistrias et al. (2021) show that, compared to 2019, in 2020 European food banks redistributed a significantly higher amount of food despite numerous social restrictions and other challenges associated with the pandemic. This was made possible by organizational innovations, new strategies and new internal structures in the food banks, as well as the establishment of new types of external network relations with other firms and/or public organizations. In relation to urban food policy governance, Parsons et al. (2021) point to the importance of institutions as policy-structuring forces, the need to rebalance national-local powers and to develop cross-cutting food plans. Clark et al. (2021) emphasize the role of community food infrastructures and the importance of critical middle infrastructures to connect production with consumption and larger markets, thereby building resilience through intermediate markets. The overall thrust of this literature is about the importance of linking urban food policies with other urban policies, new types of place leadership for example through the anchor institutions and middle infrastructures of community-wealth building and "new localism" initiatives (Millard, 2020).

The importance of the sustainability of city-region food systems inevitably turns attention to the topic of short food supply chains (SFSCs), which are associated with extensive good practice evidence related, e.g., to re-connection of food producers with consumers (Grando et al., 2017), social sustainability (Vittersø et al., 2019), or building transparent food supply chains with the fair distribution of power among actors (Kessari et al., 2020). In addition, SFSCs are associated with the production of quality and safe food when consumers buy products from trusted suppliers who are able to guarantee genuine and safe products, not necessarily located nearby (Baldi et al., 2019). Pandemic experience has highlighted the vulnerability of globalized agri-food systems as well as societies in the relatively developed world, to which the research is already responding. Matacena et al. (2021) see this situation as an opportunity to strengthen the sustainability agenda, e.g., by pursuing the *Farm to Fork strategy* of the EU and thus, enhancing the resilience of regional and local food systems and empowering consumers to make informed food choices. Murphy et al. (2021) mention the importance of local food supply chains for supplementing the global market and ensuring normal product flow during emergencies, whilst Vidal-Mones et al. (2021) propose strengthening independence in the form of support for local and seasonal consumption.

An extremely short food supply chain is represented by home food gardening, which tends to be neglected by most food systems research and policies but remains relatively widespread across European countries and regions as Vávra et al. (2018b) and Jehlička et al. (2021) show. The habit of growing one's own food as well as available land (e.g., home, allotment, weekend home, and community garden) are important elements of sustainable food systems. For example, gardening households in Czechia produce 33% of their own consumed fruit, vegetables and potatoes (Vávra et al., 2018a), whilst 20% of fruit and vegetables consumed by all Czech households is grown at home (Jehlička et al., 2019). This figure includes non-gardening households which receive some food from their food-producing relatives, friends or neighbors. Edmondson et al. (2020) investigated individual crop production in Leicester city, UK, by monitoring production in 80 different self-provision locations through a citizen science project showing that average crop yield increased by 2.3 ± 0.2 kg m^2. The authors combined these results with GIS data to upscale their findings across the whole city and found that "total fruit and vegetable production on allotment plots in Leicester was estimated at 1,200 tons of fruit and vegetables and 200 tons of potatoes."

McEachern et al. (2021) point out that "*while existing literature has predominantly focused on larger retail multiples, we suggest more attention be paid to small, independent retailers as they possess a broader, more diffuse spatiality and societal impact than that of the immediate locale. Moreover, their local embeddedness and understanding of the needs of the local customer base provide a key source of potentially sustainable competitive advantage*" and thus help underpin both urban and community resilience. Finally, Vittuari et al. (2021) document how the COVID-19 pandemic unveiled the fragility of food sovereignty in cities and confirmed the close connection urban dwellers have with food and suggested how citizens would accept and indeed support a transition toward more localized food production systems. The paper proposes the reconstruction and upscaling of such connections using a "think globally act locally" mind-set, engaging local communities, and making existing and future citizen-led food system initiatives more sustainable to cope with the growing global population.

Household Responses to the Pandemic

At the household level, a large amount of literature has already examined the impact of COVID-19 on food systems and consumer behavior. In a survey of households in Denmark, Germany and Slovenia, Janssen et al. (2021) found that between 15 and 42% of households changed their food consumption patterns during the first wave of COVID-19 and that this was related to the closure of physical places to eat outside the home, reduced shopping frequency, individuals' perceived risk of COVID-19, income losses due to the pandemic, and socio-demographic factors. A meta-analysis of COVID-19 induced changes in food habits in Italy, France, Spain, Portugal and Poland indicated the generally negative effect of quarantine on eating habits and physical activity with an increase in food consumption and reductions in physical activity and consequent weight gain (Catucci et al., 2021). Some psychologically oriented studies point out the potential increase of negative psychological aspects during the pandemic, like panic buying, herd mentality, changing discretionary spending, especially during first signs of disaster (Loxton et al., 2020).

Regarding diets, the results of several studies vary across countries, regions and also economic groups of inhabitants. Profeta et al. (2021) show that the pandemic has a significant impact on consumers' eating habits in Germany. The purchase of ready meals and canned food increased, including the consumption of alcohol and confectionery, at the same time as there was a decrease in the purchase of high-quality and more expensive food like vegetables and fruits especially by economically vulnerable groups (income-loss households and with children). This study warns about negative health consequences if the trend continues. In contrast, research conducted in Spain (Rodríguez-Pérez et al., 2020) shows the opposite trend and a move toward Mediterranean diets and thus healthier dietary habits. The authors examine dietary behavior in Spain, including the differences between 3 large regions (north, central, south), and noted that adherence to the Mediterranean diets before and during COVID-19 was significantly influenced by the region, age and education level, being highest in the northern region. Households' responses to COVID-19 can be observed not only in consumption but also in food production. Recent research shows how variable the effect was. On one hand the anti-pandemic travel limitations and gardeners' health concerns have led to lower frequencies of visits to allotments in some cases (Schoen et al., 2021), whilst on the other hand gardens were seen as a safe space, other leisure activities were restricted and food concerns increased too. According to some studies this led to more time spent in the gardens and more people growing their own food (Mullins et al., 2021; Schoen et al., 2021).

Regional Perspectives

Although not directly focused on food systems, there are relevant sources that examine the impact of COVID-19 on cities and regions. The EU's Committee of the Regions 2020 report examined the territorial dimensions of COVID-19 across the EU and showed that, although government responses were largely national, they resulted in very different regional impacts. The socio-economic asymmetry of consequences across Europe, countries, regions and cities is largely shaped by diverse regional characteristics that call for higher levels of place-sensitive policy responses, taking into account a region's economic structure, structural challenges, and social profile. Although much of the analysis is focused on specific regions rather than regional types, the findings show both that, because COVID-19 responses vary so much, the usual urban-rural differentiation does not apply, but that also metropolitan areas have generally been strongly hit but also tend to experience quicker recovery (European Committee of Regions, 2020). Sharifi and Khavarian-Garmsir (2020) report that cities that don't have a diverse economic structure are more vulnerable to COVID-19. For example, in Poland, cities going through trans-industrialism, with hard coal mining, large care centers and shrinking cities, are the most vulnerable ones. Whilst the evidence is mainly on the negative impacts, more positive developments are also seen, for example COVID-19-induced transportation restrictions and border closures have disrupted food supply chains in cities but have in turn provided additional momentum to urban farming movements. It is expected that more attention will be paid to local supply chains in the post-COVID-19 era. There are also successful cases of social innovation and collaboration, such as in Naples where efforts have been made, through volunteering programs, to get people involved in local practices that contribute to meeting local food demands and also strengthen social ties during the pandemic (Cattivelli and Rusciano, 2020).

Although there appear to be few systematic studies on the regional food systems, an important Czech study undertaken before COVID-19 by Spilková (2018) looked at whether alternative food systems (AFN, covering farm markets, street markets, cooperatively owned or solidarity shops, specialist organic food outlets and buying food directly from the producers) attract significantly different consumers in different regions than traditional forms and large-scale outlets. Results showed that consumer choices arise from a mix of lifestyle, socio-economic determinants and contextual factors, that "*similar people with similar lifestyles 'cluster' within the same localities*" and there is a need to take account of "*'objective' (areal) variables within a given geographical area and settlement system context (p. 189)*".

To better understand processes and relations within different regional types, it is useful to consider the three stages of the urbanization process and how these can repeat themselves (Aleksandrzak, 2019; Mitchell and Bryant, 2020):

1. *Initial urbanization* accompanies the shift from an agrarian to an industrial factory-based society and sees growth concentrated in urban cores.
2. This is later followed by a *suburbanization* stage during which growth occurs beyond the urban core, at the expense of the core's population as new forms of efficient transport allow the better-off to move out of the center to new suburbs.
3. The final *counter-urbanization* (or de-urbanization) stage sees the growth of smaller cities and towns in nearby areas beyond the built-up suburban ring and is accompanied by population decline in the core and its immediate suburbs.

The cycle can re-start with a re-urbanization stage that sees new growth back in the original urban core, driven by the inward movement of both counter-urbanite and suburbanite populations. Many metropolitan regions, particularly in advanced economies, experienced a counter-urbanization period in the past, for example in the early 1970s. Since then, parts of this cycle have repeated themselves especially in the last 20 years but through somewhat different processes, this time driven by globalization and enabled by digital technologies leading to the counter-urbanization we are currently experiencing. These distinct metropolitan cycles, often reflecting at the regional scale an inverse relationship between population growth and city size, are also charted by Cividino et al. (2020) with metropolitan growth being highly positive before 2000 but declining progressively in the subsequent decades. The 1990s were a transitional period away from a spatially homogeneous demographic regime based on high rates of population growth strictly dependent on city size, to the regime we largely see today grounded on low rates of population growth varying over space. This seems synonymous with Mitchell and Bryant's counter-urbanization phase and the growth of smaller cities.

According to KPMG (2021), COVID-19 has accelerated this move toward the growth of smaller cities through the adoption of online shopping, working from home and online gatherings rather than meeting in person in cities and towns in England. KPMG predict that people are unlikely to return to the old ways of doing things. With fewer people coming into very large cities to work and shop, that leaves a big space in areas that were once characterized by bustling shops and offices. Those places that are most at risk are those that have little else to attract locals and visitors from further afield. In these cities there has been a loss of commuter flow from over a tenth to under a third of commuter footfall seen pre-COVID. Apart from the largest, mainly capital, cities like London, the authors contend that it is unlikely there will be a return to old commuting habits in most very large cities, with a significant proportion of those able to work from home doing so for at least part of the week or shifting to working closer to home in smaller cities. This is likely to lead to significant reductions in office space in large cities and a collapse in their central retail areas.

Conceptual Framework

In this paper we focus on the locational characteristics and spatial dynamics of household food behavior, both before and during COVID-19 within a European city-region food system context.

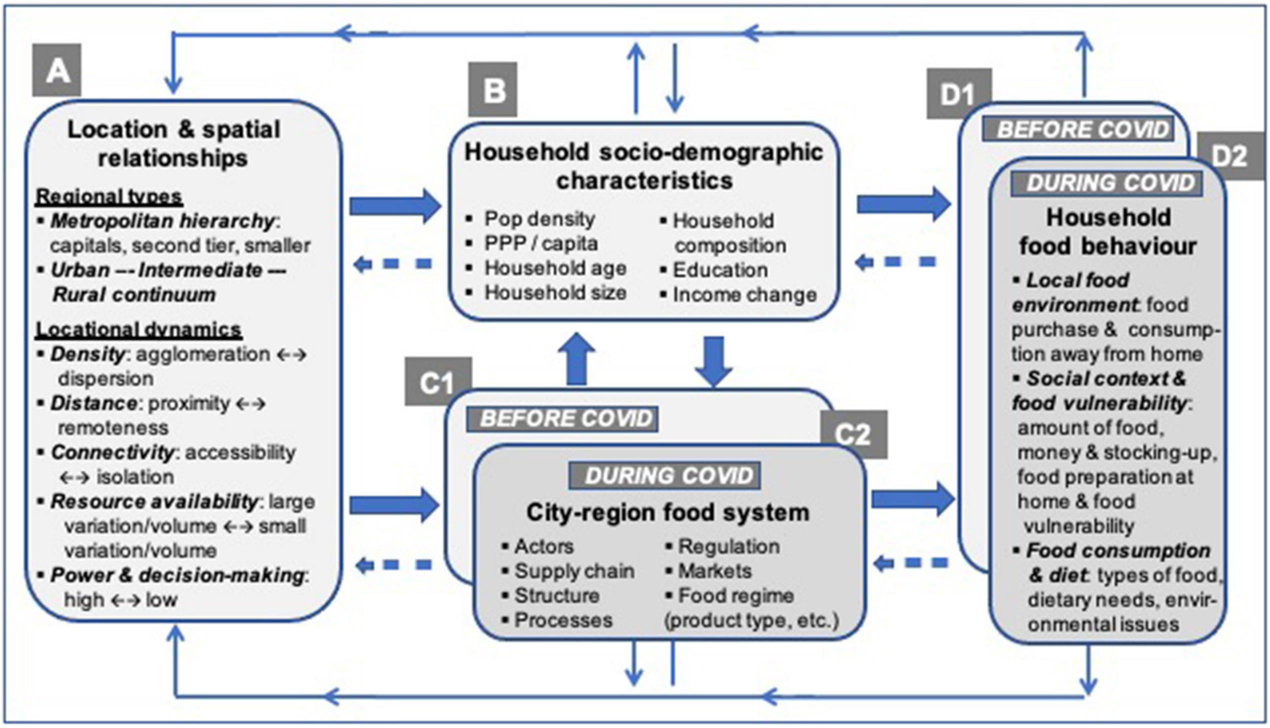

FIGURE 1 | Conceptual framework of potential relationships between regions, household characteristics and city-region food systems and their influence on food behavior before and during the pandemic.

This is expressed through the six regional types specified in **Figure 1** box A and defined in detail in Section Sample and Data Analysis. Box A also summarizes the five main locational characteristics that we propose underpin the differences between the six regional types relevant for city-region food systems.

Box B in **Figure 1** summarizes the socio-demographic characteristics of households examined in this paper. Box C1 outlines the main characteristics of city-region food systems before COVID-19 which are likely to interplay with Box B and then together shape the specific elements of household food behavior examined in the paper in Box D1. (This paper only focuses on the parts of the food system that directly interface with consumers.) Most of the literature draws a clear causative link between Boxes B and C acting together, on the one hand, and Box D on the other (for example Janssen et al., 2021), and our paper will also touch on these relationships. However, the main proposition is that much of the significant unevenness through space of Box B's socio-demographics and Box C's food system can itself be directly linked to, and in some cases determined by, the type of region in Box A in which the household is located. (Note that an accompanying proposition could, of course be, that much of the households' socio-demographic variation, in addition to regional characteristics is also related to national characteristics, including food history and culture, and to the relative geographic position of each country in Europe, across which climate zones, soils and food systems vary. However, this proposition is not pursued in this paper but might be tested in follow-up research.) The expectation is that the influence of Box A on Boxes B and C is not deterministic at the micro scale of individual households or food systems. But, at the macro aggregated scale, of which we have taken a valid sample (see Section Methodology Flow Chart below), clear spatial effects determined by the regional types can be expected (for example, see Eurostat European Commission Statistical Office of the European Union, 2020).

Thus, we expect that location has an important influence on household food behavior, both *via* the household's socio-demographic characteristics as well as *via* the structure and processes of the city-region food system itself. We might also expect that a sudden and severe shock, like that occasioned by COVID-19, will significantly change Box C1 to Box C2, and that C2 together with B, both shaped by A, will lead to a new pattern of household food behavior in Box D2. In the context of the city-region food system, this paper attempts to analyze and explain many of these influences and relationships given that cities vary down the metropolitan hierarchy and that they are embedded in different regional milieus along the urban-intermediate-rural continuum. We will then propose actions and policies needed to strengthen European city-region food system resilience and sustainability.

MATERIALS AND METHODS

Methodology Flow Chart

Figure 2 outlines the main steps in the overall methodology of this paper, commencing with data collection design and implementation based on an online questionnaire accessible

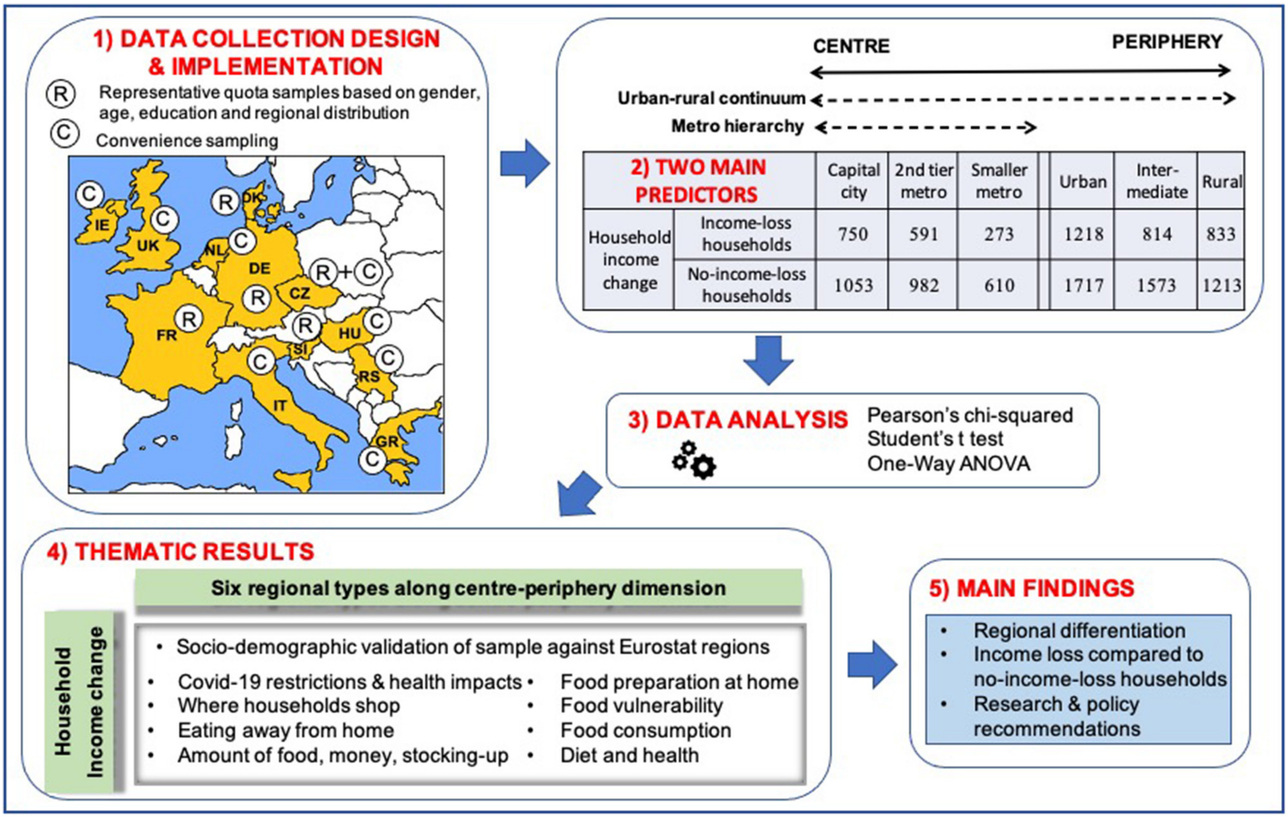

FIGURE 2 | Methodology flow chart.

via a dedicated website (https://www.food-covid-19.org/) and available as part of the **Supplementary Material**. This was designed to capture the changes in respondents' behavior in relation to food provision, preparation and consumption, as well as experiences of COVID-19-related illness, regulations and closures. Ancillary information was also collected on household socio-economic characteristics, including respondents' postcodes which were subsequently allocated to NUTS-3 regions using Eurostat conversion tables that also provide data on the regional types used in this paper. Exactly the same questions were used in each country's questionnaire, translated from the master English version by local partners. Where useful, national names of, for example, the specific types of big and ordinary supermarkets, discount and other shops in questions 2–4 were added in order to maximize data comparability between countries. A dataset was constructed based on twelve countries for further analysis—see Section Sample and Data Analysis on the sample used.

In order to meet the aims of the paper and drawing on existing literature, Step 2 illustrates the two main regional typologies along the geographic center-periphery: a metropolitan hierarchy consisting of capital cities, second-tier metros and smaller metros; and an urban-intermediate-rural continuum – see Section Regional Typologies below. Step 2 also shows the two main predictors (independent variables) deployed in the analysis—the six regional types and whether households lost income during the first wave or not. Step 3 of the methodology flow chart indicates the main statistical methods used—see Section Sample and Data Analysis. Step 4 outlines how the results section of this paper is structured in Section Results. Finally, step 5 shows how the discussion part of the paper in Section Discussion is structured, drawing upon all previous steps.

Sample and Data Analysis

The evidence base consists of online survey data from twelve countries with a good representation across Europe's varied food systems, food cultures, political systems, economic conditions, agricultural practices and climate zones: Czechia, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Serbia, Slovenia and the UK. The sampling of respondents combined two methods. First, representative quota samples of respondents based on gender, age, education and regional distribution (data collection by market research agencies), and second convenience sampling by which respondents were contacted largely *via* social media, although local researchers in these countries did attempt to reach out to all groups in all parts of the country. Questionnaire responses considered invalid and thus excluded were those where respondents took <5 min to answer or where they had responded incorrectly to attention-check questions in different parts of the questionnaire. This together resulted in responses from at least 100 households

TABLE 1 | Sample.

Country	Sampling method	Sample size (*N*)
Czechia	Combined (representative quotas and convenience)	805
Denmark	Representative quotas	1,281
France	Representative quotas	644
Germany	Representative quotas	1,020
Greece	Convenience	539
Hungary	Convenience	720
Ireland	Convenience	595
Italy	Convenience	538
Netherlands	Convenience	122
Serbia	Convenience	107
Slovenia	Representative quotas	683
United Kingdom	Convenience	314
Total		7,368

in each country yielding 7,368 responses in total (see **Table 1** for overview).

Data was collected from March to July 2020. While the research network consisting of researchers from many countries needed to be established rapidly, not all of them were able to quickly ensure enough funding for representative sampling and data collection. As mentioned, in some cases, market research agencies were hired but funding was restricted so the quota sampling and data collection were accompanied by convenience sampling. We are aware that countries relying on convenience samples are not fully representative of the respective national populations and thus there would be limitations if we were to analyze the data on a country-by-country basis. However, as we do not provide such national comparisons in this paper but instead focus on Eurostat's general regional typology with the lowest number of respondents in any regional type at 883 out of a total of 7,368 respondents from 12 countries, we provide important insights into the households' food-related behavior during COVID-19. In addition, Section Regional Typologies shows that, in terms of socio-demographics, our sample does closely mirror the different regional types as described by Eurostat European Commission Statistical Office of the European Union (2020, p. 22). Thus, from a regional perspective we are confident that the results are valid and meaningful.

The data collected by market research agencies and researchers in individual countries were merged into a large dataset of respondents from all 12 countries. IBM SPSS and MS Excel software were used for data management and analysis. As the aim of the paper is to present a geographical perspective on a wide variety of food-related behavior of households we mostly used chi-square analysis and adjusted residuals to compare the differences between the types of regions (and of the effect of income loss). Student's *t*-tests and One-Way ANOVA were also used where appropriate, as indicated in the **Supplementary Material**. More detailed and sophisticated statistical analysis focusing on selected behaviors is planned in future.

Regional Typologies

Table 2 shows the two main regional typologies along the center-periphery regional dimension, their Eurostat-derived definitions and the sample sizes of usable validated data.

Household Socio-Demographic Characteristics

Table 3 provides data on the main range of socio-economic and demographic variables of the sample along the six regional types of the center-periphery dimension. Overall, as shown below, the sample is close to the whole population of these regions as described by Eurostat. Given the importance of income loss (which does not necessarily mean complete "loss" of income but any decrease) due to COVID-19 or anti-pandemic measures, data for income-loss and no-income-loss are presented separately where appropriate.

In **Table 4**, comparisons are made between Eurostat's summaries of the whole regional population (Eurostat European Commission Statistical Office of the European Union, 2020, p. 22) with the sample taken in our survey, showing that the latter is largely representative of the former. (Note: a description of "urban" is not provided by Eurostat given it represents an approximation of all metros combined).

Table 4 demonstrates both that regional differences are statistically significant and that our sample is largely representative of the total population of regions, with only two noteworthy differences. In comparison with Eurostat's characterizations, these are that the sample's percentage of single households in capital cities is lower, and that the sample's mean household age in smaller metros is higher than in intermediate and rural areas generally.

RESULTS

In this section, a number of results are presented and commented showing different aspects of food behavior by comparing before with during the first wave of COVID-19 and how this behavior has changed during the pandemic. This is undertaken from the center-periphery perspective collectively across the 12 countries of the sample using the two regional typologies of the metropolitan hierarchy and the urban-rural continuum. Figures are presented based upon the data provided in the **Supplementary Material**, which also indicates their statistical significance. All results commented below are statistically significant unless otherwise stated. It is important to note that the vertical scales within each figure are configured differently to demonstrate the specific regional variations involved. If all scales were standardized, the illustrative power of many figures would be lost, making them redundant and the alternative would be large data tables. Most figures are in percentages and, unless otherwise stated, this refers to the proportion of households in a given regional type that either: (i) behaved as described by the given variable; (ii) or changed the behavior described either by an increase or decrease overall; or (iii) expected that this behavior

TABLE 2 | Regional typologies along the center-periphery regional dimension.

Regional categorization	Regional type	Sample size (*N*)
Metropolitan hierarchy (Sample size: 4,259)	*Capital city metros*: NUTS level 3 regions where at least 50% of the population live in functional urban areas of at least 250,000 inhabitants.	1,803
	Second tier metros: are the group of largest cities in the country excluding the capital.	1,573
	Smaller metros: a fixed population threshold could not be used to distinguish between second tier and smaller metros (as each country is different), so a natural break in metro population sizes is used in each country.	883
Urban-rural continuum	*Predominantly urban regions* (NUTS level 3 regions where at least 80% of the population live in urban clusters)	2,935
(Sample size: 7,368)	*Intermediate regions* (NUTS level 3 regions where between 50 and 80% of the population live in urban clusters)	2,387
	Predominantly rural regions (NUTS level 3 regions where at least 50% of the population live in rural grid cells)	2,046

(1) These definitions are taken directly from the Eurostat categorizations across the whole of Europe where further details are given: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Regional_typologies_overview#Urban-rural_typology_including_remoteness. The last date this document was edited by Eurostat was 3-11-20 and is now marked as archived as it appears the metropolitan hierarchy typology is no longer actively in use, but NUTS-3 categorizations remain available on https://circabc.europa.eu/d/d/workspace/SpacesStore/ea154527-d900-431f-b5a8-97fbea6e4b08/regtyp.xls) and can be used to access all Eurostat's regional data: https://ec.europa.eu/eurostat/web/regions/data/database (All accessed November 20, 2021).
(2) The urban-rural continuum represents the whole sample of 7,368 valid responses. The metropolitan hierarchy is a subset of the urban-rural continuum, of course at the urban end of this continuum.

change will continue in future either positively or negatively overall. The reader is thus enjoined to note the scale of each figure and to refer to the **Supplementary Material** for all data.

COVID-19 Restrictions and Health Impacts

The analysis shows the overwhelming importance across almost all food behaviors of whether or not households lost income during the pandemic, and that this often varies between regional types. Some of this variation may be related to COVID-19 related restrictions imposed nationally or locally, as shown in **Figure 3**. This shows differences between the self-reported restrictions experienced by the income-loss and no-income-loss cohorts in 11 of the 12 countries in the sample (the exception being Hungary where restriction data was not collected). The income-loss/no-income-loss variable is also significantly related to Purchasing Power Parity (PPP) per inhabitant across the six regional types, as shown in **Table 3**, so could also function in some respects as a surrogate for actual mean income.

The data on restrictions due to COVID-19 are as reported by the sample households, which may or may not be the formal situation but, as this represents their personal experiences, is useful in putting their food behavior changes into context. It can be seen from **Figure 3** (and with reference to the **Supplementary Material**) that income-loss compared to no-income-loss households have been impacted more severely by travel restrictions and closures and that all of the metropolitan regional differences are significant in terms of travel restrictions as well as the closure of eateries (comprising restaurants and cafés as well as other outlets like hotels and pubs where the on-premises eating of food is available) and of physical workplaces. These include general travel restrictions in both capitals and second-tier metros (though not in smaller metros), as well as public transport restrictions and the closure of physical workspaces in all metro regions, all of which are often locally/regionally imposed. The differences between the two household types are much smaller and are not significant in terms of the closure of eateries and educational and similar establishments, reflecting that these restrictions tend to be more ubiquitously imposed at national level.

In terms of COVID-19 health impacts, the only significant difference is related to isolation in capital cities which is much greater than elsewhere due to a combination of higher population densities and smaller housing units, and especially a much greater proportions of high rise apartments than of individual houses. Less than one third of the differences along the urban-rural continuum are significant, and where they are this is mainly due to the contrasts between urban and rural in terms of closures of physical premises.

Local Food Environments

Where Households Shop

Figure 4 and the **Supplementary Material** show that differences in where households shop before compared to during COVID-19 are significant in most cases, thus indicating that the pandemic has had a profound impact. The figure also reveals many significant differences in terms of income-loss as well as along the center-periphery dimension. "Big market" is defined as large food supermarkets, whereas "grocery" indicates smaller establishments. (In each country, named examples of each type were provided in the questionnaire completed by households to improve the consistency of responses. Discount shops are included in both but tend to be smaller so are more often in the "grocery" category. "Grocery" also includes standalone bakeries and butchers).

Figure 4 shows a significant decrease in "big market" shopping during COVID-19 but a lower decrease in "grocery" shopping, even though "big market" shopping remains the most important. Again, these changes are more likely to be significant down the metropolitan hierarchy than along the urban-rural continuum, but significant changes are also seen in the latter. Despite these decreases, shopping in "big market" and "grocery" is significantly higher in smaller metros, except by income-loss households during COVID-19 indicating that the latter tend to react more strongly under stress.

TABLE 3 | Socio-demographic composition of the sample.

		Capital city	2nd tier metro	Smaller metro	Urban	Inter-mediate	Rural
Household income change	Income-loss households	41.6%	37.6%	30.9%	41.5%	34.1%	40.7%
	No-income-loss households	58.4%	62.4%	69.1%	58.5%	65.9%	59.3%
Regional pop. density km^2	Mean	3,467.9	590.5	632.2	3,020.4	218.4	78.5
	Standard deviation	4,573.8	925.2	815.0	4,082.7	260.9	65.4
Household member age	Mean all	22.1	28.2	32.4	24.6	26.7	25.7
	Standard deviation all	21.9	19.7	15.8	20.5	20.3	20.8
	Mean income-loss	19.5	22.5	30.2	22.8	24.0	24.8
	Standard deviation income-loss	19.8	15.6	14.0	18.4	17.0	17.0
	Mean no-income-loss	40.1	38.6	33.0	36.0	37.81	41.3
	Standard deviation no-income-loss	14.7	14.9	15.2	15.4	15.3	14.0
Regional PPP/inhabitant (EUR/year)	Mean all	43,747.7	31,555.9	35,736.4	44,175.8	27,090.2	24,961.1
	Standard deviation all	20,472.1	13,432.7	16,714.9	19,397.7	10,791.8	6,940.6
	Mean income-loss	42,648.6	31,275.6	34,237.8	42,210.4	26,315.5	25,237.7
	Standard deviation income-loss	20,079.3	14,898.9	12,603.7	18,767.0	8,330.5	5,622.2
	Mean no-income-loss	44,110.5	35,801.9	40,279.1	44,873.5	32,150.6	30,232.8
	Standard deviation no-income-loss	13,206.9	1,3412.9	20,364.7	15,299.6	12,566.2	7,022.8
Respondent education	Lower secondary all	6.8%	8.4%	6.4%	5.3%	8.6%	9.0%
	Upper secondary all	32.9%	46.7%	37.2%	33.8%	46.8%	46.0%
	Degree level all	60.3%	44.9%	56.1%	60.9%	44.4%	45.0%
	Lower secondary income-loss	3.3%	4.1%	5.6%	4.2%	4.7%	2.6%
	Upper secondary income-loss	31.0%	47.7%	39.6%	33.7%	49.3%	49.2%
	Degree level income-loss	65.7%	48.1%	54.3%	62.1%	45.8%	48.1%
	Lower secondary no-income-loss	15.2%	12.7%	9.2%	8.6%	13.8%	19.1%
	Upper secondary no-income-loss	42.8%	48.1%	43.3%	44.5%	47.9%	49.8%
	Degree level no-income-loss	42.0%	39.1%	47.5%	46.9%	38.3%	31.1%
Household composition	Single person All	23.5%	24.5%	26.8%	24.4%	23.1%	19.8%
	With children 0–19 All	16.9%	22.3%	27.1%	20.5%	22.6%	25.5%
	2+ adults, no children All	59.7%	53.2%	46.1%	55.1%	54.3%	54.6%
	Single person income-loss	16.4%	15.8%	21.0%	18.1%	14.9%	12.3%
	With children 0–19 income-loss	24.6%	34.9%	35.0%	29.2%	34.8%	38.0%
	2+ adults, no children income-loss	59.0%	49.3%	44.0%	52.8%	50.2%	49.8%
	Single person no-income-loss	29.4%	29.2%	30.5%	30.2%	28.3%	22.2%
	With children 0–19 no-income-loss	18.8%	20.3%	23.5%	21.5%	21.8%	23.9%
	2+ adults, no children no-income-loss	51.8%	50.5%	46.0%	48.4%	49.8%	53.9%

The respondent's gender is not provided as this is not a potential predictor of their whole household. All data are statistically significant at the $P < 0.05$ level, except: (i) mean household age in income-loss households along the urban-rural continuum; and (ii) household composition in no-income-loss households down the metro hierarchy (see ***Supplementary Material****).*

Shopping at AFN shops (i.e., alternative food networks including farm markets, street markets, cooperatively owned or solidarity shops, specialist organic food outlets and buying food directly from the producers) also decreased significantly during the pandemic, but this decrease was less pronounced in the smaller metros than in capitals or second-tier metros, and less pronounced in rural areas. However, given the nature of AFN, this may be due to the time the data was collected, not as a result of the pandemic itself, although there may be differences between countries as in Central Europe it is often not possible to buy local vegetables or fruits in the spring being out of season. Also in Czechia, for example, farmers' markets were banned in the spring of 2020. Interestingly, smaller metros, in strong contrast to the other metros, saw little difference in AFN shopping between income-loss and no-income-loss households as well as between before and during the pandemic, as also noted in relation to "grocery" shopping. It is also interesting to see that households in urban regions are more likely to shop at AFN than in intermediate or rural regions.

In contrast to in-person shopping, there were significant increases in the home delivery of meals ordered online or by telephone during COVID-19 across all regions and especially by income-loss households, but that this service is used decreasingly along the center-periphery dimension. This is probably related to the lower availability of such services, although smaller metros again go against this decreasing trend to some extent. In terms of meals from take-away shops, a decrease is seen from before to during the pandemic, together with a decrease along the

TABLE 4 | Comparison of Eurostat regions with sample regions.

Summary of all regions (Eurostat European Commission Statistical Office of the European Union, 2020, p. 22)	Sample regions—ignoring the "urban" type as is approximate average of all metros (definitions based on Table 2; SD = Standard Deviation)
Dynamic metropolises characterized by relatively youthful populations, large numbers of people living alone, high costs of living and buoyant labor markets.	Capital city metros: • Highest mean population density and highest SD due to large national variations. • Lowest mean household age and highest SD due to large national variations. • Highest mean income (PPP) and highest SD due to large national differences and greatest heterogeneity with mix of both very high wage and low wage sectors. • Highest education level. • Lowest presence of children. • Highest income loss households related to highest COVID-19 lockdowns. • Highest mean incomes in both income-loss and no income loss households.
Towns and cities in former industrial heartlands that have been left behind economically, characterized by relatively high levels of unemployment, poverty and social exclusion	Second tier metros: • Lowest mean population density amongst metros. • Highest mean household age after smaller metros. • Lowest mean income (PPP) amongst metros. • Lowest education level amongst metros comparable with intermediate-rural. • Mixed household composition. • Average income-loss and no-income loss related to average COVID-19 lockdowns. • Lowest mean incomes amongst metros in both income loss and no income loss households.
Commuter belts/ suburban areas which are often inhabited by families	Smaller metros: • Next highest mean population density after capitals and lowest SD amongst metros (thus more cohesive). • Highest mean household age and lowest SD (thus more cohesive). • Next highest mean incomes (PPP) after capitals. • Next highest education after capitals. • Highest presence of children. • Lowest mean income loss households related to more robust economy and lowest COVID-19 lockdowns. • Next highest incomes after capitals in both income-loss and no income loss households.
Rural regions which may exhibit declining population numbers and a relatively elderly population structure, while being characterized by narrow labor market opportunities and poor access to a wide range of services	Intermediate and rural regions: • Lowest mean population densities and lowest SDs (thus less heterogeneous). • Average mean household ages, between lowest in capitals and highest in other metros, and average SDs. • Lowest mean incomes (PPP) and lowest SDs thus less heterogeneous. • Lowest education together with second tier metros. • Average household composition. • Rural has next highest income loss households just after capitals, probably related to weaker economy and lowest mean incomes as average COVID-19 restrictions. • Lowest mean incomes in both income-loss and no income loss households and lowest SDs (thus less heterogeneous).

center-periphery dimension However, again the smaller metros seem to strongly defy this trend although only before COVID-19 and that this difference disappears during the pandemic.

As with home delivery, there is generally a significant increase in food obtained from local food producers during COVID-19, with income-loss households doing so much more than no-income-loss households. The only exception is no-income-loss households in capital cities. The move to local producers is exceptionally strong in the smaller metros and especially amongst income-loss households, which also are much more likely to state that this shift will continue after the pandemic. Such households in rural areas also state that this behavior is likely to continue. These patterns are generally supported by households traveling shorter distances to food shops during COVID-19 compared to before, and again this is especially marked in the smaller metros. However, no regions expect this behavior to continue after the pandemic, although smaller metros are less likely to state this than any other regional type.

Thus, during the pandemic the food-purchasing behavior of both household types changed toward smaller, more specialist and local geographically proximate outlets, probably both because this was perceived as less risky due to exposure to fewer people, but also because of travel and other restrictions.

Eating Away From Home

Figure 5 illustrates the substantial decreases in all types of eating away from home during COVID-19, especially for income-loss households which, before the pandemic, tended to eat more often out of the home than no-income-loss households. This is perhaps because they were more likely to avail themselves of the typically subsidized meals in workplace canteens and/or eat in cheaper fast-food eateries, which many of the comments made by the respondents show. Both types of household decreased away from home eating from between 15 and 40% down to 10% or less, but with little difference between the two household types during the pandemic. The latter probably reflects the severely reduced

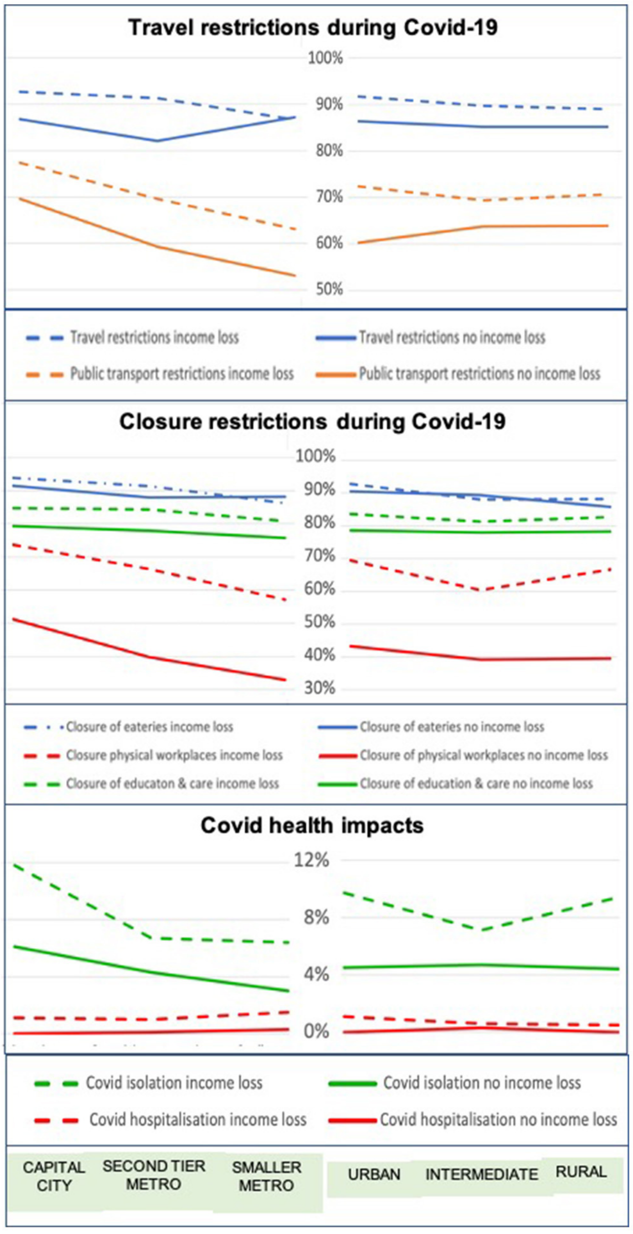

FIGURE 3 | Covid-19 restrictions and health impacts.

opportunities for eating outside the home that affected both types of households equally. The greatest reductions are in visits to eateries, followed, respectively, by eating in work canteens and from street-vendors, clearly as a consequence of the closure of most of these food outlets by national and local regulations. In contrast, eating away from home with family or friends was greatest for no-income-loss households before COVID-19. This is probably because these more affluent households have fewer children (see **Table 3**) and are more likely to have family or friends with homes that are better suited to hosting meals for others.

As above there is often a significant decreasing trend between center and periphery in line with a decrease in the availability of away-from-home eating outlets as population densities decrease. However, smaller metros again throw up some interesting exceptions in all examples except the use of eateries. Thus, for each of the other three examples, there is little difference between income-loss and no-income-loss households in the smaller metros, whether before or during COVID-19.

Social Context

Amount of Food, Money, and Stocking Up

How the amount of food, money spent and food stocking changed during COVID-19 is illustrated in **Figure 6**. In terms of food eaten, income-loss households report increased intake more than non-income-loss households, and the former also expects that this change will continue after the pandemic. This is perhaps because eating food helps more-financially stressed households seek some solace from the COVID-19 shock more so than no-income-loss households. Moreover, in both household types there is a relatively large increase in unhealthy "comfort" food whilst fresh food consumption tended to decrease, and this difference is greater in income-loss-households (see Section Food Consumption). In line with the increased food consumption, income-loss households also increased the amount of money spent on food during COVID-19 much more than no-income-loss households, although both types saw increases. Thus, although money was increasingly scarce for the former, it is likely that the lack of many other spending opportunities during the pandemic, especially in rural areas which saw the biggest difference between the two household types, reinforced the displacement behavior that increased food consumption and spending provided.

It is also noteworthy that, as observed in many other food behaviors, the difference between the two household types was very low in the smaller metros. Income-loss households also expect that this change will continue more than the no-income-loss households so that, both in terms of the amounts of food eaten and money spent, income-loss households predict that food behavior changes induced by the pandemic are more likely to continue for the longer term. In other words, the pandemic has impacted income-loss households more deeply and probably for a longer period, than it has other households. A very similar situation is seen in relation to the stocking of food during COVID-19, so that income-loss households do this much more, again reflecting their greater food anxiety and stress, although the only exception, once again, is in the smaller metros where there is little difference between the two household types.

In terms of regional differences, there are only weak, inconsistent and largely insignificant changes along the center-periphery dimension, except in the case of the smaller metros. Here, the differences between income-loss and no-income-loss households are in all cases smaller than elsewhere. When looking at all metropolitan households, changes in the amounts of food eaten and money spent during COVID-19 are lowest in smaller metros. Thus, smaller metros seem again to exemplify a more balanced overall affluent type of region with more money to

FIGURE 4 | Where households shop.

spend on less, but higher quality and healthier, food (see also Section Food Consumption).

Food at Home

There are many significant differences in how food behavior changes from before to during COVID-19 across the different types and locations of households. **Figure 7** shows that the use of ready-made meals has decreased especially for income-loss households. However, there is little difference across the six regional types with the marked exception of the smaller metros which before COVID-19 used such meals more than any other region and continued to do so during the pandemic. Smaller metros also behave against the overall center-periphery trend in the use of processed ingredients in meal preparation. Income-loss and no-income-loss households make the similarly highest use of processed ingredients before COVID-19 in the smaller metros, whilst all other regional differences are small. However, during COVID-19 this distinction largely disappears. In terms of the use of raw ingredients, both household types use a similar amount before COVID-19, but during the pandemic income-loss households increase their use of raw ingredients much more than no-income-loss households and these differences are greater

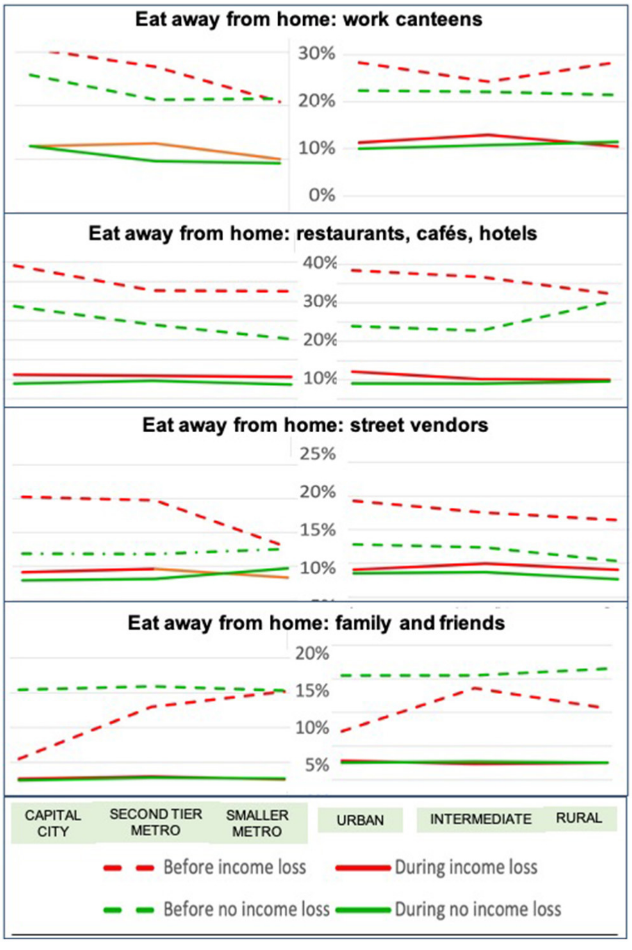

FIGURE 5 | Eating away from home.

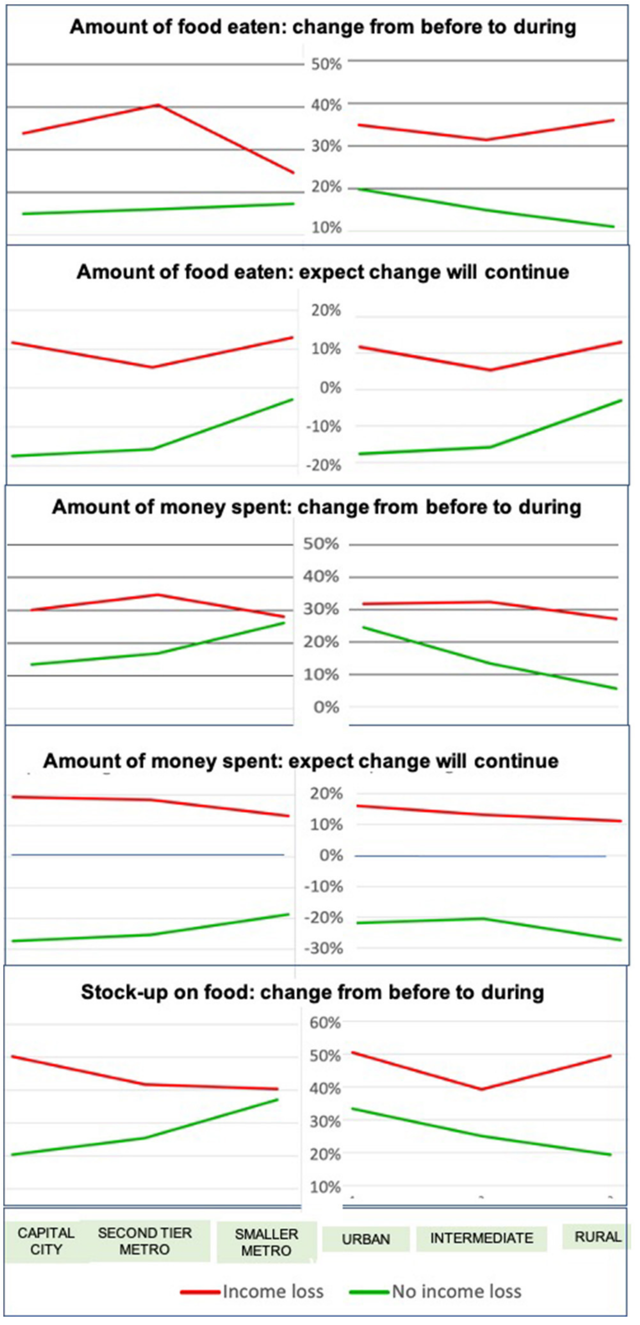

FIGURE 6 | Amount of food, money and stocking up.

in the smaller metros. Overall, the use of raw ingredients is greater than of processed ingredients at between 80 and 90% of all households compared with between 45 and 60% before and during COVID-19. The pandemic also induces a general increase in the use of raw ingredients and a decrease in processed ingredients in a largely similar manner in both income-loss and no-income-loss households, and this is most conspicuous in the smaller metros which again stand out against the overall trends.

In terms of households growing their own food at home, it is unsurprising that this is significantly greater in intermediate and rural regions, where generally there is more land available, and that the activity increases significantly during the pandemic in all regions to about the same extent. In addition, in metropolitan regions the activity is overall significantly higher in the smaller metros, and there is also greater expectation here that this will continue in future, as there is in rural regions. Self-produced food has grown in importance for all households but to a much greater extent in income-loss households which could be explained by the income-loss shock. However, income-loss households also grew their own food more often before COVID-19 than no-income-loss households which suggests that it could either be because there is more need or that food growing is a habit of the social groups which suffered income-loss during the pandemic, although their motivation could be very diverse, not only economic. These households also expect their increased awareness of home-grown food to continue in future, whilst non-income-loss households generally do not. In both types of households, however, those in the smaller metros are significantly more positive that this change will continue. As also shown

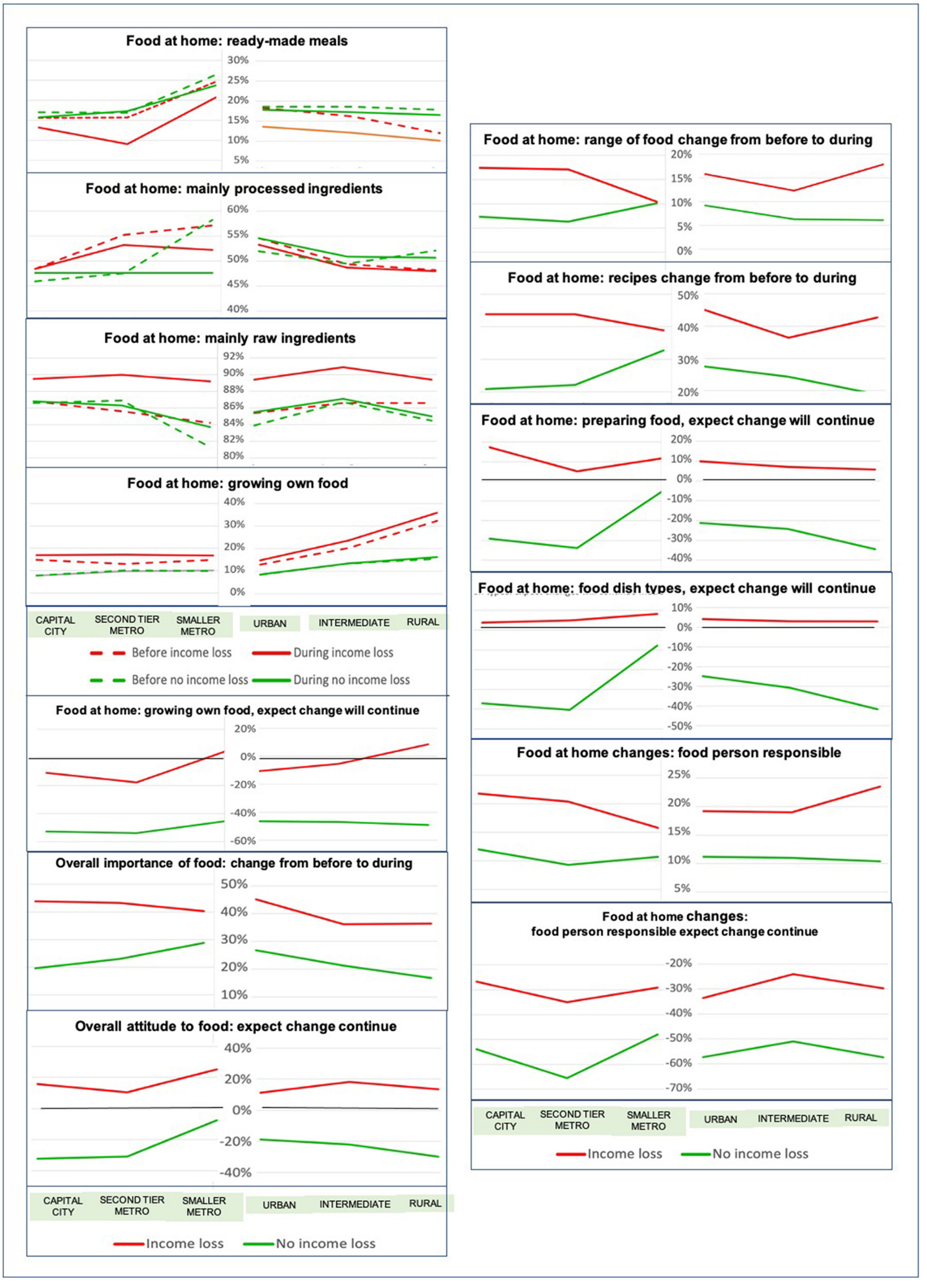

FIGURE 7 | Food at home.

below in Section Food Vulnerability, income-loss-households also obtain more food from food banks, eat more free hostel meals, are more anxious about obtaining enough food and have missed more meals than no-income-loss households, and these differences generally increased sharply during COVID-19. This underlines the critical nature of such shocks on financially weaker and more food-vulnerable households.

When looking at the range of food prepared at home, **Figure 7** shows an overall increase of between 6 and 18%, but with few differences between regions except when broken down into income-loss and no-income-loss households. The former have increased the range of food prepared significantly more than the latter, apart from in smaller metros where there is little difference. Again, this appears to point to the conclusion that these regions are more socially balanced and inclusive. This also seems to apply to the increase in the number of ingredients and recipes used during the pandemic which is again significantly higher in income-loss compared to no-income-loss households but with much less difference between the two in smaller metros. These differences are replicated in households' expectations that these changes in how food is prepared and in food dish types will continue in future—again there are significant differences between the two types of households, with income-loss households generally positive while no-income-loss households generally negative, except in smaller metros where the differences are much smaller though still significant. This is again evidence that financially weaker households have been obliged to change much more than financially stronger households.

Finally, the pandemic has changed the person responsible for food by between 9 and 24% of households, with a significantly greater change in income-loss households, although again this is much less in the smaller metros. Overall, the biggest change has taken place in capital cities, perhaps because here COVID-19's induced stress on family life tends to be more acute. In most capitals many more households live in small apartments and there have been more stringent lock-down restrictions here, as shown in **Figure 3**. This means that more people were forced out of workplaces and more eateries closed, putting even greater focus on food and meals at home often for longer periods than in other regions, leading to the re-jigging of personal responsibilities. **Figure 7** also shows that all households do not expect these changes to food responsibilities to continue, but that this is less so in income-loss households and in smaller metros.

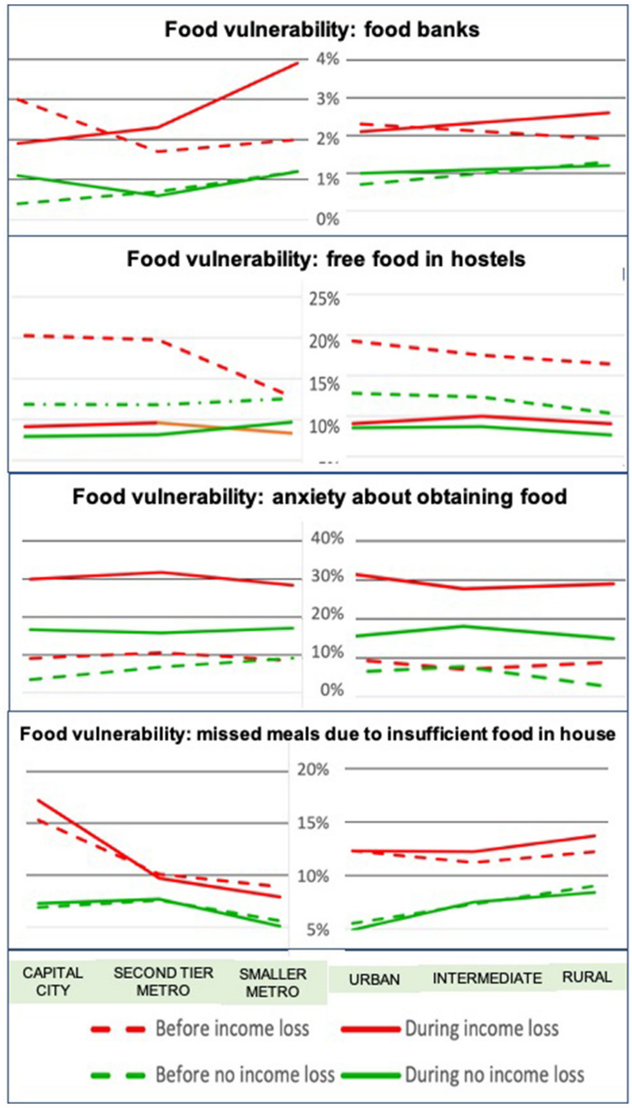

FIGURE 8 | Food vulnerability.

Food Vulnerability

Figure 8 presents several variables examining food vulnerability and how this has changed from before to during COVID-19. These build on the many results already presented regarding the relative vulnerability of income-loss compared to no-income-loss households and how this is typically higher in second-tier metros and, depending on the issue, sometimes higher in capitals and rural areas. The use of food banks generally doubled during the pandemic but from a very low base of about 1–3%, perhaps reflecting the early nature of the survey during the first wave, given there is substantial evidence of much greater subsequent increases amongst certain types of households and locations Capodistrias et al. (2021). But, compared with other kinds of food obtained, this category is the smallest and also food bank increase is in general low. As would be expected, income-loss households both had a higher before COVID-19 use of food banks but also much greater increases than no-income-loss households. Both were greater in metro regions than elsewhere, probably because the number of food banks is large here reflecting the population density, although during COVID-19 the focus shifted to smaller metros perhaps for this reason. Similar results are seen for the access of free-food in hostels although this is much greater at between 10 and 20%, with fewer differences between metro regions and others, and at their lowest in the smaller metros. This may be because hostels have a much more visible presence than food banks as already prepared food is consumed in public compared with the food-banks' provision of ingredients that households take home to prepare meals in private.

In terms of psychological worries and anxiety about obtaining food, this has risen from between 10 and 20% before COVID-19 to up to 30% during. Again, this is greatest in income-loss-households, and lowest in the smaller metros where the differences between the two household types is smallest. Similar results are seen regarding missed meals and food insufficiency which tend to be highest in capitals and rural areas, despite the latter growing more food at home but where there are more likely to be pockets of poverty. These concerns are lowest in smaller metros which generally combine relatively high incomes with low poverty.

Food Consumption and Diet

Food Consumption

The survey examined 11 types of food consumption, as presented in **Figure 9**, first showing pre-COVID-19 consumption levels and, second, how these types form four groups depicting how consumption changed during the pandemic. The figure shows that the highest consumption frequencies before COVID-19 are of fresh everyday food (fresh fruit and vegetables, bread and dairy products), followed by fresh meat, then so-called comfort food (cake and biscuits, chocolates and sweets and alcohol), and finally by processed foods (frozen, canned and ready-made) and fresh fish. There are few variations across the six regional types, although there is some greater tendency to consume fresh meat and comfort foods in rural areas, fresh meat in capitals and comfort foods in smaller metros (the latter may be due to the larger number of families with children in these regions consuming cakes and sweets). Otherwise, these apparently quite typical European food consumption patterns seem relatively ubiquitous, at least across the 12 countries in the survey, resulting from the strong moves over recent decades to a common European food sector producing and consuming increasingly standardized foodstuffs. This is, however, not to imply that strong national, regional and local food types and cuisines are no longer important in Europe, but their importance has become diminished over recent decades, an issue which our survey has not examined.

The second part of **Figure 9** shows that the COVID-19 shock has led to some dramatic changes in food consumption behaviors. Fresh food consumption decreased significantly, whilst both processed and comfort food increased. **Figures 9A,B** both show decreases of between 0 and 15%, but with different patterns. Fresh everyday food decreased most in capital cities and generally least in smaller metros and rural areas, which might be explained by tighter supply constraints on fresh food in the former, although in the latter two areas fresh fruit/vegetables did decrease strongly amongst income-loss households. In terms of fresh fruit/vegetables and bread, both with the shortest shelf-lives, the decreases were greatest amongst income-loss households, but least for dairy products with longer shelf-lives. The consumption of fresh meat and fish saw similar decreases but geographically the reverse compared to fresh everyday food. Apart from this, in all regions fresh food decreases were greatest in income-loss households.

In contrast to decreases in fresh food consumption during the pandemic, **Figures 9C,D** show strong increases in processed and comfort food of up to 15%. Both phenomena might be explained by greater supply constraints on fresh foodstuffs, compared to more stocking-up and the advantages of longer shelf-lives of non-fresh foodstuffs during COVID-19 restrictions. In terms of processed foodstuffs, although there were a few decreases in most regions (ready-made in income loss households, and frozen in no-income-loss households), increases were greatest in the smaller metros. Income-loss households consumed more canned and frozen foods than no-income-loss households, but the reverse was the case with ready-made meals. The comfort food category increased more than any other type, with no decreases. This is possibly because of their potential stress-ameliorating characteristics and the fact that many more adults and children were at home virtually constantly, which clearly increased snacking and in-between meal-time consumption. This pattern appears to be similar across all regions, although income-loss households in second-tier metros consumed more cakes/biscuits and alcohol than elsewhere, and no-income-loss households in intermediate regions consumed most cake/biscuits. Apart from the latter, income-loss households always consumed more comfort food than other households. If these trends continue, it could bring serious negative health consequences especially in these more distressed regional types and amongst the most financially stressed households, made worse by the decrease in fresh food consumption.

Diet and Health

The first diagram in **Figure 10** shows the regional variations of households with special dietary needs and that these are significantly greater in income-loss households in capital cities and rural areas where, as noted above, there are more likely to be pockets of poverty.

The second diagram depicts some of the environmental impacts of food consumption and diet. The purchase of unpackaged foodstuffs (mainly fresh fruit and vegetables) has increased across all regions by up to 20% and more so amongst income-loss households and in smaller metros, although in the latter both household types purchase to the same extent. This is a relatively positive finding given the more careful approach taken by shops to foodstuffs and the application of stricter hygienic measures during the pandemic. The consumption of organic foods has, however, generally decreased by up to -10% in all households and significantly more so in smaller metros although this is mainly due to income-loss households.

Significant decreases in food waste have occurred in the context of the greater importance given to food during the pandemic by all groups, perhaps because of food supply problems. Interestingly, this reduction is seen more in income-loss households probably related to the greater financial stress they experience, so that not immediately discarding uneaten food, and even consuming food after the sell-by date, can become important. Reduced food waste is also seen across all regions with the greatest decreases in smaller metros. These regions seem generally to be the most environmentally aware, probably related to their relatively large incomes, high educational levels and their

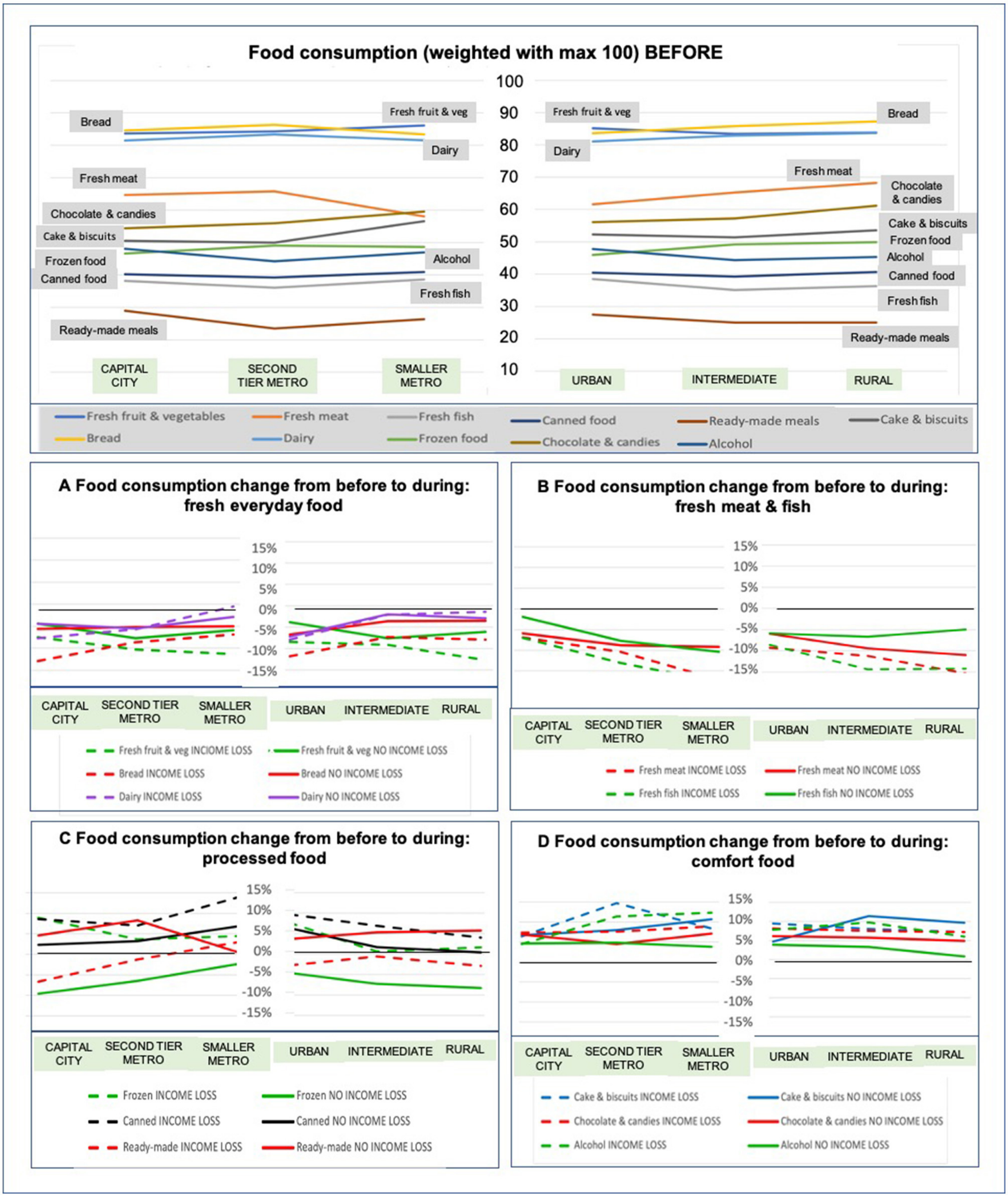

FIGURE 9 | (A–D) Food consumption. Data for the top diagram is a sum of each households' consumption before the pandemic of the 11 food items shown, weighted on a 6-point Likert scale by the frequency of consumption: less than once a fortnight or never; between once a week and once a fortnight; once a week; 2–3 times a week; 4–6 times a week; daily. Summed results were then standardized out of a possible maximum of 100, for example if all households in a specific regional type consumed a particular food item daily then the score would be 100.

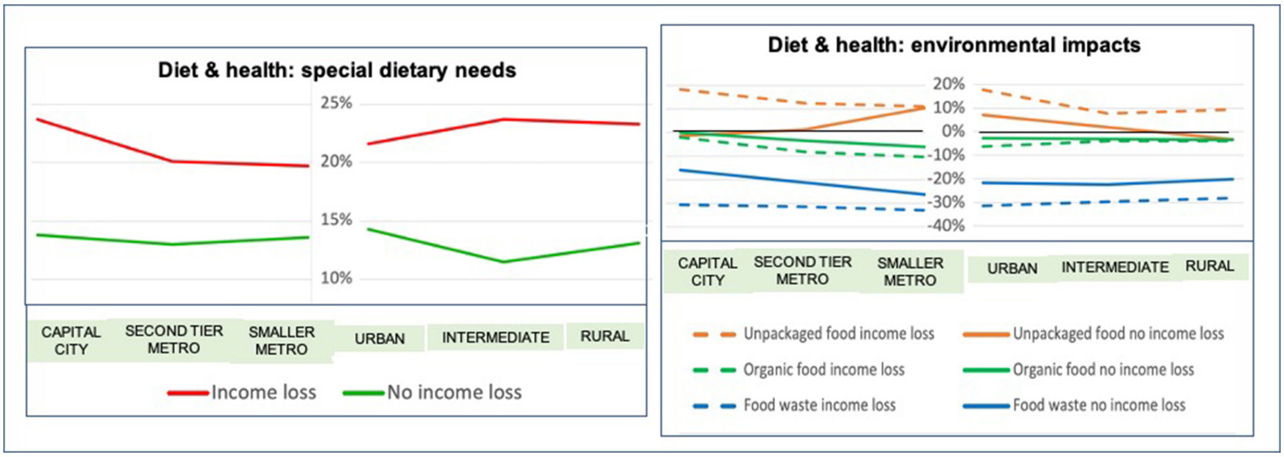

FIGURE 10 | Diet and health.

overall more balanced socio-demographics. Smaller metros also have the highest proportion of families with children which is likely to make households more aware of the importance of both diet and environmental issues, even though at the same time comfort food eating increased more in smaller metros than other regions (except second-tier metros), perhaps itself also related to consumption by children.

DISCUSSION

Main Findings

Regional Differentiation

In line with Eurostat European Commission Statistical Office of the European Union's (2020) description of Europe's regional geography, this paper's sample of 7,368 respondents across 12 European countries demonstrates distinctive regional variations often revealing the highly significant alignment and interaction between geography and society. Thus, there are regular trends from higher to lower from the center of capital cities to the rural periphery, for example in terms of the data in **Table 3** on population density, income (PPP) and education. These are molded by five locational dynamics that play out over geographic space (see the conceptual framework in **Figure 1**) that are largely determined, shaped and sorted by the mutual relationships between them, both within a given region as well as between regions:

- Density: ranging from agglomeration to the dispersion of people, consumers, stakeholders and their activities along the food value chain, as well as the organizations and firms that support this.
- Distance: the relative distance between these actors, activities and organizations of the food value chain across space, ranging from proximate to remote.
- Connectivity, both physical and virtual: ranging from accessible to isolated in terms of how easy, quick, timely, costly and convenient it is to connect with any location. New technology is increasingly enabling food producers to undertake many product monitoring, cultivation and harvesting tasks remotely, and consumers are able to select and order food online and get it delivered rapidly, phenomena which have been considerably magnified during COVID-19 as evidenced by the significant growth of home delivery during the pandemic (**Figure 4**). However, food is, and will remain at least for the foreseeable future, a physical object and thereby subject, to a greater or lesser extent, to these locational and spatial dynamics.
- Resource availability for all food stakeholders and organizations: ranging from large to small variation and volume, for example in terms of all human resources, capital, soft and hard infrastructures, etc., required along the whole food value chain.
- Power and decision-making, both political and market: ranging from high to low within a national context, for example the ability to determine and allocate resources and make rules and regulations for all relevant stakeholders and organizations along the food value chain.

These five locational dynamics operate along the whole of the center-periphery dimension and are visible in most of the results presented in Section Results. For example, they are very clear in terms of home delivery (**Figure 4**) but not at all when eating away from home with family and friends (**Figure 5**). The former likely reflects the relatively density, connectivity and resources of retail outlets offering these services away from the center, while the latter is predominantly determined by social relations and, although this can be affected by population density, it only appears to be important for income-loss households which have limited resources and probably less accommodation space regardless of where they live. Another contrast is food consumption before COVID-19 which, in a European context, is hardly affected by where people live (**Figure 9**), whereas geography clearly becomes important during COVID-19 (also

Figure 9), thereby suggesting that in some cases a shock like the pandemic can re-prioritize geography over the market.

There are also smaller scale regular center-periphery trends around individual cities and towns, for example around capitals, second tier metros, smaller metros, as well as towns in rural areas, each operating over shorter distances with smaller hinterlands as manifestations of individual city-region food systems. When regional, national and continental markets become stronger, however, these have increasingly overlapped and nested within each other while becoming weaker. As seen in the food consumption example above during the pandemic shock, this process can be temporally and perhaps permanently reversed in favor of shorter value chains, exemplified by the move to smaller retail outlets, local producers and shopping (see **Figure 4**).

There is, however, one very prominent exception to the center-periphery trend regularity, i.e., the smaller metros which in most cases in Section Results have disrupted these trends acting more like local/regional capital cities in terms of their socio-demographics and food behavior. In fact, they often display many of the advantages of capital cities while foregoing some of the disadvantages, such as having the lowest percentage of income-loss households, the most balanced household composition and relatively high incomes but with fewer extremes as compared with capitals (see **Table 3**). Capitals typically exhibit pockets of poverty alongside very wealthy households, while second-tier metros are more likely to be characterized by the lowest metro incomes as former industrial areas that have been left behind economically with relatively high levels of unemployment, poverty and social exclusion. As outlined in Section Regional Typologies, these differences are typical of most European regions recognized by Eurostat European Commission Statistical Office of the European Union (2020), in our sample's socio-demographic characteristics, as well as in most of the results presented in Section Results. For example, smaller metros typically change less during COVID-19 as well as exhibit no or smaller, though sometimes still significant, differences between income-loss and no-income-loss households. In this way, they demonstrate their relative demographic and food system cohesion and resilience compared with the other regional types.

The specific role of smaller metros in food systems is an important conclusion arising from this paper and is clearly reflected in the modeling of the current stage of the urbanization cycle, described in Section Regional Perspectives. This is the current counter-urbanization trend resulting in the growth of smaller cities beyond the traditional suburbs accompanied by population decline in the core and its suburbs. This is being recognized in many countries, for example, the Danish Knowledge Centre for Housing Economics Boligøkonomisk Videnscenter (2021) is charting the movement of population out of the five largest Danish Cities, including Copenhagen, to the smaller provincial cities in their hinterlands. These are today the fastest growing municipalities in a development that is expected to continue to at least 2040 and which is also being fueled by movements from rural areas. This dynamic is being driven by a better quality of life balancing urban and rural advantages, high services levels, as well as continued good connectivity to the larger cities when desired.

Income-Loss Compared to No-Income-Loss Households

Another main finding of the study which has, unlike the regional dimension, been noted by other authors (see Section Household Responses to the Pandemic) is the high importance of the income-loss/no-income-loss variable in this study. It is significant in many before-COVID-19 food behaviors as a good surrogate for individual household income, so that households with income-loss during COVID-19 were likely to be fragile even before the pandemic which then made their situation worse. Income-loss households nearly always experienced food behavior changes arising from COVID-19 much more than no-income-loss households, probably because their financial and social situations are more precarious, so they are more sensitive to external shocks and are likely to react more strongly under stress. The precariousness of income-loss-households is also related to the fact that they over represented in regions with the lowest PPP/inhabitant, have a lower mean age and are more likely to be families with children, which together imply both lower earning potential and that finances need to be stretched further.

On the other hand, income-loss-households are much more likely to state that the positive changes they have made, and perhaps forced to make, during COVID-19 are more likely to continue post-pandemic. For example, shopping with local producers and in more local shops, growing own food, and using a wider range of food dishes and recipes. This could be a useful policy issue but is only likely to be realized if it is made as easy as possible for such changes to continue through better designed and simplified choice architectures with incentives and other focused supports, and where the household benefits can readily be seen within a short timeframe. However, it is not known whether this expectation that the changed behavior will continue is because they can see the benefits of such changes, which in some though but by no means all cases are already practiced by no-income-loss households, or because they expect their relatively precarious situation will persist regardless of the state of the pandemic. How these impacts will play out over the longer term is a critical issue and needs focused research, especially because the likelihood of other shocks with similar effects is high, whether these are new pandemics, climate change, new disruptive technology, geo-political and economic-trade tensions, etc. These concerns are, for example, voiced by the European Commission (2020, 2021), IPES-Food (2020), KPMG (2021), Millard (2020), OECD (2020), and World Economic Forum (2021b).

The income-loss/no-income-loss household balance also typically varies significantly between regional types, more often down the metropolitan hierarchy than along the urban-intermediate-rural continuum, although when there are differences in the latter this is almost always between urban regions on the one hand and rural regions on the other. However, the relative vulnerability of income-loss compared to no-income-loss households is typically highest in second-tier metros and, depending on the issue, sometimes higher in capitals and rural areas.

Research and Policy Recommendations

It is clear from the literature review, and now strongly supported by this paper, that an interdisciplinary and strong regional approach to food system development is necessary to advance food research and practice and to improve our understanding of how to create more effective, inclusive and sustainable city-region food systems. The results above, describing the changes at household level, especially in terms of income-loss or no-income-loss as well as household composition and along the center-periphery dimension, illustrate how food systems are regionally differentiated despite the majority becoming increasingly globalized over recent decades (von Braun et al., 2021). Moreover, the disruption caused by COVID-19 has further exacerbated inequalities and regional differences, highlighting both societal and regional winners and losers. Besides being an original contribution to the debate, the paper gives further strength to the pledges for the post-pandemic reform of food systems that must start from the socio-economic and geographic reality that also recognizes how these two dynamics are interrelated (IPES-Food, 2020). Also, in light of the EU's *Farm to Fork Strategy* (2020), this means making city-region and especially local food systems the main focus for addressing food security and sustainability (European Committee of Regions, 2020). The upcoming new European Common Agricultural Policy could become the most important policy framework to support the structuring of such food systems, directly addressing the weak spots that have been exposed by COVID-19 (European Commission, 2021). For instance, the objective of greater food security cannot disregard the role of small farmers and local supply chains that need enhanced roles in the market, and the implications this has for the production, processing, transportation and selling of food. The socio-economic crisis caused by the pandemic has also highlighted a need for much more equitable supply chains that are capable of guaranteeing fair remuneration, high quality and resilient security along shortened value chains and at affordable prices for consumers.

From a wider policy perspective, it is also necessary to strengthen urban-rural linkages and to ensure that food systems are properly included in urban and area planning and programming, for example in relation to land access and tenure for food production, market access for smallholders and investment in both the urban and rural axes of value chains (Sharifi and Khavarian-Garmsir, 2020). It is moreover necessary to institutionalize the commitment of cities to include food and nutrition as a high priority policy, adequately embedded within and supported by all other city policies. Thus, effort needs to be placed on building widespread government support, in addition to the commitment of other actors in the private and civil society sectors. Overall, it is often the food system related issues, as described in the Milan Urban Food Policy Pact (2015), that can provide a "breakthrough" moment that can bring silos together, also with spill-over impacts on the cities' other non-food issues. However, policies and strategies should not rely on market-oriented approaches alone as the potential of non-market food provisioning is far from being negligible even in urban areas as shown by our results and previous research (e.g., Vávra et al., 2018b). Various forms of urban gardening, as well as growing food in publicly accessible spaces often labeled as the "edible city" concept (Artmann et al., 2020), can play an important role in redesigning city food region systems.

This paper shows that COVID-19 has many asymmetrical impacts across territories, while many policy responses remain place-blind and uniform, thus highlighting the need for more place-based and people-centered approaches. In the context of food provisioning and consumption, the rediscovery of proximity will provide a window to shift faster from the status quo to more sustainable food systems, based on equitable relationships along the supply chain, social justice and market equity (Klassen and Murphy, 2020; Picchioni et al., 2021). Overall, the COVID-19 shock calls for a stronger focus on resilience as preparedness for future shocks requires managing who does what at which scale and how, especially at the city-region scale.

New business models are also needed that encourage a social economy to engage citizens through cooperatives or other forms of social enterprises in food production and distribution. Many of the lessons are already being learned and applied but to date have mostly appeared autonomously and bottom-up in many cities and towns in Europe and worldwide as a response to the crisis. It is up to policy makers at all levels to recognize, support and further develop them, so that future crises, no matter their nature, will have fewer detrimental impacts. Thus, dedicated long-term efforts are needed, first, to break through siloed sectors and agencies, and then establish shared priorities and joint programs. In most city regions, increased collaboration between health, nutrition and social services, environmental planning and economic development, in addition to the traditional food system actors, is urgently needed.

The differences between the three types of metro region outlined above, as well as the urban-rural contrasts and links they imply, clearly have profound implications on how city-region food systems should be developed and supported. Research and policy should be re-directed to focus on re-scaling the food system by shifting significantly away from the conventional approach and transforming toward more sustainable and resilient food systems with significantly shortened value chains in an increasingly circular city-regional food cycle. This also specifically requires deploying circularity principles which look beyond the current "take, make, and waste" industrial model of food production, processing, provisioning and consumption in order to design out waste and pollution, keep products and materials in use, and regenerate natural systems. Circularity also boosts local commerce, jobs, social inclusion and more responsive local governance (Millard et al., 2021).

The household, neighborhood, city and peri-urban area are nested within the wider regional, national and global food systems. One fundamental question is, what is the hinterland/catchment area required to provide a town or city with its basic needs for nutritious, safe, secure, sustainable local and seasonal food, and how is this organized and governed? To answer this question, a transformation is required from a predominantly international and planet-wide system toward a more circular city-region food system that becomes much more self-sustaining and resilient. This implies a much greater emphasis on strong interrelations between the household, neighborhood, town/city and region. A nexus approach and thinking are thus needed—a city is only as resilient as the surrounding region is in terms of water, energy, food, logistics and natural ecosystems, all of which need to be seen as part of one interrelated system.

An important conclusion for city-region-food-system resilience policy is to learn the lesson that smaller cities are best able to cope with system shocks. They have the most balanced socio-demographic characteristics, are affected least and come through the shock best, and have the lowest schisms between weaker and stronger households. Joined-up policy should thus focus on emulating such conditions as best as possible, for example in terms of scale so that in capitals and second-tier metros a neighborhood or district approach should be prioritized especially where there is an over-representation of vulnerable households. This could include introducing the 15–20 min walkable neighborhood concept so that healthy food is accessible within 500 m for all residents as pioneered in Paris. This is a policy for developing a polycentric city, where density is made pleasant, one's proximity is vibrant, and social intensity, as a large number of productive, intricately linked social ties, is real (World Economic Forum, 2021a).

This paper also shows the importance and position of households as a basic socio-economic and "food" unit and reveals their different conditions and abilities to tackle the crisis. The potential of household resilience ranges from food logistics and planning and the structure of diet to various aspects of obtaining, preparing and stocking food. This also reflects the household's potential to grow its own food in the future as the possibility for this otherwise changes along the rural-urban continuum. Although our research shows the highest proportion of own food gardening is in intermediate and rural regions and by income-loss households, it also shows that significant increases during the pandemic were seen in urban as well as in rural areas. It is thus important to take into account the trends in urban areas as mentioned above, also given that other authors, like Schoen et al. (2021), show increasing interest in growing more food mainly in urban areas during COVID-19. Thus, municipalities should rethink their approach to urban planning and design (Mullins et al., 2021) in order to incorporate urban gardening into the sustainable development of towns and cities. Focus should be on, for example, allotment gardens, community gardens, schools, etc., including education and raising public awareness. Many cities and towns have initiated and implemented elaborate food plans, inspired by the Milan Urban Food Policy Pact (2015) and other strategic plans adding food issues into their agenda.

These are the only feasible ways in which both biological and technical materials can become part of a circular food ecosystem that is, in practical terms, able to massively reduce waste as well as increase efficiencies along the whole value chain. This shift does not imply that city-regions should or will become cut-off in terms of food from their wider national or international context, or from global interactions and trade, as this is likely to be both impractical and undesirable over the long-term, but the move to more local and circular food systems having a strong food justice component needs to be substantial. Such a transformation can also lead to huge environmental, social and economic benefits which make the short-term transformation costs and effort significantly worthwhile in aiming at the desired outcomes and impacts over the medium and longer-term.

DATA AVAILABILITY STATEMENT

Requests to access the datasets should be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JM, AS, MJ, and JV designed and prepared the dataset for this paper based on the questionnaire designed and promoted by the organizations listed in the Section Acknowledgments. JM led the development of the paper's concept and writing with contributions from AS, ZS, BD, and JV. MJ provided critical reviews. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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A participatory tool for assessing land footprint in city-region food systems—A case study from Metropolitan Copenhagen

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The ongoing COVID-19 pandemic has exposed the fragility of current food systems to feed populations around the world. Particularly in urban centers, consumers have been confronted with this vulnerability, highlighting reliance on just-in-time logistics, imports and distant primary production. Urban food demand, regional food supply, land use change, and transport strategies are considered key factors for reestablishing resilient landscapes as part of a sustainable food system. Improving the sustainability of food systems in such circumstances entails working on the interrelations between food supply and demand, rural and urban food commodity production sites, and groups of involved actors and consumers. Of special significance is the agricultural land in close proximity to urban centers. Calling for more holistic approaches in the sense of inclusiveness, food security, citizen involvement and ecological principles, this article describes the use of a new decision support tool, the Metropolitan Foodscape Planner (MFP). The MFP features up-to-date European datasets to assess the potential of current agricultural land use to provide food resources (with special attention to both plant- and animal-based products) and meet the demand of city dwellers, and help to empower citizens, innovators, companies, public authorities and other stakeholders of regional food systems to build a more regionalized food supply network. The tool was tested in the context of the food system of the Copenhagen City Region in two collaborative workshops, namely one workshop with stakeholders of the Copenhagen City Region representing food consultancies, local planning authorities and researchers, and one in-person workshop masterclass with MSc students from the University of Copenhagen. Workshop participants used the tool to learn about the impacts of the current food system at the regional and international level with regard to the demand-supply paradigm of city-regions. The ultimate goal was to develop a participatory mapping exercise and test three food system scenarios for a more regionalized and sustainable food system and, therefore, with increased resilience to crises. Results from this implementation also demonstrated the potential of the tool to identify food production sites at local level that are potentially able to feed the city region in a more sustainable, nutritious and way.

KEYWORDS

food systems, Metropolitan Foodscape Planner, Copenhagen, spatial decision support, food supply and demand, collaborative workshops, living lab approach

Context: COVID-19 and the crisis of food systems

The globalized, industrial agri-food system has unveiled major inherent shortcomings with regard to sustainability and resilience (IPCC, 2019), being responsible for one third of the global anthropogenic GHG emissions (Crippa et al., 2021) and the main driver of biodiversity loss (Benton et al., 2021). Paradoxically, at the same time the trend in increasing the logistical complexity and globalization of the food system increases its vulnerability to negative environmental feedback effects, such as shock propagation, spillovers and simultaneous shock events (Davis et al., 2020). During the COVID-19 crisis this vulnerability was drastically exposed, highlighting the dependency of numerous countries on complex and vulnerable international supply chains (Bailey and Wellesley, 2017; Puma, 2019), with insufficient capacity in domestic food supply (Garnett et al., 2020). Furthermore, there have been several reports of countries having difficulties in acquiring migrant labor for domestic agriculture, exacerbating challenges in local food production. In Europe alone, it is estimated that this shortage accounts for 1 million workers (FAO, 2020).

Recently, some authors assessed the impact of the COVID-19 on the food systems resilience for specific groups of countries or from a specific viewpoint (e.g., soil management). For example, Béné (2020) developed a review on food security in local food systems and their resilience under the COVID-19 crisis in low- and middle-income countries. Nordhagen et al. (2021) assessed the impact on small farmers in these countries and implications for longer-term food system resilience. Other examples of food system assessment across the world include: Farrell et al. (2020), who assessed the food systems resilience under the COVID-19 crisis in Pacific Island Countries and Territories, Orden (2020) who assessed the resilience and vulnerability of the North American food system during the pandemic. In Asian countries, we have the study of Fan et al. (2021), who assessed the case of Asian countries with a special focus on a post-pandemic world and the possibility of future international shocks and disruptions, or Woertz (2020), who related the food self-sufficiency in Arab Gulf Countries with the inequalities in food availability, especially visible in the COVID-19 crisis. In the context of European territories, the perspective paper by Vittuari et al. (2021) reviewed the trends in production and consumption in several European cities during the first wave of COVID-19 and identified challenges and future strategies for research and innovation toward the creation of resilient and sustainable city-region food systems (CRFSs). Along similar lines, a study by Meuwissen et al. (2021) assessed the impact of the COVID-19 in 11 farming systems in Europe, observing that even though they managed to cope with the special situation, transformative measures in the face of future pandemics are needed.

At the city-region level (i.e., city-region food systems, CRFSs, or local food systems, LFSs), Blay-Palmer et al. (2021) assessed how to increase the resilience of the food systems by building CRFS and how we can learn from the pandemic to foster them. Indeed, resilience is not a given and needs to be purposely nurtured in order to facilitate the creation of distributive food systems. In particular, these food systems must be based on local needs and capacities that assure a fair redistribution of value, knowledge and power across actors and territories to deliver sustainable food for all (Moragues-Faus, 2020). Furthermore, authors like Vaarst et al. (2017) propose to apply the agroecology framework in order to achieve resilience at the agroecosystem scale in the city-region context. Other examples include the assessment of whether urban agriculture (UA) can offer a robust solution for feeding city populations. UA has gained traction in recent years and has also been proposed by diverse governments and institutions as a tool for improving food security (Badami and Ramankutty, 2015). In some cases, scenario analyses have been conducted for particular cities to establish whether UA can make a significant contribution to the local food supply, for example in Chicago, as conducted by Costello et al. (2021). Other authors consider LFSs as socio-ecological systems (SESs), since they are held by common culture and identities, in order to create adaptive governance to facilitate action in LFSs (Skog et al., 2018). In this of thought, there is a call to also integrate the social reproduction when designing new sustainable and resilient food systems (Picchioni et al., 2021).

These examples above show opportunities for alternative approaches to the industrial, globalized agri-food system. Indeed, they point at the need to better understand and foster the connections between people, places and the environment. The approaches contrast the often "blanket" procedures applied in global food systems which have led to severe externalities and vulnerabilities in the food system. The EU's goals are to reduce the environmental and climate footprint of the EU food system, strengthen its resilience, ensure food security in the face of climate change and biodiversity loss, and to lead a global transition toward competitive sustainability from farm to fork by tapping into new opportunities. This is reflected by the HLPE (the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security) reports on sustainable agriculture (HLPE, 2016) and forests (HLPE, 2017a), which call for more diverse and integrated production systems at different scales, from farm, community, landscape and even broader levels, in order to strengthen food system resilience to external shocks (including climate variability, natural disasters or economic shocks) and contribute to dietary quality and diversity through a more diverse food supply. In other words, there is a need for a radical transformation of the food systems. The participation of different stakeholders in transdisciplinary partnerships can play a key role in this transition, for instance in the regional co-creation of solutions delivering rapid transformational changes (Augustin et al., 2021). In response to the COVID-19 crisis, the EU's Farm to Fork Strategy stresses the need for a "just transition" in which environmental, health and social benefits of a more sustainable food system become accessible for all parts of society, but especially those being severely affected by the pandemic crisis, and more recently, the cost of living crisis. Quoting from the strategy, "ensuring a sustainable livelihood for primary producers, who still lag behind in terms of income, is essential for the success of the recovery and the transition" (European Commission, 2020a). This article describes the use of a new decision support tool, the Metropolitan Foodscape Planner, which features up-to-date European datasets to (1) assess the potential of current agricultural land use to provide food resources with special attention to the share of both plant- vs. animal-based products, and meet the demand of city dwellers, and (2) enable stakeholders to geographically allocate land use change decisions concerning desirable food groups to move toward a sustainable city-region food system.

The next Section Theoretical framework: The sustainability of food systems and the resilience of food supply presents the theoretical background to this article. First, it provides a definition of sustainable food systems through the lens of food supply resilience and a description of their main elements, then it goes on to discuss current approaches to assess the environmental, social and economic impacts of food systems, and the role played by spatial decision support tools in these assessments. Section Materials and methods presents the tool we used (MFP) and the methodology used, with a particular focus on components, GIS software, hardware and processware, and the assessments undertaken. Section MFP implementation describes the application of the methodology to the Copenhagen city region food system and Section Collaborative FAL Copenhagen workshops presents the results of the use of the tool in two collaborative workshops. Section Discussion discusses the results in the context of food systems sustainability and resilience. Finally, conclusions are provided in Section Conclusions.

Theoretical framework: The sustainability of food systems and the resilience of food supply

Food systems

The HLPE on Food Security and Nutrition (HLPE, 2017b) defines food systems as "gathering all the elements (environment, people, inputs, processes, infrastructures, and institutions) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes." The concept of food system is gaining more attention amongst the scientific community and policymakers (Béné et al., 2019) due to its increasing impacts on sustainability, namely the three dimensions of environment, society and economy (FAO, 2018). Therefore, it requires comprehensive assessments to ensure informed decision-making for a responsible and sustainable development (Lal et al., 2020).

Food systems constitute a complex, multi-actor system in which drivers influence their components and outcomes (Brouwer et al., 2020). Drivers represent external trends such as urbanization, climate change, energy prices and technology development. The constituent elements of a food system, according to the framework proposed by the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, include (1) food supply chains, (2) food environments, (3) individual factors, and (4) consumer behavior, and (5) diets (HLPE, 2017b). Food supply chains can be divided into stages starting from production, through storage and distribution, processing and packaging up to retail and markets. Food environments focus on food availability and physical access, affordability, promotion and information, as well as food quality and safety. Individual factors include economic, cognitive, aspirational and situational conditions. Consumer behavior influences both food supply chains and food environments and therefore is crucial to understand in relation to health.

The sustainability of food systems through the lens of food supply resilience

The sustainability of the current food systems is questioned as they do not provide food security and nutrition to everybody without undermining the provision to future generations (FAO, 2018). Modern food systems, compared to the traditional ones as described in Ericksen (2008), are more susceptible to system disruptions, due to their long supply chains, international pricing and trade problems, increasing amounts of processed food and animal products, increased packaging and retail (Maxwell and Slater, 2003). On the other hand, territorial markets and short supply chains are often a key component of agro-ecological systems, and can enhance access to fresh food, ensure greater value goes to the farmer, and reduce vulnerability to disruptions on international markets (IPES-Food, 2020). Therefore, supporting local short food supply chains, as well as strengthening participatory approaches in creating healthy food environments are key challenges in future-oriented food systems, especially in the context of global crises such as COVID-19.

One of the major barriers to the assessment of the current state of regional food production capacity, food flows, and regional food stocks is the fragmentation of landscape issues, which according to Lal et al. (2020) can be categorized into three types of fragmentation: (i) multiscale fragmentation of land policies, (ii) separate management of land for environmental and agricultural issues, and (iii) incomplete and fragmented geospatial knowledge about land and soil processes and properties. It is in this context spatial decision support tools can be of great value for assessing food systems and supporting decision making aimed at the development of place-based strategies for the implementation of resilient food systems that are tailored to the region in question. Spatial assessments can facilitate the quantification of environmental state, efficient resource management (water, soil, land), or improvement of environmental quality as a base for formulation of planning and policy recommendations (González et al., 2013). Decision makers require effective management tools for policy making that provide cognitive results in consideration of dynamic changes in underlying assumptions (Kersten et al., 1999). These capabilities are provided by decision support systems (Yang et al., 2010). Lal et al. (2020) highlights the linkages between soil management and the COVID-19 crisis, as well as the importance of geospatial decision support systems for land use planning and management.

Decision support systems for assessing food systems sustainability

Decision support systems (DSSs) process the data describing our surroundings into information and knowledge necessary for more suitable decision-making. DSSs have been used since the 1960s and were first described in the 1970s by Morton (Kazak and van Hoof, 2018). "*DSSs are computer-based systems designed for managers to help them to choose one of several options, by analyzing large amounts of data in a relatively short period of time*" (Kazak and van Hoof, 2018). Therefore, the DSSs are seen as multicriteria analyses. It guarantees the prediction of potential effects of planned development strategies, as well as creation of alternative scenarios to avoid negative impact of intended actions of decision makers (Kazak and van Hoof, 2018). DSSs are user-friendly solutions, which improve communication between decision makers, boost their satisfaction, increase organizational control, and as a result enhance effectiveness of decision-making (Alshibly, 2015).

DSSs can combine non-spatial (statistical) data and/or spatial data together with indexes, factors, algorithms, and assumptions necessary to assess the potential of the area or the impact of the implementation of the proposed strategy (Kersten et al., 1999). Therefore, one of the advantages of DSSs is perceived in this ability to combine multiple variables within a single system without having to perform calculations in external software (Kazak and Szewrański, 2013; Alshibly, 2015). The relevance of DSSs allows one to optimize the decision-making process by taking into account various factors, weight these criteria, express them in one denominator and thereby reduce potential failures (Kazak and Szewrański, 2013; Kazak and van Hoof, 2018). Despite the adequacy of DSSs, there is still a need for critical validation of obtained results, as well as integration into participatory processes. DSSs allow processing the data and provide output information. However, it is the decision-maker who is responsible for obtaining this information, understanding the results (knowledge) and making the final decision (wisdom) (Kazak and van Hoof, 2018).

We can distinguish spatial decision support systems (SDSSs) referring to geospatial futures (Kazak and van Hoof, 2018) or even Web-based spatial decision support systems (Web-based SDSSs) based on cyber-infrastructure platforms (Yang et al., 2010). These SDSSs allow us to describe potential future developments according to scenario analysis. Scenario methods belong to the strategic management concept and are a part of so-called macro-analysis groups. Scenario analyses consider the object and purpose of the scenario, its spatio-temporal scale, the type of indicators used to evaluate it (Kazak, 2018), as well as different spatial data as land use or soil (Terribile et al., 2015). The SDSSs could be implemented for validation of different spatial issues starting with adaptation to climate change

(Kazak et al., 2018) through land development (Stula and Kazak, 2019; Broza et al., 2020) to food system assessments (Heinemann et al., 2010).

The application of DSS for food and agriculture have been introduced in many journals and books presenting various applications from crop production, through water management, ending with machinery management (Heinemann et al., 2010). The DSSs allow for evaluation of suitability of land to produce quantity and/or quality of any commodity. The implementation of land suitability assessment using DSSs allows to maximize obtaining food, feed, fiber or energy on one hand, and safeguard the sustainable production on the other. Moreover, it supports the use of land according to its functions and provided services, as well as within the carrying capacity of the land (Wijffels et al., 2010). A recent example addressed Danish agricultural land use and associated GHG emissions from a more international perspective (Prag and Henriksen, 2020). In this study, the effects of a global adoption of the EAT-Lancet Planetary Health Diet on Danish agricultural GHG emissions were estimated through a calculation of the potential changes in land use in Denmark associated with a reduced animal production. It was evident that these changes enabled an increased local production of protein crops for animal feed to replace imported soy, restoration of drained wetlands as well as afforestation, all of which contribute to lowering agricultural GHG emissions (Prag and Henriksen, 2020).

Notably, one of the main approaches currently applied for such purposes are quantitative foodshed assessments. According to Schreiber et al. (2021), they can be classified in three types: (a) agricultural production capacity, (b) food flow and (c) hybrid analyses. The majority of the assessments are based on assessing the potential agricultural production capacity in order to feed the specific population of the city-region (i.e., foodshed) (Joseph et al., 2019; Zasada et al., 2019; Kurtz et al., 2020; Vicente-Vicente et al., 2021b); or to assess more specific issues as part of sustainability impact and ecosystem services assessments of regional food systems and land uses (Swiader et al., 2018; Tavakoli-Hashjini et al., 2020). The food flow assessments map consumers and producers, being thus useful when studying distribution networks (Karg et al., 2016; Wegerif and Wiskerke, 2017; Moschitz and Frick, 2020). Finally, hybrid foodshed analyses combine agricultural capacity and current food flow analyses (Porter et al., 2014; Mouléry, Sanz Sanz, Debolini, Napoleone, Josselin, Mabire et al., 2021; Vicente-Vicente et al., 2021a) and, therefore, are able to assess the dependencies on foreign food sources, vulnerabilities of the food system, and the environmental impacts of the food system re-localization (Schreiber et al., 2021).

In this context, a spatial-functional assessment tool "Metropolitan Foodscape Planner" (MFP) at the level of metropolitan regions was developed as part of the EU project FoodMetres (2012–2015). Drawing largely on European data sets, MFP allows the identification of the land footprint in the form of "local hectares" of agricultural productive land needed to feed urban populations according to the typical diets that are recognized for specific countries or regions. The assessment results in a spatial allocation model of food landscapes, differentiating between (1) an urban core, (2) a recreational-natural buffer zone around this core, (3) a plant-based food production zone including vegetables, fruit, cereals etc. for human consumption, and (4) a meat-based food production zone mainly covering fodder and grounds for livestock rearing. MFP can be operated on a digital MapTable allowing for participatory processes involving stakeholders to make concrete propositions for land use change in order to decrease the land footprint by increasing plant-based food production (Wascher et al., 2015). Figure 1 illustrates the model of Von Thünen (1826) which dictates the development of MFP2.0, and is based on distance from the city, preservation of food and amount of space. The main principle is that agricultural products that have intensive land use, have high transportation costs and are in great demand, would be located closer to urban markets.

Materials and methods

The method on which MFP is based includes a number of interconnected components, namely a dynamic Geographic Information System (GIS) and its map/data library, an interactive platform for stakeholder interaction: a touch-enabled screen (the MapTable) for face-to-face workshops, or a digital platform for online workshop interaction, and a series of interconnected workshops. In a nutshell: during a collaborative workshop, stakeholders use MFP to get informed about the status quo of the city region's food system as well as potential food system scenarios, discuss these scenarios, and utilize this information to propose changes in the foodscape on the MapTable that will improve the status quo of the food system. Section Collaborative FAL Copenhagen workshops describes such a workshop in the context of the food system in the Copenhagen city region.

Dynamic GIS with map library

The GIS included in the MFP (Figure 2) is an interactive layered digital map that (1) stores and communicates the map layers used in the assessments, (2) enables stakeholders to propose changes in the spatial patterns of the foodscape around the city region, and (3) provides real-time feedback on the impacts of these changes *via* dynamic charts. As soon as new food classes are assigned on the MapTable, the system recalculates food commodity shares and the supply/demand effects of the new spatial foodscape configuration (see Figure 3C).

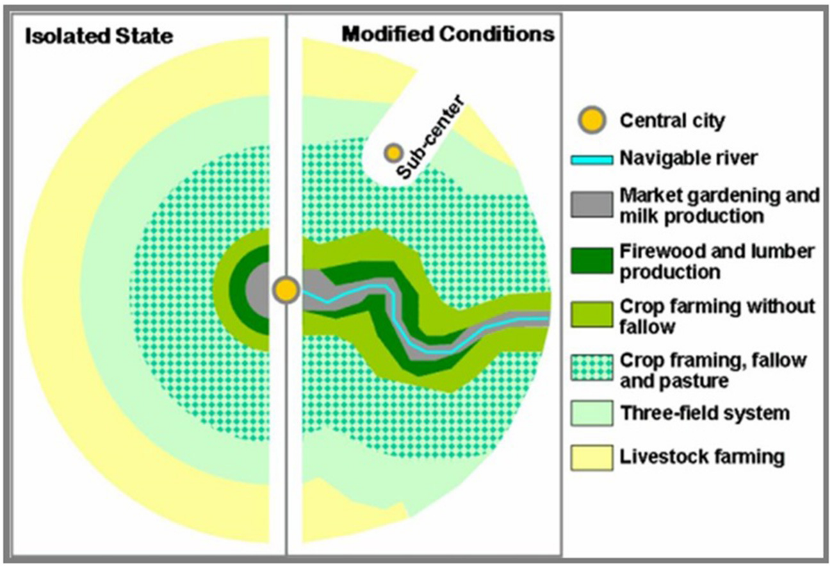

FIGURE 1
Concentric rings model for locational theory of Von Thünen (1826).

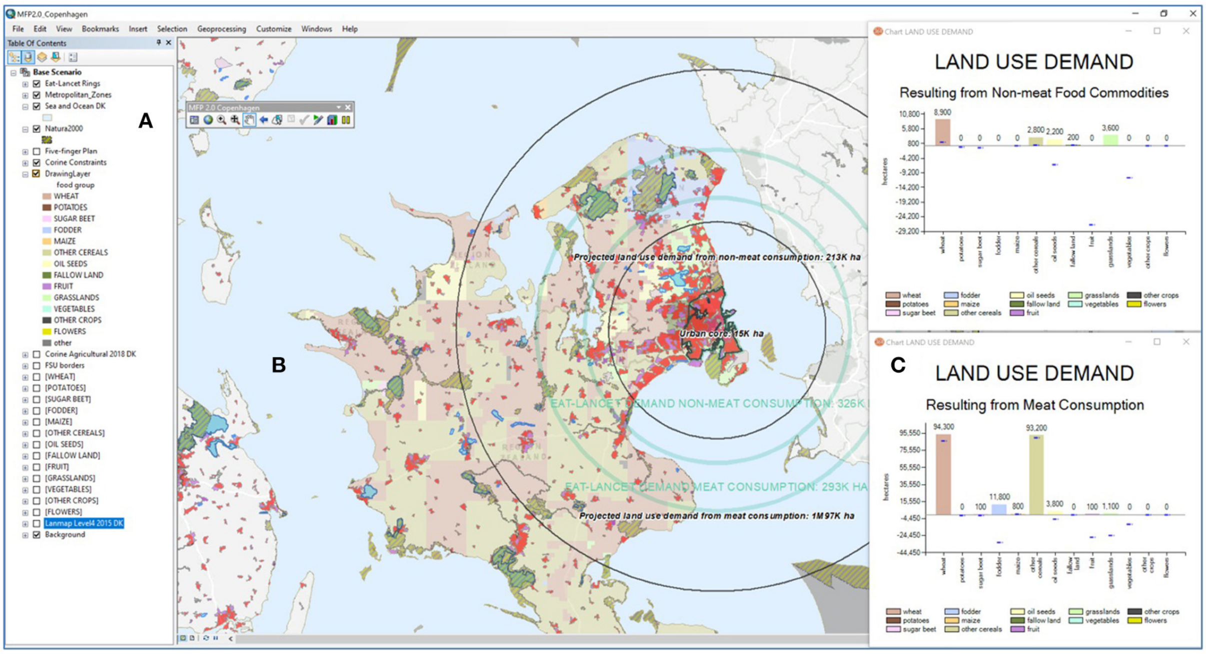

FIGURE 2
Main interface of the MFP Tool featured by a dynamic GIS, which contains three main frames: **(A)** the map library, **(B)** the interactive map area, and **(C)** two dynamic charts showing supply and demand figures for the food system of the Copenhagen city region.

Map library and available datasets

The dynamic GIS of the MFP2.0 is built within the environment of the software combination Esri® ArcMap 10.6 and CommunityViz Scenario 360™ 5.2. ArcMap provides the layered mapping environment while Scenario 360, acting as an extension to ArcMap, provides the interactive foodscape allocator and the dynamic charts that react to foodscape changes

TABLE 1 Datasets utilized in MFP.

Name of dataset	Description	Source
CORINE Land Cover 2018	European land cover map	https://land.copernicus.eu/pan-european/corine-land-cover
Natura2000 2020	European ecological network of protected areas	https://natura2000.eea.europa.eu/
Homogenous soil mapping units FSU 2019	European map of predicted crop areas on farm structure units. 3rd-generation Homogenous Soil Mapping Units (HSMU) as modeled by CAPRI (Kempen et al., 2005) and Eurostat crop area data disaggregated to FSU's by CAPRI for 33 crops.	https://ec.europa.eu/jrc/en/research-topic/crop-yield-forecasting
LANMAP2	European landscape map	https://www.wur.nl/en/show/The-European-landscape-map.htm
Multi-ring buffer around city start point	Concentric rings around city center based on Von Thünen model (1823) representing the urban ecological footprint of a food system	GIS data processing by the authors
Food Consumption literature	Figures on food and agriculture data (crops and livestock products) both at European and local level	Available food (FAO, 2018) (kg/capita/year) plus local data on food consumption

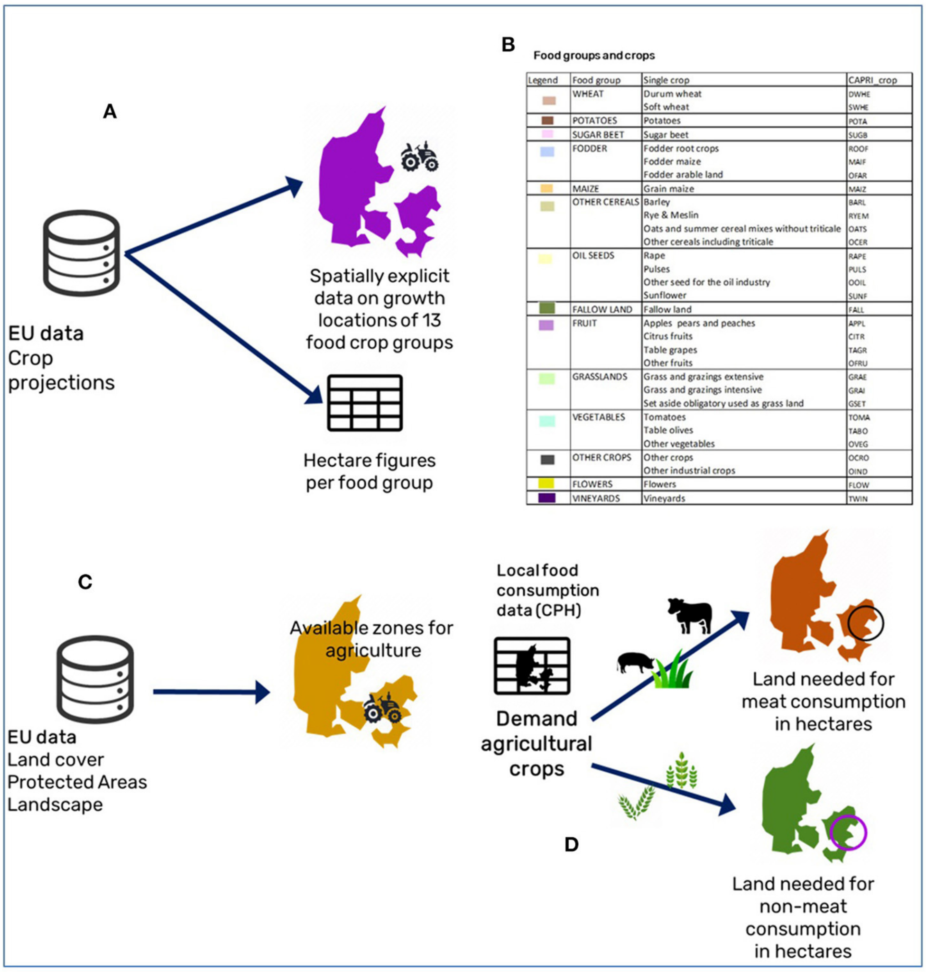

FIGURE 3
Determining the footprint of urban food consumption. **(A)** Steps to generate a map of growth locations for 13 food crop groups. **(B)** A food group is an aggregation of specific crops based on the table of food groups and crops. **(C)** Steps to generate a map of available zones for agriculture. **(D)** Determining the amount of land needed for animal- and plant-based food production.

made by stakeholders. The "table of contents" frame contains the map layers available in the MFP tool. Table 1 shows both the map layers and datasets included in the tool.

Determining the land footprint of an urban food system

Figure 3 shows a scheme illustrating the four steps within MFP to determine the land footprint (i.e., resulting area demand from a consumption pattern) of a metropolitan area. The first step to estimate the land footprint of human food consumption using the aforementioned datasets is to map food crop patterns and to estimate aggregated food supply figures. European FSU datasets are used for this purpose.

The FSU datasets contain growth projections for 33 CAPRI crops at the European level (Figure 3A), mapped on top of HSMU units (European Commission, 2020b). Out of this dataset it is possible to generate a map of dominant crops, which in turn can be aggregated into a European map of food groups. MFP utilizes the aggregation crop scheme shown in the table of step b in Figure 3B. For example, crop group "Oil seeds" consists of crops rape, pulses, other seeds for the oil industry, and sunflowers. Out of this European crop map, country-specific crop maps are cropped out (see Figure 4 for a Danish food group map). A cropped country-specific map of crop projections is used to determine aggregate supply food group values. Food demand values are calculated using available country-specific FAO food data (kg/capita/year) (Figure 3D). If local datasets for a particular city region are available, FAO food figures can be disaggregated, and then converted into required hectares per capita. The next step is to determine the zones suitable for agriculture, which form the input for determining the amount of land required to feed an urban population, i.e., the land footprint.

Within this implementation of the MFP tool, we chose the principle of the "local footprint" as the amount of land required to grow the food consumed by the population of a city differentiating between the land needed for animal-based food consumption and the land needed for non-animal (plant-based) consumption. Thus, for the remainder of this paper and for the sake of simplicity, animal-based food production will denote cow, chicken and pig meat production, excluding eggs and dairy products; while plant-based will cover plants for human consumption. In this MFP version, animal-based food production is represented by food groups Fodder and Grasslands, while plant-based is represented by the remaining food groups: Wheat, Potatoes, Sugar beet, Maize, Other cereals, Oil seeds, Fallow land, Fruits, Vegetables, Other crops, Flowers. Section Assessing the land footprint

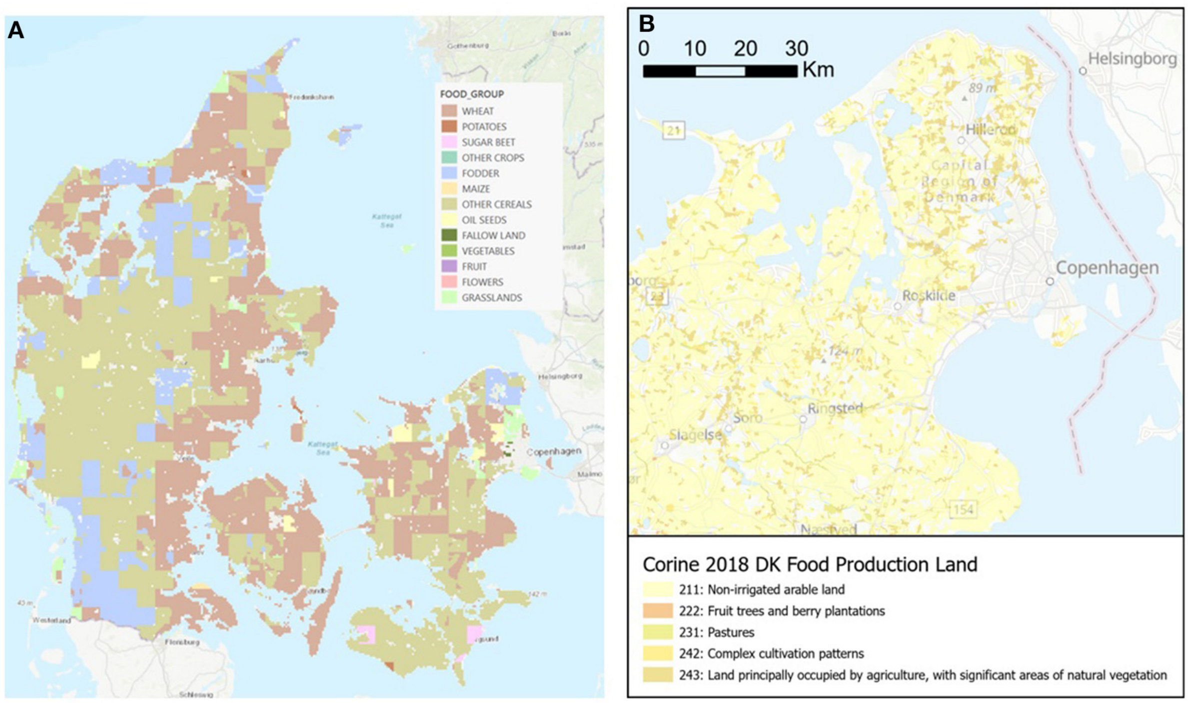

FIGURE 4
Map of Danish food group production for 2019 as extracted from FSU data, at a 1-km resolution **(A)** and agricultural zones around Copenhagen as extracted from CORINE **(B)**.

of food consumption in Copenhagen explains how this was done for the Copenhagen case. Building upon von Thünen's economic theory, the resulting zonation of an inner plant-based supply ring and an adjacently located external animal-based supply ring is mainly meant as input to the policy debate on the principle impact of meat consumption on regional food supply patterns. Determining a map of available zones for agriculture requires a map overlay process involving several spatial datasets (Figure 3C). The European CORINE land cover map is used to extract areas suitable for agriculture production (areas allocated land cover classes: "Non-irrigated arable land," "Fruit trees and berry plantations," "Pastures," "Complex cultivation patterns," and "Land principally occupied by agriculture, with significant areas of natural vegetation,") and to filter out unsuitable areas (urban areas, water areas, forest). Protected habitat areas are also filtered out using the European Natura2000 map. The LANMAP2 map is also used to include landscape-related suitable areas for agriculture and to exclude unsuitable landscapes. This overlay process produces a European map of available zones for agriculture, out of which country-specific maps can be generated (see Figure 4B). City-specific food demand values are used to determine the total amount of hectares required for meat and non-meat consumption.

The next step is to generate two concentric rings around the urban core, namely the plant-based ring and animal-based ring. The width of each ring depends on the available productive agricultural land in hectares and is estimated *via* an iterative spatial analysis process in which one ring buffer is first drawn around the city and then overlaid on with the available agriculture zones. The width of the buffer is then incrementally adjusted until the total demand food value in hectares matches the total area of agriculture zones fitted inside the ring. For plant-based diets, the total demand relates to all crops used for human consumption, whereas for animal-based diets the total demand relates to those crops used for animal feed, and thereby cow, pig and chicken meat production, hence excluding dairy and egg production. The result is two concentric rings, whose area sizes *portray* the amount of land factually required to feed a city on a plant-based consumption diet, and an animal-based food consumption diet, assuming that all available productive land would be used for covering the current food consumption of the urban core.

MFP implementation

This section describes the implementation of the MFP method using datasets from Denmark, and the Copenhagen city region. First, it describes the steps to determine the land footprint of Copenhagen in the context of the 13 food groups. Second, it shows how to map the aggregated land footprints for both the status quo and a projected diet consumption scenario. Third, it compares both footprint maps.

Assessing the land footprint of food consumption in Copenhagen

The method illustrated by Figure 3 was applied to assess the land footprint of (1) the current consumption situation (status quo) of the Copenhagen City Region Food System, and (2) a food system scenario based on the EAT-Lancet dietary advice. This dietary advice is available in The EAT-Lancet Commission Summary Report (EAT-Lancet Commission, 2019) and proposes a varied plant-rich diet that encourages an increased consumption of vegetables, fruits, whole grain foods, vegetable oils, legumes, as well as low-fat dairy products, fish and a decreased consumption of meat. Figure 4 shows the map of the 13 aggregated food groups for Denmark and the available zones for agricultural production as extracted from public European datasets (based on Figures 3A,B).

The assessment of crop-based food consumption in Copenhagen was based on food supply data (annual consumption per capita) for Denmark (FAOSTAT, 2021), using 2018 as reference year (Figures 3C,D). This data was adjusted with a factor accounting for variation in consumption patterns between the country as a whole and the Copenhagen city region, based on a study of Danish dietary habits (Pedersen et al., 2015). The resulting estimate of food supply per capita in Copenhagen was translated into land footprint (or area demand) using yield data from Statistics Denmark, averaged over 5 years (Danmarks Statistik, 2021d). An exception includes nuts, of which the Danish production is so small that it is not tracked in the national statistics. Data on nut yield was obtained from FAO, where data for 3 years was available (FAO crops). Area demand for animal-based foods was estimated directly through national statistics on fodder use, combined with yield averages (Danmarks Statistik, 2021b,c). Because Denmark has a significant net export of pork and dairy (~85 and 10% of production is exported, respectively), and a small net import of beef, poultry and eggs, the resulting area was subsequently adjusted to represent only area demand related to national consumption. This was done using a factor derived from data on production, export and import of relevant product groups (FAOSTAT, n.d.) and an estimate for how the use of different general groups of fodder is distributed among individual animal species in Denmark (Hermansen et al., 2017). Finally, national area demand per capita was calculated and adjusted with the factor accounting for variations in dietary habits between Copenhagen and Denmark. Table 2 compiles the resulting values for food supply and demand for both plant- and animal-based status quo production in Copenhagen.

Land footprint—Status quo in Copenhagen

Following the same method of Figure 3, we determined the land footprint of food consumption in Copenhagen for 2018. Maps in Figures 5A,C show two concentric rings, whose sizes were calculated by matching food supply and demand on top of the available agricultural land. Figure 5B compares the total footprint values of animal- and plant-based food consumption. Figure 5D shows aggregated food group supply values in hectares within each ring.

Projected EAT-Lancet diet consumption scenario

Food consumption in the EAT-Lancet scenario was based on a dietary scenario calculated by Lassen et al. (2020) in the development process for the new Danish dietary guidelines, based on the EAT-Lancet Planetary Health Diet. This diet differs slightly from the global diet developed by the EAT-Lancet Commission (Willett et al., 2019), because it was adapted to match Danish commodities. As the recommended amounts in the diet are only valid for adult consumption (Lassen et al., 2020), the diet was adjusted with the assumption that children (aged 0–14) consume on average 86.5% of the calories consumed by adults, based on a study of Danish consumption patterns (Pedersen et al., 2015), and data on the current age demographics showing that at present 16.2% of the Danish population are in the relevant age bracket (Danmarks Statistik, 2021a). Subsequently, the average per capita consumption was adjusted with an estimate for food waste, to be comparable with the baseline consumption data, representing food supply. The estimate used is that on a European level approximately 20% of food is wasted, most of it at the household, food service and retail stages (Stenmarck et al., 2016). Calculations of area demand for plant-based products were done according to the same method applied in the assessment of area demand of the current food consumption. For animal-based products, area demand results from the baseline assessment were adjusted using the relationship between the supply of animal foods needed for the Danish EAT-Lancet diet and the current supply, again using estimates from Hermansen et al. (2017) to allocate production of feed crops to individual animal species. The resulting values for food supply and demand for both plant- and animal-based food production for the EAT-Lancet scenario in Copenhagen are found in Table 3.

Figure 6 shows a map of the food groups (1-km resolution) overlaid with the resulting two concentric rings for the EAT-Lance diet scenario, whose sizes were calculated in a similar manner as done for the status quo: by matching food supply and demand on top of the available agricultural land.

Comparing land footprints of status quo and EAT-Lancet diet

Figure 7 shows the land footprint of the status quo overlaid with that of the EAT-Lancet scenario. By visual inspection, we see that the EAT-Lancet diet scenario requires a lot less land for meat production, while it does require more land for plant-based consumption.

This section presented the MFP implementation with Danish datasets. Next section presents the interactive

TABLE 2 Food demand and supply for Copenhagen: status quo (in hectares).

Food group	Demand plant-based	Supply plant-based	Demand animal-based	Supply animal-based	Area demand (ha/capita)
Wheat	8,603	110,100	0	94,300	0.0108
Potatoes	1,416	0	0	0	0.0018
Sugar beet	2,804	600	0	100	0.0035
Fodder	0	30,700	141,302	11,800	0.1766
Maize	0	0	0	800	0
Other cereals	2,906	106,800	0	93,200	0.0036
Oil seeds	794	13,600		3,800	0.0010
Fallow land	0	1,000	0	0	0
Fruit	7,747	0	0	100	0.0097
Grasslands	0	26,600	52,581	1,100	0.0657
Vegetables	3,189	0	0	0	0.0040
Other crops	0	0	0	0	0
Flowers	0	0	0	0	0
TOTAL	27,459	289,400	193,883	205,200	0.2767

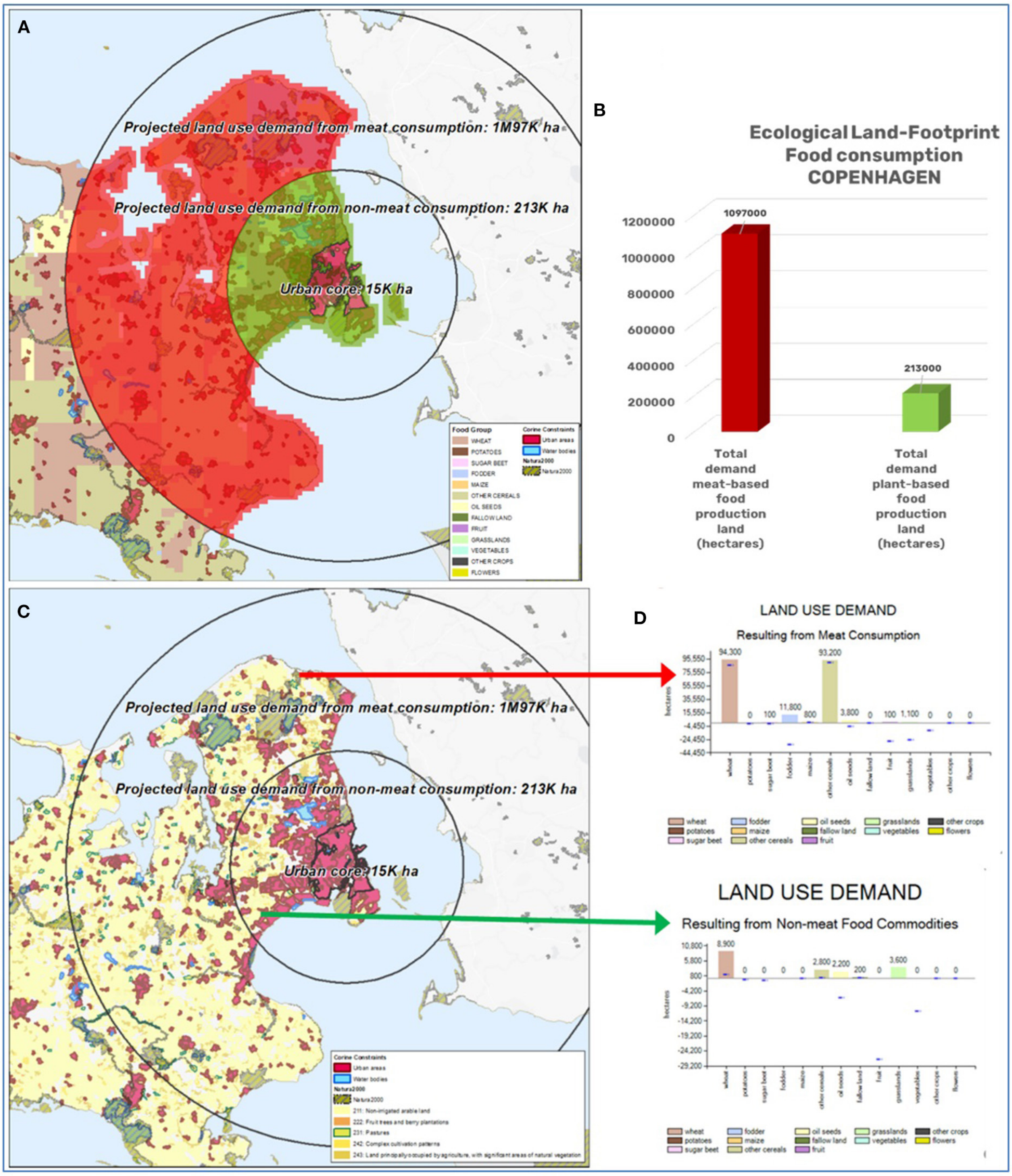

FIGURE 5
Land footprint food consumption in Copenhagen: **(A)** overlaid with map of food groups, and **(B)** as aggregated total food demand values in hectares. **(C)** Overlaid with a map of agriculture production zones. **(D)** Chart showing aggregated food group supply values in hectares within each ring.

part of this study, which deals with the co-creation of food system scenarios for the Copenhagen city region in a collaborative workshop setting as part of an ongoing H2020 EU-funded research project called FoodSHIFT2030. FoodSHIFT2030 aims to launch an ambitious citizen-driven transition of the European food system toward a

TABLE 3 Food demand and supply for Copenhagen: EAT-Lancet scenario (in hectares).

Food group	Demand plant-based	Supply plant-based	Demand animal-based	Supply animal-based	Area demand (ha/capita)
Wheat	7,551	13,400	0	25,000	0.0094
Potatoes	469	0	0	0	0.0006
Sugar beet	606	0	0	0	0.0008
Fodder	0	2,300	44,250	4,700	0.0553
Maize	0	0	0	0	0
Other cereals	2,551	5,200	0	28,900	0.0032
Oil seeds	8,700	2,800	0	500	0.0109
Fallow land	0	200	0	0	0
Fruit	26,946	0	0	0	0.0337
Grasslands	0	4,400	25,779	0	0.0322
Vegetables	10,969	0	0	0	0.0137
Other crops	0	0	0	0	0
Flowers	0	0	0	0	0
TOTAL	57,792	28,300	70,029	59,100	0.1598

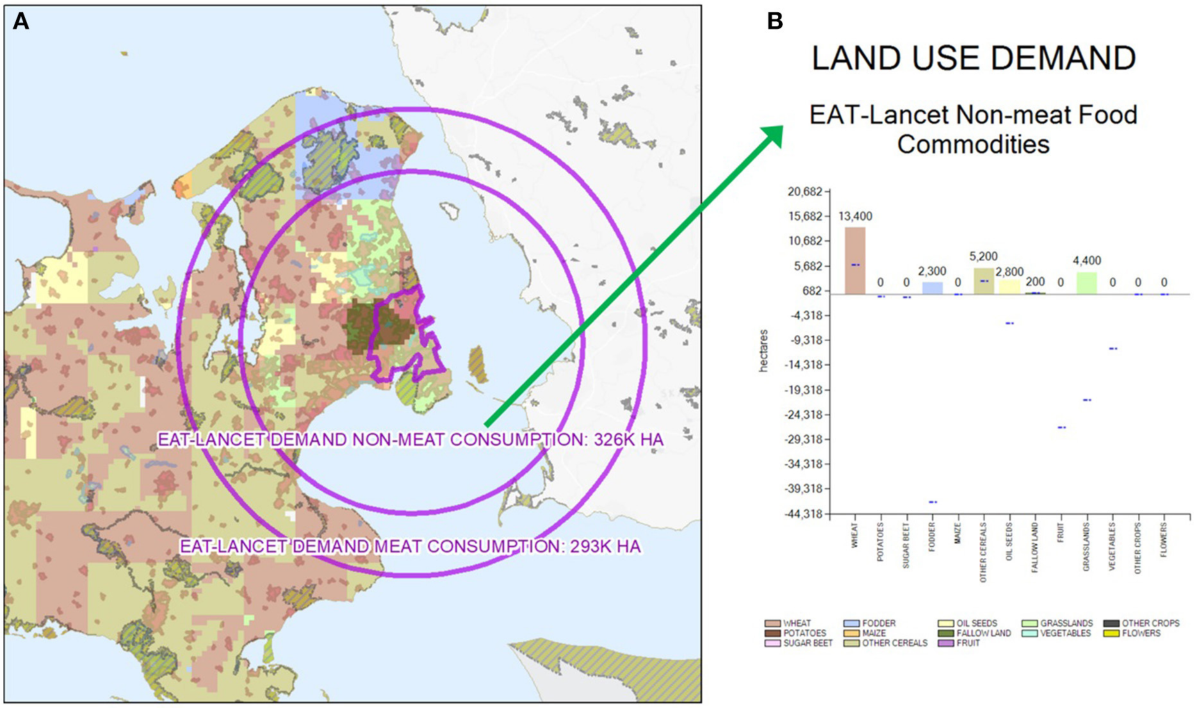

FIGURE 6
Land footprint EAT-Lancet food consumption in Copenhagen: **(A)** overlaid with map of food groups. **(B)** Chart showing the aggregated food group supply values in hectares within each ring for this scenario.

low carbon circular future, including a shift to less meat and more plant-based diets. FoodSHIFT2030 establishes FoodSHIFT Accelerator Labs for maturing, combining, upscaling and multiplying existing food system innovations across nine city regions, of which Copenhagen is one of the pilot cities.

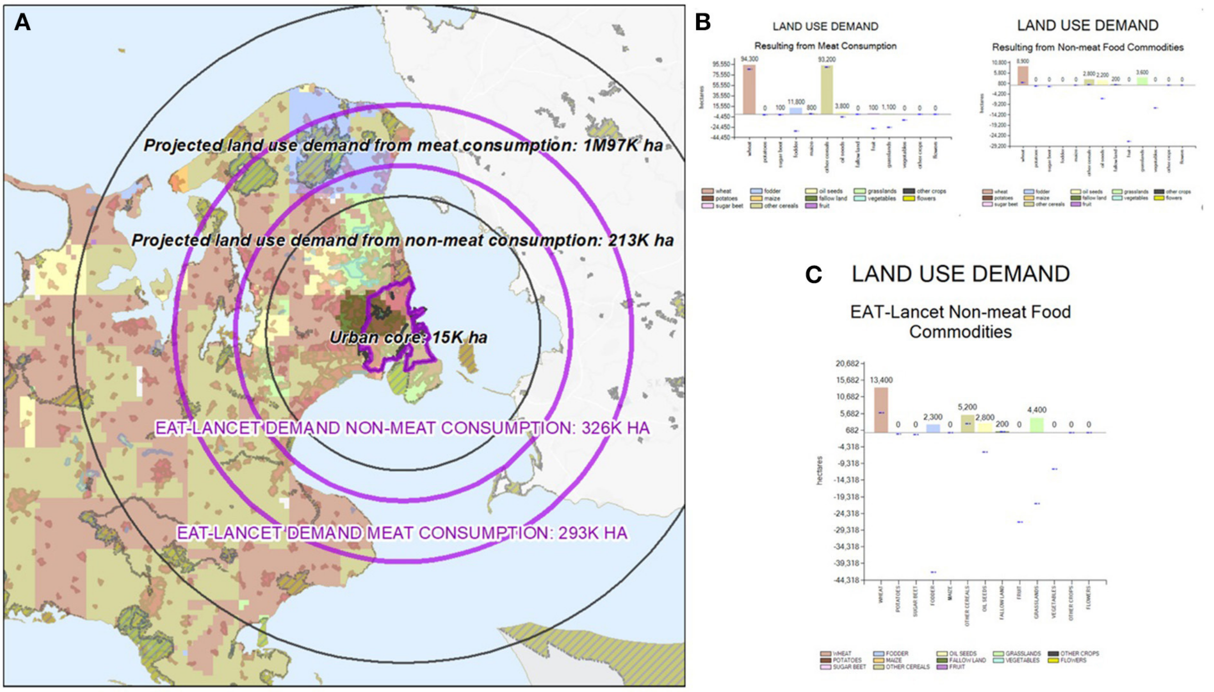

FIGURE 7
Land footprints of status quo and EAT-Lancet diet scenario: **(A)** overlaid with map of food groups. **(B)** Charts showing aggregated food group supply values in hectares within each ring for the status quo. **(C)** Chart showing aggregated food group supply values in hectares within the plant-based ring for the EAT-Lancet scenario.

Collaborative FAL Copenhagen workshops

We tested the MFP tool in the context of the food system of the Copenhagen City Region. Two interconnected collaborative workshops were held with participating members of the FoodSHIFT Accelerator Lab of the Copenhagen City Region representing food consultancies, local authorities, MSc students, and researchers. The first exploratory workshop was held digitally using the Zoom® online meeting platform. The second workshop was held in person as a workshop masterclass with MSc students from the University of Copenhagen. The format of the workshops follow the structure proposed in the MapTable-based methodology by Arciniegas and Janssen (2012), which features and tests collaborative SDSSs.

Workshop 1. Status quo of the CPH food system

The first digital collaborative workshop was held with members of the FoodSHIFT Accelerator Lab of the Copenhagen City Region representing food consultancies, local planning authorities, and researchers. The main purposes of the workshop were:

- Get a better understanding of current agricultural land use of the wider Copenhagen city region in the light of food demand vs. supply
- Highlight the impact of meat-based food consumption on land demand
- Discuss potential scenarios food system around Copenhagen that are more regionalized and sustainable

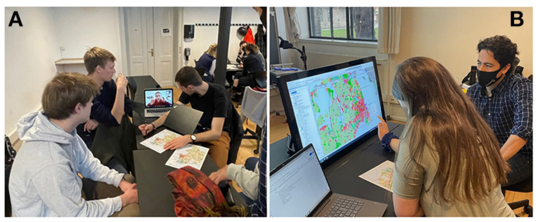

FIGURE 8
(A) Participants of one group propose scenarios on printed maps as an online participant co-discusses this scenario, and **(B)** participant applies the proposed scenario on the MapTable.

- Contrast the impact of current food demand with (future) alternative diets.

Workshop participants used the tool in "online mode" *via* the online platform Zoom to learn about the status quo of over-usage of resources in the city region, and to brainstorm and propose visions for food system scenarios for a more regionalized food system with increased resilience and less vulnerability to crises. The workshop was facilitated by the hosts, who acted as "chauffeurs" of the tool, and asked the participants to indicate orally or *via* the chat function which map layers to be turned on or off, where to zoom in or out, and on particular sports of interest in the study area. The workshop agenda included the following parts: (1) Introduction to workshop and project, (2) Introduction to the MFP tool and its map layers/data, (3) Current land footprint of CPH and food landscape, (4) Comparison with EAT-Lancet diet, (5) Discussion on scenarios, (6) Recap and prospects/Post-workshop survey.

Despite the limitations of holding a tool-centered workshop over Zoom (e.g., limited facilitation, lack of hands-on experience, less dynamic discussion), the workshop was considered to be a success. All nine participants found the MFP to be a useful addition to the strategic planning inventory when considering a city region's food system. The workshop was held in collaboration with the Copenhagen FoodSHIFT Accelerator Lab (FAL) and aligned with the FAL's innovation focus of reconnecting the city with its hinterlands. The workshop was attended by nine people representing the Lejre Municipality, local food consultancy firms, the University of Copenhagen and SUSMETRO. The workshop allowed for direct feedback from a diverse group on potential use cases for the tool and certain needs of stakeholders that would be required. As such, the workshop served as a practical application to co-develop the tool with key stakeholders, and to brainstorm on potential pathways for new foodscape strategies in Copenhagen.

As the main outcome of this workshop, three food system visions were discussed and proposed for further analysis in the MFP tool, based on the presented analysis rings, namely (1) a plant-based food & recreation vision (in the plant-based ring), (2) a meat-based food and nature vision (in the animal-based ring), and (3) agroparks as islands of plant-based food production (across both rings and the urban core). These three visions were discussed in the following face-to-face masterclass workshop held with students at the University of Copenhagen.

Workshop 2. Masterclass at the University of Copenhagen

The second MFP workshop was held as a masterclass called 'Future Foodscapes in the Copenhagen Region—New tools for political decision-making processes—The Metropolitan Foodscape Planner MFP Copenhagen'. The workshop lecture was attended by 20 students from University of Copenhagen MSc programs in Agriculture, Animal Science, Agricultural Economics and Climate Change. While the majority of the participants were physically present, a couple of students also joined the workshop *via* the Zoom online platform. The students used the MapTable-MFP combination to co-develop, draw, and discuss the impacts of the three diet scenarios which were proposed in the previous online workshop. The 2-h masterclass contained the following agenda points: (1) Welcome, (2) Introduction to the MFP tool: status quo in Copenhagen, (3) Results of the EAT-Lancet Scenario,(4) Work sessions, (5) Presentation and application to the MapTable, and (6) Discussion.

The workshop started with an intro lecture to the tool and its underlying models and philosophy, followed by a description of the status quo in Copenhagen, resulting in concentric rings that portray the land footprint. Next, the 20 class attendees were divided into three groups. Each group worked on a specific food strategy vision and was asked to draw their food strategy scenario proposals on A4-format paper maps (see Figures 8A, 9).

The three food strategy visions were: (1) Strengthening plant-based food and recreational qualities (inner ring), (2) Allocating land reserved for meat-based food and nature (outer ring), and (3) Agroparks as islands of plant-based food (across all rings). Figure 9 shows the three scenarios sketched on paper by the students. Once each group had drawn out their proposals onto paper, they were then asked to digitize their scenario by relocating food group classes of a reference situation on the MapTable by allocating new food groups to 1-km cells on the map (Figure 8B). Figure 10 shows these new digital food strategies as proposed by the groups, next to the reference situation for comparison purposes.

Results group 1: Plant-based food and recreation

Participants of this group proposed to allocate three food groups within the plant-based ring, namely Fruits, Grasslands, and Vegetables in order to increase plant-based food and recreation (see Figure 10, top-right map). The recreational dimension of these land use types will require adequate planning to allow easy access, education values and space for experiencing the new foodscapes. Figure 11 shows the impact of the scenario proposed by group 1 relative to the reference situation (status quo, Figure 11A) for both plant- and animal-based production. Within the animal-production ring (the outer ring) the situation did not change as no classes were allocated within it. Within the inner plant-based ring, there is a visible increase in the number of hectares for food groups Fruit and Grasslands, and a decrease in food groups Wheat and Other cereals, which aligns with the recommendation of the EAT-Lancet dietary. Consequently, the position of the blue lines on these bars

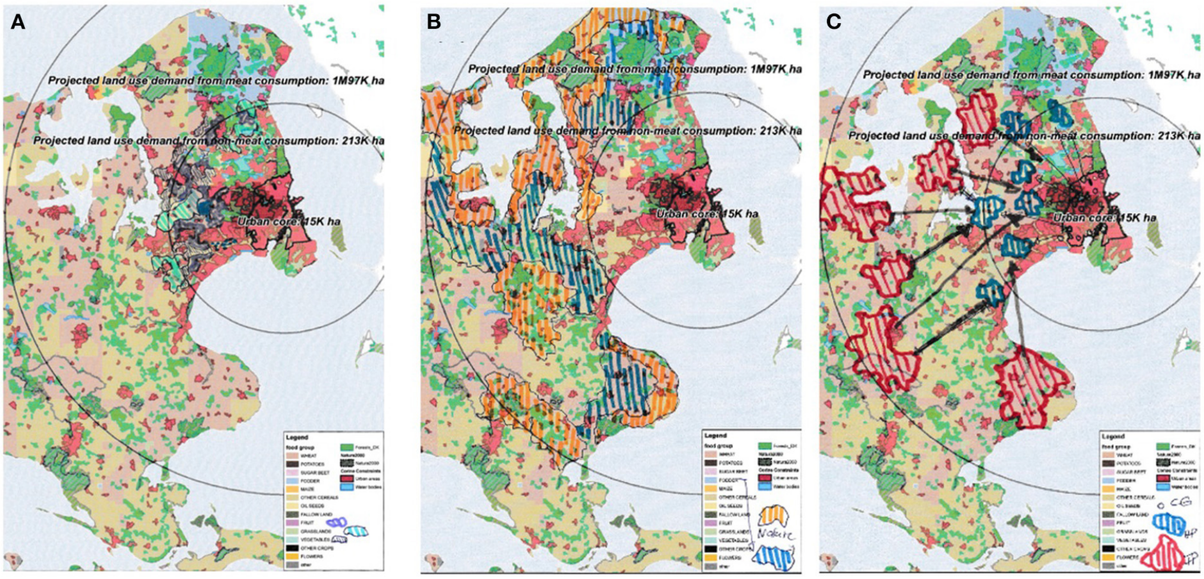

FIGURE 9
Scenarios sketched on paper by the three groups. **(A)** Plant-based food and recreation (inner ring), **(B)** Meat-based food and nature (outer ring), and **(C)** Agroparks as islands of plant-based food (across all rings).

in the chart got closer to zero (for Wheat it decreased by around 700 ha, for Other cereals by 700 ha), which means the supply for these food groups were farther from meeting the demand. For Fruits, however, the supply-demand difference got closer to zero by adding around 2,000 hectares, yet still lacked a substantial number of hectares needed to balance supply and demand.

Results group 2: Meat-based food and nature

Participants of group 2 proposed to allocate three food group classes within the outer animal-based ring, namely Fodder, Nature, and Grassland in order to represent food and nature areas in the outskirts of Copenhagen (see Figure 9B bottom-left map). Figure 12 shows the impact of this scenario relative to the reference situation (Figure 10) for both plant- and animal-based food production. Within the animal-based ring, there is a visible increase in the number of hectares for food groups Fodder and Grasslands and class Nature, which were mostly allocated to areas where food groups Wheat, Other cereals and Oil seeds were present. Concerning supply-demand, the position of the blue line for Fodder got farther from zero by some 10,000 ha, which implies that fodder supply got farther from meeting the demand. This results from a substantial increase in Nature areas, which does not have an effect on supply-demand difference, but does reduce the amount of animal-based food producing land, again in alignment with the EAT-Lancet diet, which feature less meat-demand and consumption, and thereby more non-agricultural lands. Within the plant-based food production ring (the outer ring) the situation did not change significantly.

Results group 3: Agroparks as islands of planted-based food

Participants of group 3 proposed to allocate Agroparks, Community gardens, and Family Parks across all rings in the Copenhagen city region (see Figure 9C bottom-right map). Family parks were drawn mostly near the edges of the outer animal-ring far from the city center. Agroparks were allocated for the most part within the plant-based ring in areas where Wheat and Other Cereals were present. Community gardens were drawn in open green areas inside the Copenhagen urban core and their areas are much smaller in comparison to Agroparks and Family parks. Figure 13 shows the impact of this scenario relative to the reference situation (Figure 10) for both plant- and animal-based food production. Changes can be seen across both rings. Within the animal-based ring, there is a visible increase in the number of hectares for Family parks and a slight increase in Agroparks. Most allocations were made at the cost of food groups Wheat, Other cereals and Oil seeds. Within the plant-based ring, an increase can be seen in Community gardens (CG), which is portrayed by class Agroparks - CG. Regarding supply-demand, the position of the blue line for Wheat and Other cereals got closer to zero by some 10,000 hectares. For class Agroparks (which is equivalent to Vegetables in the reference situation) there was also an increase in the supply-demand difference by a couple thousand hectares, which

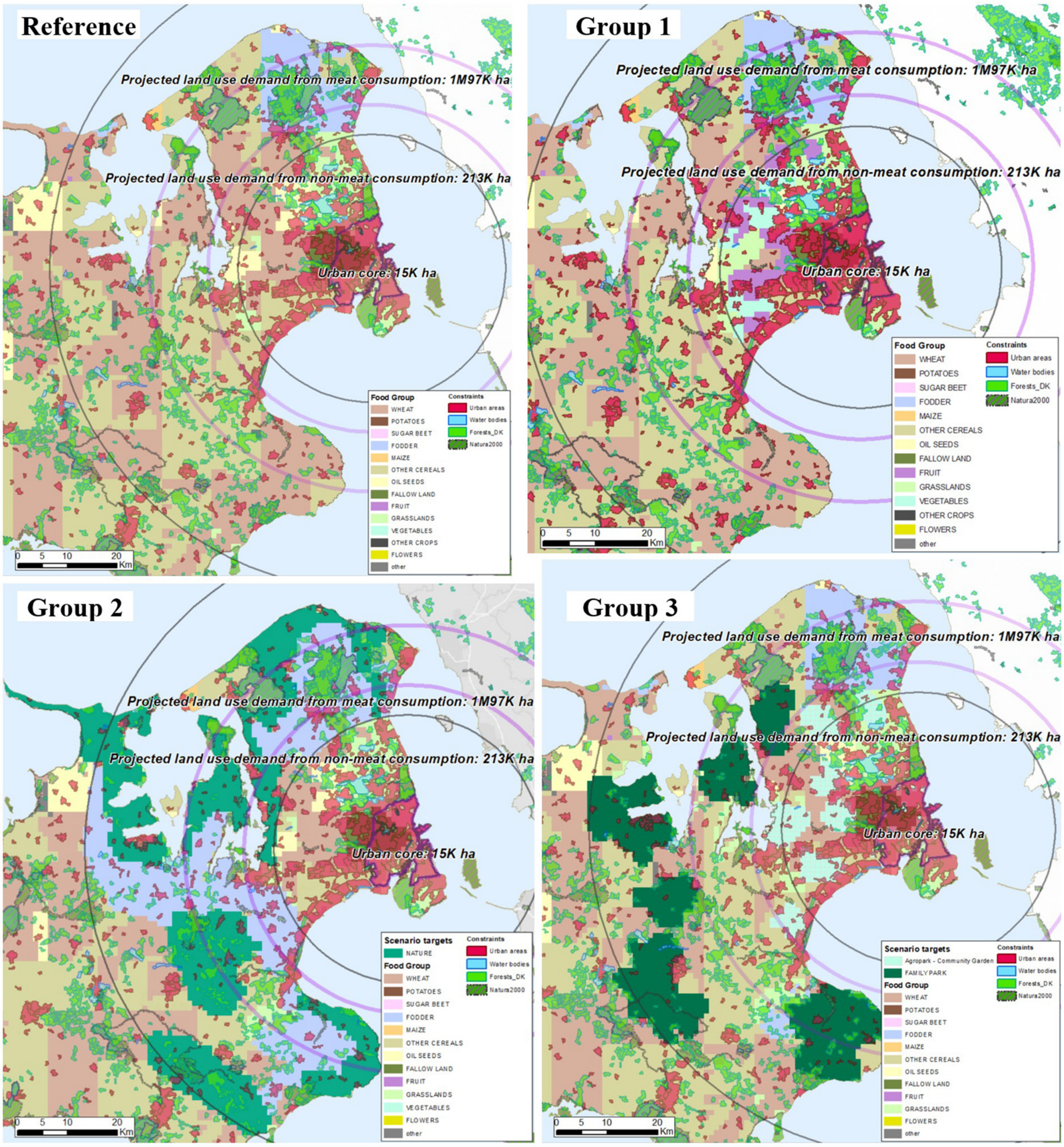

FIGURE 10
Reference situation and results from three groups as applied to Copenhagen on the MapTable. Black circles represent the land footprint of current consumption (outer: animal-based, inner: plant-based), while the purple circles represent the land footprint of the EAT-Lancet scenario.

implies the new supply for vegetables in this ring is getting close to meeting the demand.

Workshop evaluation

After the workshops, a survey was distributed. This survey was completed by the workshop participants, whose backgrounds and expertise include Sustainability consulting, Agronomist and Program manager, Scientific Project Manager, Innovation Support Officer for FoodSHIFT2030, background in sustainable agri-food systems, PhD Agroecology/geography, Sustainability Consultant at City of Aarhus (Mayors dept.), Director, FOOD, Food Policy Director, Research Assistant, University of Copenhagen Postdoc. The post-workshop surveys contained questions on their experience and specific aspects of

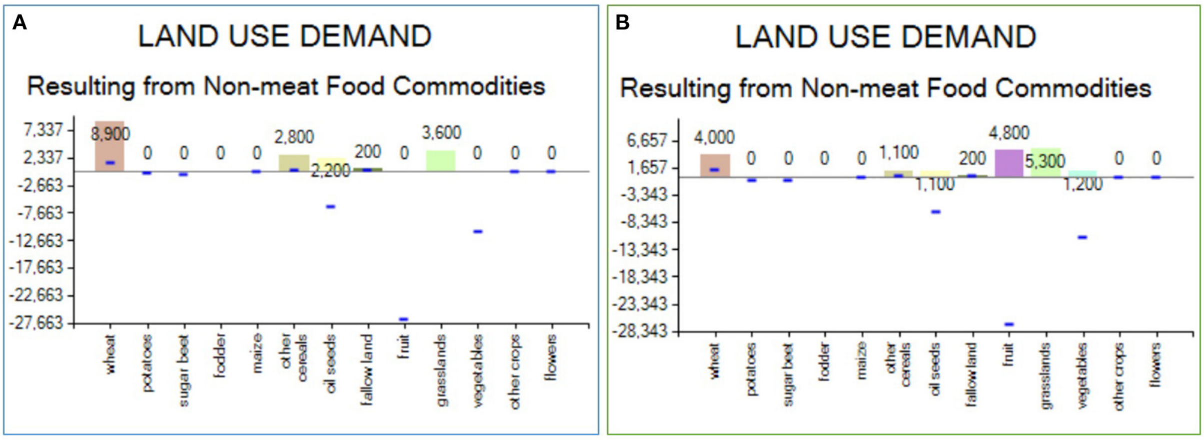

FIGURE 11
Assessment of scenario proposed by Group 1. **(A)** Reference, **(B)** Group 1's scenario. Charts show the supply-demand values for each food group within a particular ring. Bar charts show total supply hectares for each food group. Blue lines on bars portray the supply-demand difference, i.e., how much the supply is meeting the demand. Demand is met when the blue line is at ZERO point.

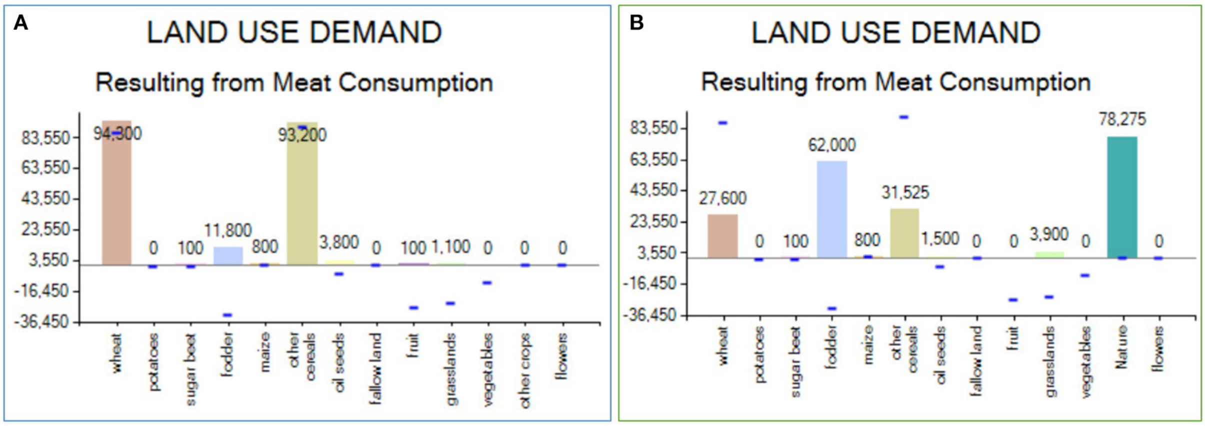

FIGURE 12
Assessment of scenario proposed by Group 2. **(A)** Reference, **(B)** Group 2's scenario.

workshop effectiveness. Participants were also asked to rate the MFP tool on the basis of several features. Tables 4, 5 summarize these responses. This table reveals that participants rated the interactive maps, the assessment module, and the portrayal of the status quo with the highest scores, whereas the portrayal of the EAT-Lancet diet was rated with the lowest scores.

Finally, participants were also asked about the workshop experience. Sixty-seven percentage of all participants indicated that the workshop fulfilled their expectations. Particularly, 89% of all participants considered the workshop to make a crucial contribution for developing a food system scenario for Copenhagen. When asked about the effectiveness of delivering a food strategy, 56% of all participants thought the workshop might do this to a marginal extent, while 34% to some extent. Regarding their opinion on Copenhagen's food system situation, 11% of all participants thought the workshop changed their opinion to a great extent, while 56% to a marginal extent, and 22% to some extent. Eleven percentage of all participants considered MFP a tool to support to a great extent the process of achieving consensus regarding possible locations of food strategies in Copenhagen, while 56% to some extent and 22% to a marginal extent.

Discussion

The impact of humans on the environment has been researched for years (Collins et al., 2020). As early as 1969, during a session of the General Assembly, a report by U Thant discussing problems of the human environment was

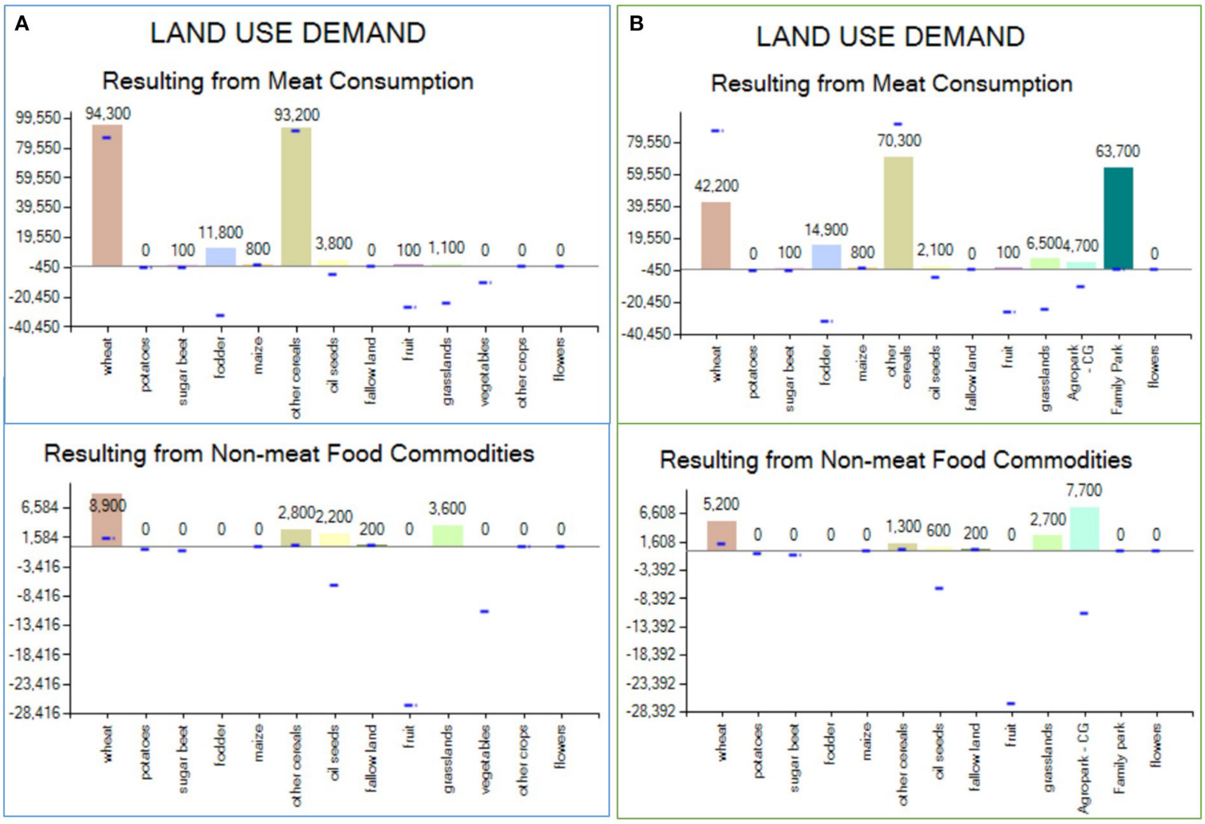

FIGURE 13
Assessment of scenario proposed by Group 3. **(A)** Reference, **(B)** Group 3's scenario.

TABLE 4 MFP workshop ratings: 1 denotes low and 10 high.

Workshop feature	Average rate
Content	7.6
Design	7.4
Support tools and aids	6.5
Facilitation and pace	7.8
Objectives	7.3

presented, pointing out the need to reverse unsustainable socio-economic trends affecting the environment. More than 50 years after that report, we are still consuming more resources and generating more pollution than the environment can withstand and regenerate. We are living in a time when humans are called the planet's largest ecological footprint, and the level of environmental and planetary overshoot is alarming (Swiader et al., 2020). Achieving cross-cutting goals, such as sustainable development, and addressing large-scale global challenges, such as climate change, should be served by evidence-based policy as an instrument for rationalizing the policy-making process (Weiland, 2016). MFP can become such a tool for knowledge-based decision-making by tool providing land footprint maps and data on food demand vs. supply for developing sustainable foodscapes in metropolitan regions.

Reducing land footprint by shifting diets in the CPH city-region

Previous research focused on using MFP to quantitatively determine the land footprint of human food consumption in metropolitan areas. Wascher and Jeurissen (2017) utilized an earlier version of MFP to determine the land footprint of the Antwerp-Rotterdam-Düsseldorf region, demonstrating that regional food supply does not depend on existing agricultural land use. Wascher et al. (2015) compared the land footprints of Berlin, London, Milano and Rotterdam by means of a demand-supply analysis. Both studies showed meat-based land footprints larger than plant-based. Table 2 shows that the land footprint for animal-based food production is larger than that of plant-based production for the status quo, whereas the EAT-Lancet scenario shows a larger plant-based land footprint (see Table 3,

TABLE 5 MFP tool ratings: 1 denotes poor and 5 excellent.

Tool feature	Average rate	Rate
Maps	3.6	Good
Interactive charts	3	Good
Interactive food allocator	3	Good
Clarity of support information	2.9	Moderate
Assessment	3.4	Good
Portray status quo	3.4	Good
Portray EAT-Lance diet	2.7	Moderate
Define key regions	2.9	Moderate
Co-develop food system scenario	3.3	Good

Figure 7). The obtained MFP results for the Copenhagen case showed that the current state of food habits requires ensuring 0.2767 ha per capita. However, the change into EAT-Lancet diet will connect with a land footprint of 0.1598 ha per capita (decrease of 42% in comparison to status quo). Results obtained for status quo are higher than those for cities such as Rotterdam (1.2 million inhabitants)—0.21 hectares per capita or Milano (1.2 million inhabitants)—0.20 hectares per capita (Wascher and Jeurissen, 2015). The results obtained based on EAT-Lancet scenario are close to data quantified for: Berlin (3.5 million inhabitants)—0.18 ha per capita or Antwerp (1.4 million inhabitants)—0.134 ha per capita (Wascher and Jeurissen, 2017). Such a high footprint obtained for the status quo can be associated with the significantly high human development in Copenhagen and Denmark overall (Human Development Index of 0.948 in 2021; United Nations Development Programme, 2022). As research shows, most countries with high HDI (above 0.7) have high land footprint and exceed biocapacity (Hickel, 2020).

MFP guarantees a few possibilities: (a) it allows the assessment of the current state; (b) it allows the creation of alternative scenarios based on certain assumptions from reports or studies—such as the scenario based on the EAT-Lancet diet for Copenhagen; and (c) it allows the creation of hypothetical scenarios based on changes to population or food consumption (Kazak and Szewrański, 2014). Therefore, the hypothetical scenarios are created on a "what if" basis (Pettit et al., 2015), i.e., verifying what the impact on the environment (in this case, the land footprint) will be, e.g., changing meat consumption by 30% vs. increasing potato consumption by 25%. Such assumptions can be created on the fly, e.g., during workshops, and thanks to pre-prepared calculation functions—automatically calculated. Moreover, the MFP does not represent a finite solution. It could be adapted to emerging new data and the assumptions chosen by the stakeholders for whom research is conducted. Therefore, in other cases, new assumptions could be made regarding the assignment of the land footprint differentiated between meat and livestock products. This assumption can be made based on research conducted, i.e., by Poore and Nemecek (2018), which indicates the land footprint per kg of product including such division, i.e., land footprint of beef: beef herd (369.81 m^2 per kg) vs. dairy herd (43.24 m^2 per kg). We plan to explore such assumptions in future studies.

MFP as a pedagogical tool for academic programs in the world

The University students found the MFP tool easy to use and using the MapTable allowed for learning by doing. This is backed by the high ratings on the tool given by the students in the post-workshop survey. After a lecture and short demonstrations, the students were able to perform the foodscape allocation tasks with further support. The awareness of the current young generation is significant enough to introduce this kind of cognitive workshop in various types of classes ranging from geography and spatial management to social economics. Classes using such methods and tools as MFP can be conducted equally well in universities and high schools. In particular, it was representatives from these schools who launched the climate strikes (e.g., Fridays for Future, Extinction Rebellion). Therefore, there could be no better time to push socio-economic and cultural change toward more sustainable development.

Land use conflicts with projected sustainable food landscapes

There are a number of conflicts connected to power, legal, and real estate speculation issues The role of private sector is crucial in projected sustainable food landscapes, along with the reality of power relations, such as in land use, finance, expertise, political lobbies. Participatory processes should pay attention to giving a voice to both private and public stakeholders, in order to have a good picture of the dynamics and power relations shaping regional food system to emerge. Methodologies like that of MFP provide platforms for bottom-up collaboration where the focus is on informed decision making by means of a transparent communication of impacts of human actions, which in turn inform the planning of interventions.

Conclusions

This article described the use of a spatial decision support tool in two workshops as part of the living lab activities aimed at improving the sustainability of the food system in the Copenhagen city region.

MFP to improve food system sustainability

MFP is a spatial decision support system, designed to be used in a workshop setting using a MapTable as the main interface between spatial and food-related datasets, scenarios, and users. This article investigated the applicability of such a system to assess the footprint of food consumption and to allow for the co-development of food system scenarios that reduce this footprint and might address resilience in times of food-related crisis. Recent work on assessing resilience considers diet regionalization and crop diversification as factors that positively influence the resilience of a food system (Vicente-Vicente et al., 2021a). Results from this study indicate that there is potential for MFP to support decision-making processes that aim to design more regionalized food systems. MFP proved effective to communicate the impacts of human food consumption by means of combining geographical layers on land use, agricultural production, and spatial constraints and presenting them on the MapTable. MFP can seemingly make a good fit for gathering input and/or ideation, especially at the beginning of such decision-making processes, where visions are developed and discussed. As reported in the post-workshop surveys, city officials, planners, and the students gave positive feedback on the tool. MFP can be particularly relevant to scenario co-development methodologies, which makes MFP useful as a tool of persuasion and opportunities for change. As it is based on public European datasets, MFP can be applied in other city regions in a relatively straightforward process. The tool is flexible enough to consider other diet scenarios depending on cultural and/or local factors if EAT-Lancet is not applicable. The exchange of scenarios and lessons learned from different city regions could offer a wealth of inspiration and knowledge across Europe in these times of crisis. It can be argued that the use of MFP can contribute to fostering the regionalization of the food system, which in turn can contribute to the sustainability and potentially the resilience of the food system amidst the effects of COVID-19 restrictions. For example, despite restrictions, the tool can be implemented online without losing the participatory element. As previously noted, participatory processes are essential for informed decision-making, for which hybrid tools are key in providing flexible options for continued progress, despite external circumstances such as COVID-19. The methodology could be helpful for assessing other CRFS and to meet goals, such as, e.g., Farm to Fork strategy, net-zero CO_2 emissions by 2050. New versions of the tool might include new indicators that take the assessment beyond land footprint measurement, which can engage more stakeholders. Indicators, such as reduction of GHG emissions for livestock as a result of the implementation of new plant-based diets, food waste reduction or a quantification of the regionalization of food systems by means of measuring spatial patterns (e.g., clustering) of new foodscapes, and overlaying these results with transportation infrastructure datasets can constitute compelling additions for future MFP implementations.

Collaborative workshops

Similar workshop approaches have been effective in supporting collaborative land use relocation processes (Arciniegas and Janssen, 2012). Workshop participants found the MFP-MapTable approach innovative and potentially useful; particularly, its capability to visually inform about the land footprint impacts of current food consumption, and how new, healthier and sustainable diets can diminish this impact while meeting the food demand. Participants indicated that the approach offers concrete opportunity and objectives for stakeholder cooperation, and a good starting point for opening discussions. The tool played a central role in facilitating two crucial tasks for improving the resilience of the food system of the Copenhagen city region, namely (1) the co-development of three vision pathways with concrete spatial scopes that relate to respectively animal-based and plant-based food production (and their combination), and (2) the co-development of three new food system scenarios that took this vision as the departure point. Results showed that the interactive element was well received and could open doors for much more participatory-oriented strategy development, which could be part of a wider participatory trajectory on a city-region basis. Workshop participants indicated that the MFP results contributed marginally to delivering a food system scenario. Future studies could expand the methodology to include recommended follow-up steps for a more detailed food system scenario, addressing the question of how to use the MFP results to help forming a concrete scenario.

Lessons and limitations

The MFP-MapTable approach has several limitations connected to its scope. Firstly, the ongoing COVID-19 global pandemic hindered the organization of face-to-face workshops. Consequently, the first workshop was held online *via* Zoom, and the second workshop was held using a combination of in-person (keeping a 1.5-m distance) and online, i.e., a hybrid workshop. Organizing such a hybrid policy workshop requires more effort than organizing a face-to-face workshop, and this also plays a role in reducing the proven capabilities of the MapTable to support communication and interaction between workshop participants, and the information provided by the tool. It is recommended to expand workshop-based methodologies for foodscape planning to include online methodologies, and to combine online and in-person. Secondly, the MFP only considers animal- and plant-based food production on land and in the city region, ignoring other sources, such as seafood and food imports, and excluding other food products such as dairy and chicken eggs. Future studies can address these weaknesses by means of targeted data measurement and collection. Thirdly, administrative boundaries were used to define the CRFS boundaries (e.g., Swedish administrative areas are not part of the study), which is also connected to the issue of overlapping analysis rings from other city regions. The case of Copenhagen is quite particular, as the city is located near the coast and close to the Swedish border, which would imply that its analysis rings might cover areas in Sweden. However, eventual food supply from Sweden was not considered. Fourthly, distinct production systems are not considered (e.g., conventional vs. organic), and the footprint assessment did not include transportation and logistics impacts. Fifthly, MFP allows for the allocation of food groups to cells of 1-km resolution. This resolution can be quite suitable for an entire city region around a city the size of Copenhagen or larger, but perhaps less suitable for smaller city regions or urban areas, such as neighborhoods. For example, allocating large-scale Agroparks proved straightforward to do in this configuration, but allocating small-scale scenario targets, such as community gardens within the urban core of Copenhagen proved challenging due to the size of the potential target areas. It is recommended to investigate the optimal ratio between city size, population, and scenario targets. Finally, the European datasets used in the tool allows the creation of food group maps for any city in Europe. However, local data on food supply (i.e., existing crops) as well as demand and consumption is needed for more accurate and realistic assessments, reliable enough to be used in food policy workshops.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Author contributions

GA led the manuscript writing process, tool development and workshop implementation, and the research involved. DW developed the initial versions of the tool, was involved in the research and organization of all workshops, and contributed to all sections in the paper. PE contributed to literature review, workshop organization, conclusions section, and proofreading. MS and MŚ contributed to literature review on food systems and SDSS. JV-V contributed to literature review on food systems and SDSS, conclusions section, and proofreading. TU contributed to workshops organization and hosting, and to the case study description. AP contributed to data collection, methods section, and participated in workshops. ML contributed to workshop organization and data collection. EW contributed to data collection and participated in the workshops. LS contributed to workshop organization, conclusions, and manuscript proofreading. ES contributed to literature review and manuscript proofreading. CH contributed to workshop masterclass hosting and preparation, and manuscript proofreading. All authors contributed to the article and approved the submitted version.

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Conflict of interest

Authors GA, DW, and PE were employed by Susmetro - Sustainable Design for Metropolitan Landscapes. Author TU is the director of Sct. Hans Have.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Accelerating the transformation to a sustainable food economy by strengthening the sustainable entrepreneurial ecosystem

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Strengthening the sustainable entrepreneurial ecosystem (SEE), particularly its support functions for small to medium-sized enterprises (SMEs), is increasingly seen as an important means of accelerating the transformation to a sustainable economy. Little is known, however, about *how* to strengthen SEEs. In this article, we evaluate a series of 16 projects intended to develop SEE functioning to accelerate transformation to a sustainable food economy in the Greater Phoenix Area of Arizona. We use an evaluative framework designed around a set of ten SEE support functions to qualitatively assess the baseline state of the SEE, how projects were executed, the effects of these projects, and the overall changes in the SEE that resulted. The findings indicate all but one projects had positive effects on the SEE (nine weak, six medium). In conjunction with other developments, the projects raised the overall SEE performance from the baseline state of two functions being performed at only minimal level, to six functions being performed minimally, and one at a medium level. Insights gained from comparing results across projects suggest tentative guidelines for future practice, which should be useful for SEE stakeholders, including policy makers, economic development agencies, financial institutions, consultants, and educators, interested in strengthening SEEs. Researchers engaging in studies on strengthening SEEs may benefit from the evaluative framework enabling larger cross-case comparisons.

KEYWORDS

sustainable entrepreneurial ecosystems, sustainable business practices, small business sustainability, entrepreneurial ecosystem functions, sustainable food economy, sustainable economic development, sustainable food systems, food economy transformation

1. Introduction

Urgent sustainability challenges such as climate change necessitate an accelerated transformation to a sustainable economy in which economic sufficiency, ecological integrity, and social justice are simultaneously pursued rather than prioritizing growth and profit (Jackson, 2016; Raworth, 2018). Small to medium-sized enterprises (SMEs) utilizing sustainable business models and practices play an essential role in such a transformation (Anglin, 2011; Rhydian Fôn and Cato, 2014; Parker, 2017; Briamonte et al., 2021). Yet, individual businesses and entrepreneurs cannot do this alone: a *sustainable entrepreneurial ecosystem* (SEE) with various support functions is required for sustainable SMEs to thrive (Cohen, 2006).

SEEs are composed of economic actors (e.g., SMEs, suppliers, customers) and various support organizations—all committed to using and supporting sustainable models and practices (Forrest et al., 2022). SEE actors include entrepreneurs, government, investors, educators, consumers, and others who exchange information, knowledge, and resources, and otherwise interact to support sustainable business practices (Cohen, 2006; Fichter et al., 2016; Bischoff and Volkmann, 2018; Volkmann et al., 2021). The SEE concept recognizes that entrepreneurs (including entrepreneurial SMEs) belong to a broader entrepreneurial ecosystem (EE) and their success in adopting sustainable practices is often predicated on support received within this EE (Cohen, 2006; Fichter et al., 2016; Bischoff and Volkmann, 2018; Volkmann et al., 2021; Wiek and Albrecht, 2022). Such support comprises a range of EE functions, such as financing, capacity building, and policy making (Forrest et al., 2022). Actors involved in performing these functions may vary from place to place and with the SEE's stage of development, but entrepreneurs are most effectively supported when all functions are provided. Accelerating the transformation to a sustainable local economy, which depends upon the uptake and scaling of sustainable business practices by SMEs, is therefore best achieved by developing the functions of an SEE.

SEE research is an emerging field and the literature is still rather limited (Volkmann et al., 2021). It includes conceptual articles describing the general nature of SEE in terms of stakeholder composition (Fichter et al., 2016; Bischoff and Volkmann, 2018), the actors, activities, and resources involved (Cohen, 2006), or the functions they perform (Forrest et al., 2022). Several empirical studies explore actual SEEs in different regions and economic sectors (Cohen, 2006; Pankov et al., 2019; Bischoff, 2021; DiVito and Ingen-Housz, 2021), providing insights into contextual factors and actions that may increase SEE effectiveness. The literature, however, pays little attention to the development of SEEs, and lacks substantive engagement with the sustainability dimension of SEE (Forrest et al., 2022).

The literature on SEEs builds on that of general entrepreneurial ecosystems (EEs), and assumes SEEs are specialized versions of EEs (Cohen, 2006; Bischoff and Volkmann, 2018; Volkmann et al., 2021). The overriding message is that EE development is a dynamic process, greatly influenced by context and stakeholder agency (Feldman, 2014), and a bottom-up, systemic, multi-stakeholder approach is advised (Feldman and Francis, 2004; Isenberg, 2010; Stam, 2015; Feldman and Storper, 2018). While some general principles are discernible on how EEs and, by extension, SEEs should be developed, they are neither specific nor comprehensive enough to be of practical use in sustainability-oriented policymaking or practice.

Against this background, this study asks *how SEEs can be purposely developed to accelerate the transformation to a sustainable economy*. We address this question through an ex-post evaluative case study of 16 projects to develop the SEE and hence accelerate the transformation to a sustainable food economy (SFE) in the Greater Phoenix Area of Arizona. The projects were conducted by the Sustainable Food Economy Lab at Arizona State University in cooperation with various partner organizations between 2017 and 2021. The focus was on the *food* economy due to shared interests, knowledge, and networks of the partners, and the opportunities for generalizable insights afforded by topically related projects.

The study makes several contributions to the theory of SEEs. First, it is an empirical contribution to a gap in the literature on developing SEEs, namely, on how different types of projects and approaches may affect the development of SEEs. Second, it generates somewhat generalizable knowledge, in the form of guidelines, of use to practitioners developing SEEs, including policy makers, economic development agencies, financial institutions, consultants, and educators. The study demonstrates that SEEs *can* be successfully developed, even with limited means, which should provide motivation to cooperate across stakeholder groups on such efforts. The guidelines then offer specific empirically-based advice on *how* to develop SEEs, which should enhance stakeholders' effectiveness in doing so, e.g., when developing sustainable financing options for sustainable SMEs, irrespective of the specific economic sector. And third, the developed and applied evaluative framework should be useful for researchers engaged in studies on strengthening SEEs by providing a methodological base for robust evaluations while allowing cross-case comparative studies through standardized variables and data collection methods. Larger cross-case comparisons will support further empirically-based theory building.

2. Advancing the sustainable food economy in Phoenix

The *Sustainable Food Economy Lab* (SFE Lab) together with other research units at Arizona State University and local stakeholders, conducted a series of 16 projects over the ∼5-year period to December 2021, with the goal of accelerating transformation toward a sustainable food economy in the Phoenix area. The projects were designed and executed using a transdisciplinary sustainability research approach (Lang et al., 2012), engaging local food entrepreneurs and SMEs, local government, and non-profit organizations (NPOs) in developing practical solutions to sustainability problems whilst building broader stakeholder capacity and generating new, solution-oriented knowledge. The projects varied in scope,

TABLE 1 Projects conducted to advance the Phoenix area sustainable food economy (2017–2021).

Years	Project (*accelerator)	Description	Stakeholder groups (*lead)	SFE sector(s) impacted	SEE function(s) impacted	Project approach
2019–2021	Coop startup program	Design/deliver a training/startup program for sustainable cooperative food business veteran and low-income entrepreneurs	SMEs (Consultancy)*; researchers*; entrepreneurs; local government*	Multiple	Capacity building	Hybrid
2018–2021	Food forest	Design and startup a commercially viable, sustainable food forest worker cooperative with low-income entrepreneurs	NPOs*; researchers*; entrepreneurs; schools	Production and processing	Consulting	Deliver
2020	Farmland conservation*	Initiate a multi-stakeholder coalition to explore/implement urban farmland conservation solutions to support local sustainable farmers	NPOs*; local government; researchers; SMEs; students	Production	Material provision	Develop
2020	SME guide*	Develop/disseminate a navigational guide to the myriad regulations faced by food SME startups	Local government*; researchers	Multiple	Policy making	Deliver
2020	Indigenous food*	Document and promote indigenous food entrepreneurs in Arizona	Local government*; entrepreneurs; researchers	Processing and retailing	Advocating (cultivating)	Deliver
2020	Craft brewery*	Lead a craft brewery through a B-Corp assessment and explore/plan sustainability solutions to address weaknesses	Researchers*; SMEs; students	Processing	Consulting	Deliver
2020	Farmland trust	Explore conversion of an urban farm collective's land lease to a sustainable farmland trust	Students*; NPOs; researchers; SMEs	Production	Consulting	Deliver
2020	Brewing economy	Review Arizona craft brewing economy sustainability, envision a sustainable future, explore solutions with state's brewing community	Researchers*; NPOs*; students; entrepreneurs; SMEs	Processing	Capacity building (networking)	Deliver
2020	Finance tool	Develop a tool and local database to assist sustainable SMEs find finance options	Researchers*; students*; NPOs	Multiple	Financing	Develop
2020	SFE training	Deliver a city staff training workshop for sustainable food economy planning and policy support	Researchers*; students*; local government	Multiple	Policy making	Develop
2019–2020	Food SME training	Integrate sustainability into the curriculum of an established minority-focused food entrepreneur training program	Researchers*; entrepreneurs; students	Processing	Capacity building	Hybrid
2019	Coop training	Develop/deliver a sustainable worker cooperative bootcamp training event to local community-minded entrepreneurs	Students*; researchers*; entrepreneurs; NPOs	Multiple	Capacity building	Deliver
2018–2019	Field trips	Organize/conduct day-long field trips for students and stakeholders to sustainable food SME clusters in Arizona	Researchers*; entrepreneurs; local government; SMEs; students	Multiple	Capacity building	Deliver
2018	Bakery coop	Design/develop and launch a sustainable worker cooperative bakery as a "turnkey" operation	Researchers*; students*; local government; NPOs	Processing and retailing	Consulting	Deliver
2018	Coop conference	Organize/deliver the first statewide conference on developing the Arizona cooperative economy	NPOs*; researchers*; entrepreneurs; local government; SMEs; students	Multiple	Networking (cultivating)	Deliver
2017	SFE solutions	Explore a range of sustainable food economy solutions with local food entrepreneurs and stakeholders	Students*; researchers*; entrepreneurs; NPOs; local government	Multiple	Capacity building (networking)	Deliver

Asterisks (*) are used to differentiate certain items in some columns: projects that were part of the accelerator program, and stakeholder groups that led projects.

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approach, and objectives, and in the participating SMEs and economic development organizations (Table 1).

Within the overall project series, a more formal partnership of academic, public, and civic sector actors was formed to explore the establishment of an "accelerator" platform to advance the Phoenix area sustainable food economy. The partnership included a university research group (Arizona State University; the authors and graduate students), staff from metropolitan area cities (City of Phoenix, City of Tempe), and a local economic development NPO (Local First Arizona). Four pilot projects, each led by one of the partners and supported by the others, were conducted in 2019–20 to learn about and explore the potential of establishing such an accelerator for the longer-term.

While this study's focus is SEE development, the ultimate goal is to advance the *sustainable food economy*. Drawing from literatures on food systems sustainability (Eakin et al., 2017; Briamonte et al., 2021; McGreevy et al., 2022), alternative food networks (Feenstra, 1997; Marsden, 2010), and sustainable economies (Anglin, 2011; Rhydian Fôn and Cato, 2014; Raworth, 2018), a regional food system can be conceptualized as a network of food businesses (incl. production, processing, distribution, and outlets) and their interactions with each other, with customers, and with other stakeholders, exchanging food products, money, information, knowledge, skills, business practices, and so forth within a region (geographical or administrative unit). What makes such a food system *sustainable* is compliance, at the levels of individual businesses, supply/value chains, and the entire network, with a comprehensive set of sustainability principles "prioritizing sufficiency over efficiency, regeneration over extraction, distribution over accumulation, commons over private ownership and care over control" (McGreevy et al., 2022). A *sustainable* entrepreneurial ecosystem supports compliance with these principles through sustainability-oriented policy making (e.g., enabling land access for sustainable food businesses), capacity building (e.g., training on how to start a sustainable food cooperative), material provision (e.g. renewable energy for food businesses), networking (e.g., connecting short food supply chain stakeholders), financing (e.g., social financing for food businesses) (Howard, 2009; Briamonte et al., 2021; McGreevy et al., 2022), and other such functions. In the SFE lab, we have used an adapted version of the B-Lab's assessment framework (Honeyman et al., 2019) to evaluate a variety of SFE-related entrepreneurial projects, businesses, supply chains, and sectors against comprehensive social, environmental, and economic sustainability criteria aligned with the above principles.

Over the course of conducting these projects, the idea of an institutionalized SFE *accelerator* emerged – hence the accelerator partnership mentioned above. An *accelerator* is usually conceptualized as an organization that speeds up business startup through a competitive, cohort-based, time-limited program in which entrepreneurs receive training, mentoring, networking, and seed-funding, often culminating in matching startups with investment opportunities and customers (Hochberg, 2016; Goswami et al., 2018). An accelerator, in this sense, is concerned with individual business development and, from an EE perspective, offers multiple services that are difficult and time-consuming for startups to access (Hochberg, 2016). The SFE accelerator concept adopted by the accelerator partnership differs from the conventional in several respects: first, it is provided by a consortium of ecosystem stakeholders rather than an individual organization; second, it focuses on developing the food economy and not just individual food businesses; third, it considers services for businesses in all lifecycle stages, not just startups; fourth, it includes services and activities beyond startup programs; and fifth, its aim is the simultaneous pursuit of comprehensive social, environmental, and economic goals rather than high growth, economic value maximization.

3. Research design

The research consisted of a qualitative, ex-post analysis of the projects and their impact on the Phoenix area SEE. The research used a nested case study approach for both tentative explanatory and exploratory purposes, in which the primary unit of analysis was the SFE-related SEE of the Phoenix area and the nested units of analysis were the intervention projects (Yin, 2003). The study is explanatory for the potential insights it offers into how SEEs can be developed, and exploratory in its creation and use of a potentially generalizable evaluative framework which may benefit further studies. Despite being a single case, the study is worthwhile as it is "representative" and "revelatory" (Yin, 2003) insofar as the case is assumed to be broadly similar to other regions and thereby insights gained are somewhat generalizable. It offers an opportunity to study, for the first time, a series of related projects aimed at developing a particular SEE for which data are still readily available.

The research is also exploratory in that – in the absence of specific, relevant theories – it seeks to gain empirical insights that contribute to building theory on how to develop SEEs, rather than being theory- or hypothesis-driven (Eisenhardt, 1989). It is, however, broadly based on the general 'theory' that may be interpreted from the EE literature that purposively developing EE is best pursued with a dynamic, bottom-up, multi-stakeholder-driven process (Feldman and Francis, 2004; Isenberg, 2010; Stam, 2015; Feldman and Storper, 2018). The research, therefore, focuses on the development approach and the impacts on the SEE, to look for possible causal effects and success factors.

We derive our research design on the basic logic model of intervention research (Fraser et al., 2009) in which an action or series of actions (*interventions*) are performed (*delivered*) for the purpose of generating *outputs* that lead to desired *outcomes*. Applying this to our study, we assess how the type of project (intervention) and the way it was performed (delivery) affected critical elements of the SEE (outputs) and the overall strength of the SEE (outcomes). To answer the research question, a five-step analytical procedure was followed (Figure 1) corresponding to five sub-questions:

1. *What was the state of the SEE functions before the first project in 2017?*
2. *What were each project's characteristics and which SEE functions did they affect?*
3. *How were the projects executed with respect to SEE function development?*
4. *What was each project's impact on SEE function development?*
5. *What was the overall state of the SEE functions after the last project in 2021?*

All research schema and analytical data are provided as Supplementary material to this article.

The pre/post SEE appraisals are based on data and knowledge acquired by the authors from their SFE-related work in the Phoenix area from June 2017 to December 2021, including participatory research, project-based teaching, conducting field trips, and being otherwise active in SEE development. The geographical scope, while centered on Phoenix, naturally extended to Arizona in some cases. Other lab projects, including conventional, non-participatory research, and projects in other geographical areas, were excluded as they did not intervene directly in the Phoenix area SEE.

Analysis is structured by Forrest et al.'s (2022) framework that decomposes the SEE into a set of functions (Table 2). These functions support the uptake of sustainable business practices by SMEs and development of the sustainable local economy overall. The primary SEE function of starting and running sustainable enterprises is fostered by a set of ten SEE support functions. The functional perspective focuses on performance, i.e., what does the SEE actually do, and indicates the range of actors that provide each function.

Projects may affect function development either by directly *developing* the function, or indirectly, by *delivering* (performing) the function, such as providing consulting services to an SME. Delivery projects are assumed to have a secondary effect on the function, beyond the immediate project scope (Figure 2).

Data on each project were collected by SFE Lab members as participant-researchers in the form of observations, notes, project reports, and reflections. The variety of sources and the differing involvement and perspectives of researchers provides some degree of triangulation, and therefore validity, of data. For the four accelerator pilot projects, additional data were also available from 90-min, semi-structured group interviews with personnel from each partner organization (seven interviews in total), asking participants to reflect on the partnership, the approach and process, the outputs generated, the outcomes, and the outlook.

Appraisal of projects and impacts on the overall SEE entailed detailed evaluation by one author, followed by more cursory evaluation by another author and discussion between the two to resolve differences, as well as a final review by the third author.

3.1. Step 1 - SEE baseline appraisal

We appraise the state of each SEE function in early 2017 (pre-intervention baseline) and their functional level. We first apply four criteria: *Sustainability* content; *Expertise* of providers; *Inclusivity* toward target audience; and *Stability* of delivery, using a three-point scale (weak – medium – strong) to appraise the fulfillment of each criterion. A rubric is then used to derive an overall function performance level, ranging from being missing (level 0) to fully functional (level 3). We also compiled a matrix of actors involved in each SEE function.

3.2. Step 2 - Project description

Projects are described using general profiles consisting of summary, timeframe, stakeholders involved, activities performed, outputs generated, economic sector, and the SEE function primarily developed.

3.3. Step 3 - Project execution appraisal

Project execution appraisal drew on insights from the entrepreneurial ecosystems literature (Isenberg, 2010; Feldman and Storper, 2018; Bischoff, 2021; DiVito and Ingen-Housz, 2021) and our own experience and knowledge. We use the four baseline criteria in a slightly modified version and add a fifth criterion, *Integration* with previous/parallel programs, to gauge how well projects were executed (i.e., how well the function was delivered and/or developed) using a three-point scale. The expectation is that projects that more closely follow those criteria in their approach will more positively impact function development.

3.4. Step 4 - Project impact appraisal

A project's impact on the SEE function is appraised by evaluating the degree to which four major functional components were generated by the project using a three-point scale. The components are: delivery documented; providers trained in delivery; delivery network strengthened; and delivery institutionalized.

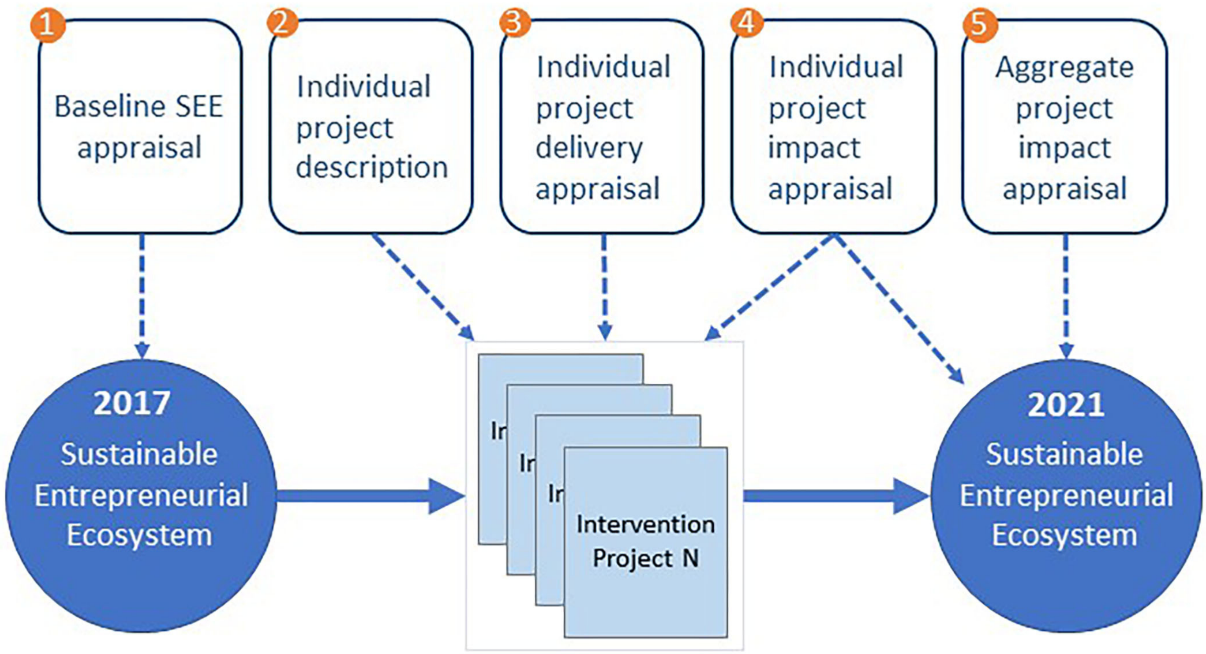

FIGURE 1
Analytical steps in relation to SEE change.

TABLE 2 Functions of SEEs (Forrest et al., 2022).

Primary function	
Starting and running enterprises	Provision of sustainable products and services, generating revenue, providing livelihoods, innovating, etc.
Support functions	
Material provision	Provision of sustainable material, equipment, technologies, and infrastructures needed for entrepreneurial activities
Financing	Provision of sustainable financial resources to entrepreneurs
Marketing	Provision of specific promotional information on sustainable products and services to or promotional activities for customers
Consulting	Provision of advice and knowledge needed for sustainable entrepreneurial activities (might include experiments and pilot projects)
Capacity building	Provision of sustainable education and training for sustainable entrepreneurial activities
Networking	Provision of opportunities for sustainable entrepreneurs to interact, share information, learn and innovate
Policy making	Provision of rules and regulations to support sustainable entrepreneurial activities
Advocating	Provision of promotional information on the industry to or promotional activities for policy makers, investors, intermediaries
Cultivating	Provision of general information on the industry to or activities for a wide spectrum of stakeholders and the public
Researching	Provision of generalized knowledge pertaining to sustainable business practices, business models, ecosystems

3.5. Step 5 - Aggregate impact appraisal

To appraise the overall state of the SEE functions in late 2021, the aggregate impact of all projects on the baseline state of each function is qualitatively considered. The change in each function and its resultant new state is gauged across the same criteria and performance-level rubric used in the baseline appraisal.

4. Results

4.1. Phoenix area SEE baseline (2017)

The Phoenix area SEE was barely developed in 2017, with eight functions at level 0 (missing) and the remaining two at level 1 (minimal) (Table 3). At least 19 stakeholder groups were involved, including NPOs, local government,

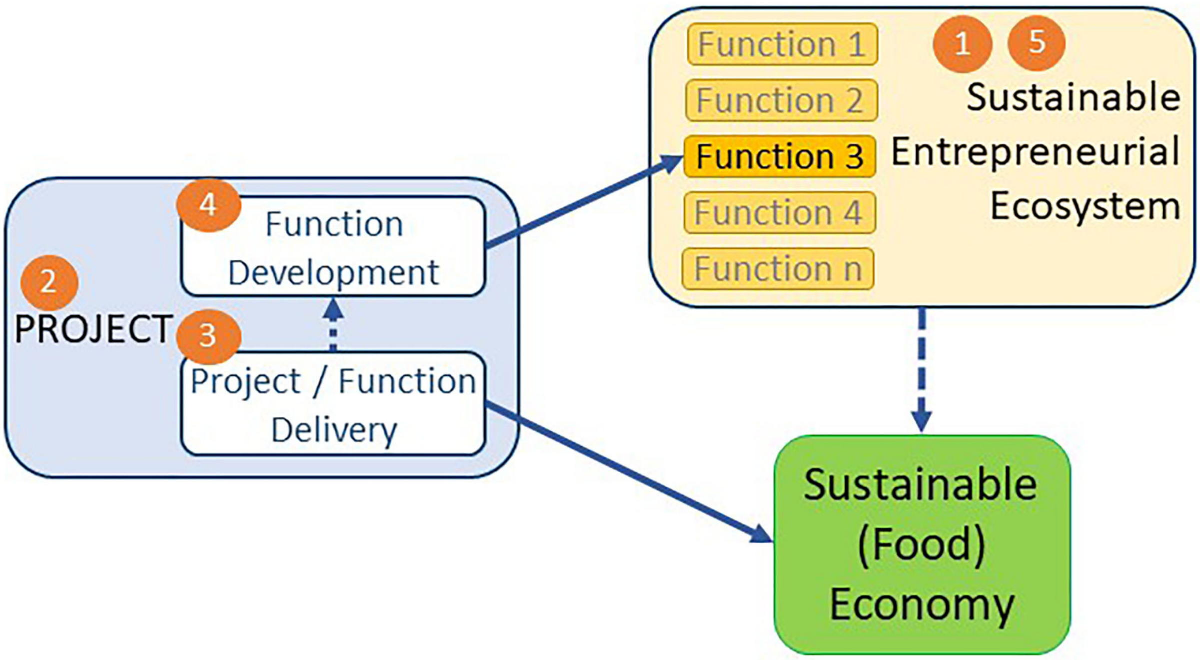

FIGURE 2
Analytical steps (numbered) in relation to project approach and impact on the SEE and the sustainable (food) economy.

TABLE 3 The state of Phoenix area SEE functions in 2017 (baseline) with number of actors involved in each function, appraisal of criteria for function strength, and overall function performance level (0 = missing, 1 = minimal, 2 = intermediate, 3 = full).

Function	Number of actors	Sustainability	Inclusivity	Capacity	Stability	Level
Consulting	7	Medium	Medium	Medium	Medium	1
Marketing	3	Medium	Medium	Medium	Medium	1
Networking	14	Weak	Medium	Medium	Medium	0
Capacity building	10	Weak	Strong	Medium	Medium	0
Cultivating	7	Weak	Strong	Medium	Medium	0
Policy making	7	Weak	Medium	Medium	Weak	0
Advocating	5	Weak	Medium	Medium	Medium	0
Material provision	5	Weak	Strong	Medium	Medium	0
Financing	4	Weak	Medium	Weak	Weak	0
Researching	2	Weak	Medium	Medium	Weak	0

universities, and entrepreneurial individuals and businesses with most participating in multiple functions, and three in five (Table 8). The 2017 state of each function is briefly described below, including identification of stakeholders involved using abbreviated name codes, the function level, and an example of function delivery.

- ***Material provision*** (IRC, RISN, CoP, CoT, and ACFMA) – Level 0 (missing). Although several organizations provided material support, the range and availability were limited and there was little sustainability focus. For example, the NPO International Rescue Committee supports refugee farmers with access to urban farmland, but there was no program requirement to adopt sustainable practices (although many farmers already do).
- ***Financing*** (IRC, PREPPED, FZL, and VH) – Level 0 (missing). The number of providers, range of finance options, scope of financing, knowledge and skills of financing for sustainable SMEs was very limited. For example, the NPO Vitalyst Health provided competitive

grants for health and nutrition projects, but generally not for business development, while Fuerza Local, a non-profit micro-business accelerator, awarded graduates a $1,000 stipend. Lacking, are local banks, credit unions, social investment firms, etc. offering appropriate finance for SMEs that often lack credit score/history or conventional security.

- ***Marketing*** (LFAZ, Entreps. LGN, and ACFMA) – Level 1 (minimal). Despite only three active organizations, they had notable success in developing sustainable food markets, particularly for fresh produce and grain products. However, the scale, range, and variety of efforts was limited. For example, the local grain network, including entrepreneurs, businesses, and support organizations, grew the local grain economy from scratch in 2011 to $1 million by targeting supply and demand-side development of local baking and brewing businesses (Forrest and Wiek, 2021).
- ***Consulting*** (TNC, Entreps, LGN, RISN, ACI, ACLT, and MCDHS) – Level 0 (missing). A healthy number of organizations were providing various consulting services, but expert help for key business development services was limited and sustainability was not a key element. For example, the Arizona Co-operative Initiative NPO offered cooperative development support but without specialized legal or accounting expertise, or sustainability framing.
- ***Capacity building*** (MCCXS, IRC, TNC, Entreps, PREPPED, FZL, SVFB, ACI, and MCDHS) – Level 0 (missing). Strong entrepreneurial capacity-building programs for underserved groups existed, but they were still establishing themselves, did not meet the demand, and lacked attention to alternative organizational models (e.g., cooperatives) and sustainable practices. For example, the PREPPED food micro-business accelerator, offering free training to underserved minorities and women, was proving successful but had only been operating for one year, and sustainability was not a key element.
- ***Networking*** (MCCXS, LFAZ, TNC, Entreps, PREPPED, LGN, FZL, VH, PP, RISN, CoP, CoT, ACFMA, and MCDHS) – Level 0 (missing). Well-established networks supported the sustainable food economy but lacked open forums (vs. intermediated connections), bottom-up entrepreneurial drive, members from critical fields, overarching sustainability purpose, and high cultural diversity. Only one organization—the NPO Local First Arizona—was conducting regular networking opportunities, such as its annual Farmer-Chef event, for local food entrepreneurs and supporting stakeholders.
- ***Policy making*** (LFAZ, VH, PP, SVFB, CoP, CoT, and MCDHS) – Level 0 (missing). Although there were committed and capable organizations involved in policy making, the number of organizations, their diversity and inclusivity, resources, coordination, and sustainability focus were generally too limited to significantly impact sustainable food economy policy. One exception, Pinnacle Prevention, a health promotion NPO, was leading efforts to extend government food stamps to include locally produced foods available at farmers' markets, though without a sustainability focus.
- ***Advocating*** (LFAZ, IRC, VH, PP, and ACLT) – Level 0 (missing). A few committed organizations were effective advocates for some aspects of a sustainable food economy, but lacked inter-organizational leadership, in-depth sectoral knowledge, and application of sustainability. For example, Vitalyst Health, a health promotion NPO, was a strong voice for health solutions, community gardens, urban farming, and farmers' markets, but with little regard for the overall food economy (e.g., processing or distribution sectors) or broad-based sustainability.
- ***Cultivating*** (LFAZ, IRC, TNC, Entreps, PREPPED, LGN, and FZL) – Level 1 (minimal). A small number of committed organizations were nurturing a culture of diverse, locally focused, community-minded food entrepreneurship although lacking clear and explicit focus on sustainable business models and practices. Local First Arizona was leading here, again, through public events, partnerships, conferences, media connections, and information tools.
- ***Researching*** (MCCXS and ASU) – Level 0 (missing). While valuable food systems research was being conducted, it was not particularly relevant to the local sustainable food economy, few research organizations were involved, it was uncoordinated, and was not stakeholder-engaged. Arizona State University research consisted of, for example, studies investigating food deserts, information signals at farmers' markets, or the health impacts of community supported agriculture. While advancing knowledge generally, there was no research directly supporting local businesses or stakeholders, or SEE function development.

4.2. Projects

The overall set of projects is described here in terms of aggregate characteristics (Table 4). Half of the projects (8) cut across multiple (>2) economic sectors, e.g., the cooperative training program projects, or the craft brewing economy project, while the remaining projects were on production, processing, or dual sectors. Multiple stakeholders were involved in most projects, with researchers and students being most frequently involved. Projects concentrated on developing Capacity Building (6) and Consulting (4) functions, while several functions were developed by only one or two projects, and three (3) were not developed by any project. Most projects (11) delivered rather than developed the respective SEE

TABLE 4 Aggregate profile of the set of projects: a) economic school sector; stakeholders involved; primary SEE function; and project approach.

Characteristic	Number of projects	Percent
Economic section		
Multiple	8	50%
Processing	3	19%
Processing and retailing	2	13%
Production	2	13%
Production and processing	1	6%
Stakeholder group		
Researchers	13	81%
Students	12	75%
NPOs	10	63%
Entrepreneurs	9	56%
Local government	9	56%
SMEs	6	38%
Schools	1	6%
SEE function		
Capacity building	6	38%
Consulting	4	25%
Policy making	2	13%
Material provision	1	6%
Financing	1	6%
Networking	1 (+2)	6%
Advocating	1	6%
Cultivating	0 (+2)	0%
Marketing	0	0%
Researching	0	0%
Project approach		
Delivered function	11	69%
Developed function	3	19%
Hybrid	2	13%

function, while only three (3) focused on function development (3), and two adopted a hybrid approach.

4.3. Project execution/approach

The projects delivered/developed the respective function well, with 11 projects achieving at least a medium (=1) score on at least four of the five appraisal criteria (Table 5). Of those 11 projects, all but two were capacity-building and consulting function projects—perhaps a result of these projects being co-initiated and/or co-led by a university research and teaching group. Similarly, as all of the projects were designed to advance the *sustainable* entrepreneurial ecosystem, it is not surprising that all but one (15 out of 16) achieved at least a medium score on "sustainability" (11 – high score; 4 – medium score). At the bottom are projects that focused on the delivery/development of a policy document (SME Guides) and a tool (Finance Tool).

4.4. Individual project impact on SEE functions

Almost all projects (15 of 16) had a positive effect on at least one SEE function (Table 6). Yet, the impacts were mostly weak (up to 0.5-score) to medium (0.75-score or higher, but less than 1.5), with nine projects having a weak impact and six projects having a medium impact. Only three projects had a strong impact on at least one element. Documenting the delivery was the weakest area with only four projects (25%) having a medium impact, and none having a strong impact. Institutionalizing the delivery and strengthening the delivery network fared better with six and nine projects (38 and 56%) having a medium or strong impact respectively. Projects were most successful, though, at training providers in delivery, where thirteen projects (81%) had a significant effect—again, not surprising considering the educational mission of the SFE Lab. Overall project impacts averaged across impact areas, ranged from weak to medium (0–1.25). The top three projects were development or hybrid types, suggesting delivery projects are less effective in the development of SEE functions.

4.5. Aggregate impacts on the SEE

Here, we consider the cumulative impact of projects and other developments [e.g., new organizations formed or expanded scope of existing organizations (Table 7)] on the state of SEE functions by 2021. Overall, the projects' contribution to most SEE functions has been positive (Table 8). Three functions (Capacity building, Consulting, and Researching) increased a full level from the 2017 baseline; three additional functions (Networking, Policy making, and Advocating) began to take-off; and one function (Marketing) stayed on the same level. Greater sustainability focus was critical to these improvements. Other contributing changes include more organizations being involved, shifts in existing organizational scope, and growing expertise within many functions. However, deep subject knowledge, skills, tools and resources are still lacking; the numbers and scope of organizations involved are still relatively low, with the sustainable food economy being of only secondary importance to many of them; function provision is of limited availability; and sustainability and its operationalization are still

TABLE 5 Summary appraisal of project approach across five performance criterion (0 = weak, 1 = medium, 2 = strong) and overall approach (mean).

Project	SEE function	General project approach	Sustainability	Expertise	Inclusivity	Stability	Integration	Overall approach
Coop startup program	Capacity building	Hybrid	2	1	2	2	2	1.8
Food SME training	Capacity building	Hybrid	2	2	2	1	2	1.8
Food forest	Consulting	Deliver	2	1	2	2	1	1.6
Farmland conservation	Material provision	Develop	1	2	2	2	1	1.6
Craft brewery	Consulting	Deliver	2	2	1	1	0	1.2
Brewing economy	Capacity building	Deliver	2	2	1	0	1	1.2
SFE solutions	Capacity building	Deliver	2	2	1	1	0	1.2
Coop conference	Networking	Deliver	1	2	1	1	1	1.2
Coop training	Capacity building	Deliver	2	2	1	0	1	1.2
Bakery coop	Consulting	Deliver	2	1	1	1	1	1.2
Farmland trust	Consulting	Deliver	2	1	1	0	1	1.0
SFE training	Policy making	Develop	2	2	0	0	1	1.0
Indigenous food	Advocating	Deliver	1	2	1	0	0	0.8
Field trips	Capacity building	Deliver	2	2	0	0	0	0.8
SME guides	Policy making	Deliver	0	2	0	0	1	0.6
Finance tool	Financing	Develop	1	1	1	0	0	0.6

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TABLE 6 Summary appraisal of each project's impact on SEE function elements (0 = weak, 1 = medium, and 2 = strong), and overall impact rating (mean).

Project	Function	Impact summary	Documented delivery	Providers trained in delivery	Delivery network strengthened	Delivery institu-tionalized	Overall impact
Coop startup program	Capacity building	Providers trained; delivery institutionalized through city partnership; network strengthened through delivery partnerships; documentation lacking.	0	2	1	2	1.25
Food SME training	Capacity building	Providers trained; existing program expansion; experts connected; documentation lacking.	0	2	1	2	1.25
Farmland conservation	Material provision	Initiating well-supported and coordinated network, anchored in existing organization; capacity built in providers; documentation lacking.	0	1	1	2	1.0
Food forest	Consulting	Expanded SFE lab's capacity for providing specialized consulting services; documented delivery; connected experts; supported spin-off of consulting service.	1	1	1	1	1.0
SFE solutions	Capacity building	Created base for SFE lab's capacity to provide training services and initiating strong delivery network; documentation lacking.	0	1	1	1	0.75
Coop training	Capacity building	One-off project led indirectly to consultancy spin-off; expanded coop training network; raised sustainability, diversity, inclusion as key coop training elements; documentation lacking.	0	1	1	1	0.75
SME guides	Policy making	Increased SFE policy making capacity of city staff; policy document created; no contribution to sustainability and very little to diversifying/opening up SFE policy making.	1	1	0	0	0.5
Craft brewery	Consulting	Strong example of sustainable business consultancy; indirectly supported consultancy spin-off (consultant capacity); documentation lacking.	0	1	0	1	0.5
Coop conference	Networking	Cooperative network strengthened; first event of its type in Arizona; created base level of capacity; institutionalization and documentation lacking.	0	1	1	0	0.5
Bakery coop	Consulting	Expanded SFE lab's capacity for providing specialized consulting services. Documentation created but no follow-up.	1	1	0	0	0.5
Indigenous food	Advocating	Increased indigenous food entrepreneurship awareness; however, no ongoing platform, programs, or associations to build on this.	1	0	0	0	0.25

(Continued)

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TABLE 6 (Continued)

Project	Function	Impact summary	Documented delivery	Providers trained in delivery	Delivery network strengthened	Delivery institu-tionalized	Overall impact
Brewing economy	Capacity building	One-off capacity built in industry and students; no documentation or platform to build on this.	0	1	0	0	0.25
Finance tool	Financing	Promising generalized tool; yet, lack of broad engagement, follow up, and making outputs available.	0	1	0	0	0.25
SFE training	Policy making	Initiated conversation around SFE in city government; lacking follow-up activities and outputs for wider use.	0	1	0	0	0.25
Field trips	Capacity building	Expanded SFE capacity building network; limited by restricted participation, no program or organization created, and lacking documentation of field trips and visited SMEs.	0	0	1	0	0.25
Farmland trust	Consulting	One-off effort with micro-level focus; no follow-up; limited reach of stakeholders; documentation lacking.	0	0	0	0	0

weak. There is also not yet a coherent approach to coordinate function delivery and SEE development.

- ***Material provision*** (1 project; +2 organizations: FZL, SoO) – Level 0 *(unchanged*). One project (*Farmland Conservation*) contributed significantly, particularly in establishing a new, multi-stakeholder organization committed to supporting small farmers. This increased function stability and to a lesser degree, capacities to perform the function. A new urban farming organization (Spaces of Opportunity) provides lots to small farmers, and an existing incubator program (Fuerza Local) now offers cooperative commercial kitchen space. While positive, the impacts have been insufficient to nudge the function's strength up.
- ***Financing*** (1 project; +3 organizations: LFAZ, TNC, SBA) – Level 0 (*unchanged*). One project (*Finance Tool*) created a potentially useful, generalized tool, but of limited access and usability. In other developments, one NPO (Local First Arizona) extended its expertise by participating in a Transform Finance workshop, while another NPO (The Nature Conservancy) took the unusual step of investing in a small craft malting business, and the federal government (Small Business Administration) extended loan guarantees to employee-owned businesses. Project impact was negligible and while the other developments increased expertise (weak to medium), this was insufficient to raise the function's level.
- ***Marketing*** (0 projects; +1 organization: TNC) – Level 1 (*unchanged*). No projects aimed directly at marketing. One NPO (The Nature Conservancy) became directly involved in developing supply and demand sides of locally grown grain markets. While TNC's involvement was significant, it was insufficient to raise the function's level.
- ***Consulting*** (4 projects; +4 organizations: SFEL, LFAZ, SBA, TC) – Level 2 (+1). The function was indirectly developed through four delivery-type projects (*Food Forest, Bakery Coop, Craft Brewery, and Farmland Trust*) by a university lab (SFEL). The Food Forest project made the strongest contribution (medium), whilst the others had weak effects (Table 6). Cumulatively, the projects established the SFE Lab as a consulting organization, albeit of varied, irregular, and limited services, and their aggregate impact increased the sustainability focus of this function (previously absent from consultancy offerings). A new sustainable business development consultancy (Thrive Consultancy) was formed as an SFE Lab spin-off. In addition, an NPO (Local First Arizona) started a green business certification service, and the federal government (Small Business Administration) nominally extended its SME support to employee-owned businesses. Overall, the range of organizations and services significantly increased, along with the knowledge and skills base, and a greater

focus on sustainability. Gaps in capacity still exist (e.g., legal and accountancy) and the range of services and availability needs to be further developed to reach full functionality (level 3).

- ***Capacity building*** (6 projects; +4 organizations: SFEL, SoO, CoP, TC) – Level 1/2 (+0.5). Most projects were capacity building activities with entrepreneurs and stakeholders delivered by a university lab (SFEL), including one-off workshops and events (*Brewing Economy; SFE Solutions; Coop Training*) and occasional activities (*Field Trips*). Two projects, however, developed the function directly, extending existing or creating new training programs with established partners, including "train-the-trainer" activities (*Food SME Training; Coop Startup Program*). All projects were strongly sustainability-oriented. In addition to the SFE Lab becoming a capacity building provider, an NPO coalition founded a community-based urban farm providing training for farmers (Spaces of Opportunity), a local government expanded its community development to provide sustainable food entrepreneurial training (City of Phoenix), and a new SFE Lab spin-off consultancy offered training on sustainable business practices (Thrive). Function stability and capacity have been significantly increased with two new or enhanced programs and three additional organizations, while the capacity for delivering capacity building has been broadened across these and other organizations. These positive changes result in an increase in overall functionality.
- ***Networking*** [1 project (2 projects indirectly); +3 organizations: SFEL, MARCO, ACI] – Level 0/1 (+0.5). One project focused on networking (*Coop Conference*) in which the SFE Lab partnered with an NPO (Arizona Co-operative Initiative) to organize the state's first cooperative economy conference. Whilst it was a strong networking event, it made little contribution to ongoing networking support due to a lack of follow-up and documentation. Two projects (*Brewing Economy, SFE Solutions*) facilitated new connections between economic actors. In addition, a new NPO coalition formed (Maricopa County Food Coalition) to further the local food system with networking as one of its primary purposes. An increase in stability (more organizations) and a shift toward sustainability have been enough to slightly boost function strength.
- ***Policy making*** (2 projects; +2 organizations: SBA, ASU) – Level 0/1 (+0.5). One city government project aimed to directly reduce policy barriers to small food business (*SME Guides*) while the SFE Lab provided policy-oriented SFE training to another city government's staff (*SFE Training*). These projects increased awareness and commitment by city governments and helped one (City of Phoenix) obtain major federal funding (Phoenix Resilient Food System Initiative). Additionally, the policy scope of a federal agency with local operations (Small Business Administration) expanded to include employee-owned businesses, while a new Arizona State University center (Swette Center for Sustainable Food Systems) engaged in multi-level policy work. Both projects and the other developments have therefore had some impact, moving this function close to takeoff.
- ***Advocating*** (1 projects; +3 organizations: SFEL, MARCO, ASU) – Level 0/1 (+0.5). One project (*Indigenous Food*) directly advocated for indigenous food entrepreneurs but did not develop the function beyond this. Three new organizations (SFEL, Maricopa County Food Coalition, Swette Center), all with a sustainability orientation, engaged in SFE-related advocacy including informal interactions, meetings, public events, media engagement, social media, and website communications. This expansion of the organizational base has moved the function close to takeoff.
- ***Cultivating*** [0 project (2 projects indirectly); +1 organization: SoO] – Level 0 (*unchanged*). No projects aimed directly at Cultivating; yet, two projects (*Indigenous Food; Coop Conference*) made indirect contributions. In addition, one new organization (Spaces of Opportunity) was created to develop a local food culture through a community-based urban farm and food hub. Despite these positive changes, the overall impact on the function is too small for a shift.
- ***Researching*** [0 projects (several indirectly contributing); +3 organizations: SFEL, MARCO, ASU] – Level 1 (+1). None of the projects aimed directly at Researching. However, the SFE Lab, a new non-profit coalition (Maricopa County Food Coalition), and a new (research) center at Arizona State University (Swette Center for Sustainable Food Systems) conducted research on the sustainable local food system. An increase in stability (more organizations) with greater focus on coordinated, locally-relevant research performed through a sustainability lens takes the overall function performance to level 1.

4.6. Link between approach and impact of the projects

The above appraisals tentatively suggest a positive relationship between project approach and project impact, indicating the more sustainability, expertise, inclusivity, stability, and integration that goes into a project, the greater the impact in terms of documented delivery, providers trained in delivery, delivery network strengthened, and delivery institutionalized (Figure 3).

TABLE 7 SEE stakeholders in the Phoenix area, showing the number of functions participated in in 2017 and 2021 and the net change.

ID	Organization or program	Stakeholder type	2017	2021	Change
MarCo	Maricopa County Food System Coalition	NPO	0	3	3
SFEL	Sustainable Food Economy Lab (ASU)	University	0	5	5
MCCXS	Maricopa County Cooperative Extension	University	3	3	0
LFAZ	Local First Arizona	NPO	6	8	2
IRC	International Rescue Committee (IRC)	NPO	5	5	0
SoO	Spaces of Opportunity	NPO	0	3	3
TNC	The Nature Conservancy	NPO	4	6	2
Entreps	Food entrepreneurs	Entrepreneurs/SME	5	5	0
PREPPED	PREPPED	University	4	4	0
LGN	Local grain network	Entrepreneurs/SME	4	4	0
FZL	Fuerza Local	NPO	4	5	1
VH	Vitalyst Health Foundation	NPO	4	4	0
PP	Pinnacle Prevention	NPO	3	3	0
SVFB	St Vincent's food bank	NPO	2	2	0
RISN	RISN incubator	University	3	3	0
ACI	Arizona Cooperative Initiative	NPO	2	3	1
ACLT	Arizona Community Land Trust	NPO	2	2	0
CoP	City of Phoenix	Local government	3	4	1
CoT	City of Tempe	Local government	3	3	0
SBA	U.S. Small Business Administration	Federal government	0	3	3
ACFMA	AZ community farmers markets association	NPO	3	3	0
TC	Thrive Consultancy	SME/Consultancy	0	2	2
MCDHS	Maricopa County Dept. of Public Health	Local government	4	4	0
ASU	Arizona State University	University	1	3	2

5. Discussion

The results indicate a strengthening of the Phoenix area's SEE that is partly attributable to the projects conducted between 2017 and 2021, but also that there is room for improvement in designing and executing projects to increase their impact on the SEE. Along these lines, the results are discussed below to tease out some tentative guidelines (Table 9).

5.1. General project approach

Projects leant toward *delivering* rather than *developing* SEE functions, focusing on providing direct value to end users (e.g., entrepreneurs), thereby limiting impacts on function providers. *Delivery* projects can have co-benefits, such as developing the project team's capacity and creating knowledge or tools, as seen in the Coop Training project that educated the delivery team and prototyped a training module. Delivery projects may achieve greater impact by broadening their reach beyond a single end-user organization or by including at least one function provider. For instance, while the Craft Brewery project's benefits were limited to staff from one SME, the Brewing Economy project reached over a dozen entrepreneurs from multiple SMEs and numerous other ecosystem stakeholders. *Development* projects can also be of limited impact if they are narrowly focused or lack stakeholder engagement. For example, the SME Guides and Finance Tool projects both created useful knowledge but failed to engage entrepreneurs or function providers to use the knowledge. *Hybrid* projects combine the benefits of function delivery and development as seen in the two most impactful projects: the Coop Startup Program and the Food SME Training. They both involved directly working with entrepreneurs, while simultaneously training function providers (train-the-trainers) and developing material for function provision.

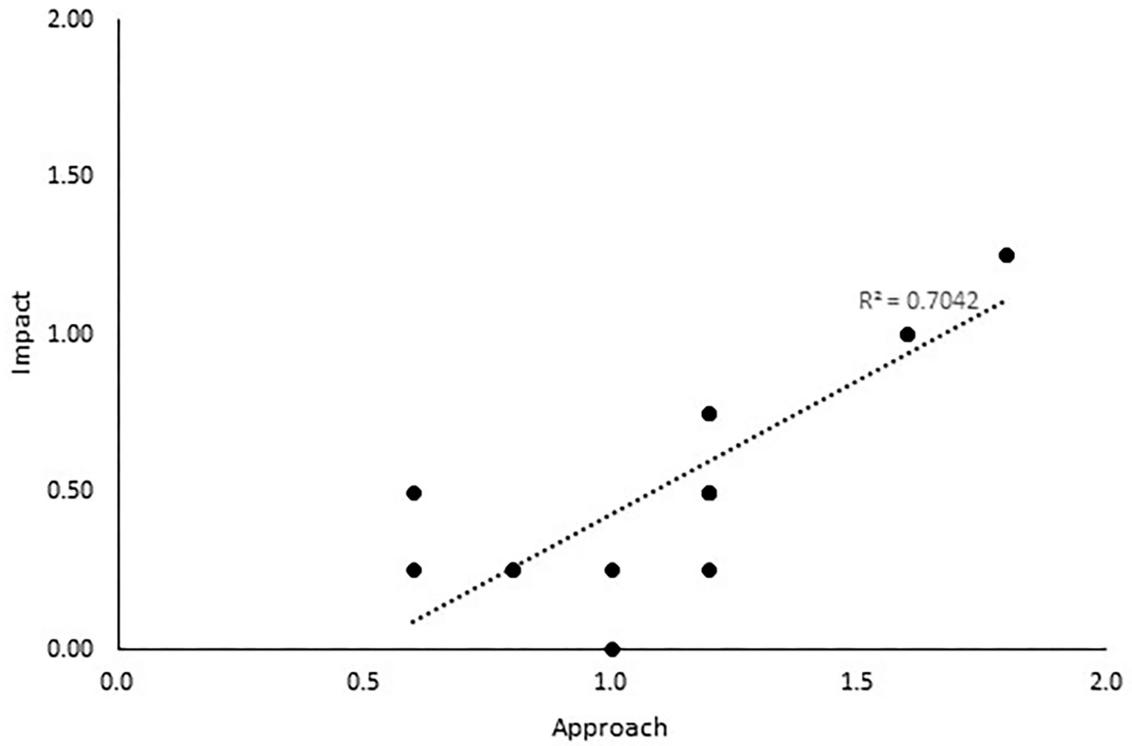

FIGURE 3
Relationship between project approach and project impact.

5.2. Specific project approach features

Too many projects were one-off actions with no planning or preparation for post-project delivery *stability*. These projects failed to follow up on opportunities created, capacity built, or connections made. The SFE Training project, for example, whetted the appetite of local entrepreneurs and government staff but went no further. Another weakness was *integration*: most projects did not build upon previous or parallel projects and activities, foregoing the benefits of prior investment to form partnerships, develop concepts and materials, win broader support, etc. One such project was the Indigenous Food project that, while promoting a much-neglected aspect of the food economy, had little connection to accelerator partners or their previous work. *Inclusivity* was moderately strong overall but weak in engagement, where few projects involved entrepreneurs in broader planning and development to enhance relevance, practical knowledge, and empowerment. For example, the Coop Bakery project approach was top-down, lacking any entrepreneur-level involvement that likely contributed to its failure. In contrast, entrepreneurs were highly engaged in the similar startup-type Food Forest project that ultimately made it to implementation. In another aspect of inclusivity, the four most impactful projects all involved multiple organizations in planning, development, and delivery, whereas most of the least impactful were conducted by single organizations. Inclusivity was also weak regarding specialist lawyers, finance experts, and business developers because the Phoenix area lacks such professionals with suitable sustainability expertise. *Sustainability* was the strongest approach feature, largely because of the SFE Lab's involvement, which prioritized sustainability as an outcome and designed projects accordingly. Projects that had little SFE Lab involvement were notably weak in sustainability.

5.3. Project impacts

Many projects had a limited impact because materials produced were not made widely accessible. For example, the Finance Tool, SFE Training, Brewing Economy, and Coop Conference projects produced useful data, tools, and insights, yet published none of it. Only four projects made documentation available, and even these were of limited practical usefulness. The Food Forest project, for example, produced a range of high-quality documentation, but on a specialized topic with limited general applicability. Documentation by media coverage as seen in the Coop Conference project, though effective at raising awareness and interest, lacks detail and

TABLE 8 The number of actors involved and overall function performance level (0 = missing, 1 = minimal, 2 = intermediate, 3 = full) of Phoenix area SEE functions in 2017 vs. 2021.

SEE function	2017		2021	
	Number of actors	Function level	Number of actors	Function level
Consulting	7	1	11	2
Marketing	3	1	4	1
Networking	14	0	17	0/1
Capacity building	10	0	14	1/2
Cultivating	7	0	8	0
Policy making	7	0	9	0/1
Advocating	5	0	8	0/1
Material provision	5	0	7	0
Financing	4	0	7	0
Researching	2	0	5	1

TABLE 9 Guidelines for developing SEEs through projects.

Designing projects
Form a loose, inclusive network of core organizations committed to developing the SEE
Maintain openness to new ideas, varied projects, and diverse participation
Select projects strategically, account for the overall state of the SEE across all functions
Prioritize projects that directly develop, rather than deliver, an SEE function
Executing projects
Conduct projects jointly with several partner organizations
Include stakeholders from multiple groups as participants in delivery projects
Include end-users (entrepreneurs) and function providers in function development projects
Include sustainability experts and apply sustainability principles in projects
Apply other criteria (expertise, stability, etc.) to guide execution of projects
Prioritize building provider capacity for function delivery (train-the-trainer) in capacity building projects
Encourage end-users participating in projects to support other end-users (peer-to-peer)
Document and share project content through accessible channels as an integral part of the project
Promote projects through media coverage (newspaper, radio, television)
Plan and commit to follow-up and institutionalization as integral project activities
Encourage follow-up activities by consensually sharing contact information, initiating social media groups, etc.

completeness. Regarding institutional outputs consolidating and continuing project work, only three projects established organizations or programs of functional significance. And though many projects made post-project connection between participants possible (e.g., the Coop Conference and Brewing Economy), none enhanced a function's networking capabilities. The most commonly developed functional component was capacity. It was strongest in the only two projects that targeted training of function providers (Coop Startup and Food SME Training projects). The lack of impacts can be partially attributed to limited project funding which often requires moving on to the next project without documenting or institutionalizing delivery.

Less apparent from these results is the cumulative effect of projects on delivery expertise and networks. For example, the Coop Startup Program, one of the most effective projects undertaken, had roots in the Coop Training project, but there was no planned pathway to it. Through conversations around other projects and participation in the accelerator partnership, new connections formed between local government staff and the SFE Lab that led to city interest in providing cooperative food business training. Meanwhile, SFE Lab graduates who participated in the Coop Training project started a sustainable business consultancy. Convergence of goals and capabilities brought the three organizations (lab, city and consultancy) together to iteratively develop and arrive at the current coop startup program. Generally, the series of loosely connected, though unplanned, projects has gradually increased stakeholders, knowledge, focus, and interactions around the sustainable food economy, that have led to significant impacts. Important elements of such developments seem to be an openness to new ideas, a wide range of projects, and diverse participation.

5.4. Project selection

Projects were selected opportunistically according to available capacities and resources rather than which functions most needed strengthening. Focusing on a few functions that make best use of scarce resources and capabilities was a reasonable approach in the early stage of SEE development; yet, as the SEE develops, a more strategic approach is needed. Indeed, this opportunistic project selection may result in particular SEE functions becoming more developed as a result of the project developer capabilities and resources. For example, entrepreneurial training programs, such as the Coop Startup Program and Food SME Training projects, resulted in strengthening capacity building and networking functions, but there is now a need for complementary financing, material provision, and marketing projects to provide newly trained entrepreneurs with the support they need.

5.5. Sustainable food economy acceleration

The attempt to find the right balance between strategic and emergent approaches was seen in the four accelerator partnership projects (see Section 2). Yet, these projects did not generate more impactful outputs than "non-accelerator" projects, with one (Farmland Coalition) performing reasonably well, and three (Indigenous Food, SME Guides, and Craft Brewery) less so. Initial attempts to closely manage the accelerator projects and partners proved unsuccessful and a more, open, emergent approach was taken instead. Overall, the accelerator has benefited SEE development by increasing the shared understanding and focus of the partners on the sustainable food economy, while further strengthening their working relationships.

These guidelines broadly align with SEE development principles found in the literature. The emergent approach, engaging entrepreneurs not only as participants but in the conduct of projects aligns with *accounting for local context* and *supporting bottom-up entrepreneurship* (Isenberg, 2010; Feldman and Storper, 2018; Bischoff, 2021). Forming loose networks among intermediary and entrepreneurial stakeholders aligns with *building support networks* (Isenberg, 2010; Feldman and Storper, 2018) and *facilitating collaboration* (Bischoff, 2021; DiVito and Ingen-Housz, 2021). *Finding common ground* (Feldman and Storper, 2018; Bischoff, 2021) was important in the accelerator partnership and emerged from the cumulative effect of projects. Other guidance found in the literature, including *changing the culture* (Isenberg, 2010, Feldman and Storper, 2018; Bischoff, 2021; DiVito and Ingen-Housz, 2021), *creating demand for created capacity* (Feldman and Storper, 2018; DiVito and Ingen-Housz, 2021), and *supporting entrepreneurship through policies* (Isenberg, 2010) map to the guideline to account for the overall SEE state across all functions in designing projects. However, Contrary to the principle *focus on projects with high visibility* (Isenberg, 2010), our analysis suggest there is value in conducting many modest and diverse projects.

6. Conclusions

The qualitative and quantitative ex-post evaluation of 16 projects intended to foster the sustainable entrepreneurial ecosystem of the food economy in the Greater Phoenix Area of Arizona, between 2017 and 2021, suggests that the projects positively impacted the SEE. The level of three functions—Consulting, Capacity Building, and Researching—was increased by a full step, and three more—Networking, Policy making, and Advocating—were nudged into take-off. Results also indicate that the project series has cumulatively increased the quantity and quality of stakeholders, networks, knowledge, and focus, leading to further opportunities for SEE development—which is still needed for many of the functions. Findings revealed the effectiveness of many projects to be weak, leaving substantial room for improvement when designing such projects in this or other regions in the future.

Answering our general research question, the findings suggest that SEEs can be purposively developed by performing an extended series of intervention projects. However, scale and longevity of project impacts on the SEE functions depends on the type of project (SEE function development vs. function delivery vs. hybrid) and its specific project design. Results indicate a positive relationship exists between the sustainability, expertise, inclusivity, stability, and integration features of the project approach and their impacts on an SEE function in terms of delivery being documented, providers trained, delivery network strengthened, and delivery being institutionalized. The guidelines for SEE development, extracted from the empirical findings of the evaluation, offer advice for practitioners developing SEEs, including policy

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makers, economic development agencies, financial institutions, consultants, and educators. Purposeful project design that pays attention to the indicated success factors (sustainability, expertise, inclusivity, stability, integration) increases the chances of soundly developing and institutionalizing SEE functions, e.g., municipal economic development policies and financing options. With this comes the evidence-supported promise of strengthening the sustainability of the respective economic sector (not limited to the food economy).

The research had several limitations. Data collection relied, to some extent, on the authors' knowledge, project notes, and reports, and results may be different if a third-party data collection across all projects was used. Analysis mostly focused on the impact of projects on one SEE function whereas most projects had affinity with multiple functions, likely leading to project impacts being under-appraised. Analysis was also limited to immediate project outputs, thereby excluding interactions between project participants, sustainable business practices adopted, or new sustainable food SMEs formed.

Irrespective of limitations, the presented study has already had formative impact on some of the projects in the Phoenix area, triggering several improvements, such as documenting the Coop Startup Program, and expanding the same program to develop the underdeveloped SEE functions of financing and cultivating.

The study also makes an empirical contribution to the hitherto under-researched area of *how* to purposely accelerate SEE development, largely confirming general EE theory, but adding nuances to several aspects (particularly emphasizing the ways *sustainability* features of the SEE functions could be developed). It has also generated somewhat generalizable insights into factors and mechanisms involved in SEE development that contribute to theory building. The evaluative framework is a further contribution that may be useful for sustainability researchers, helping them to design comparative research across numerous cases (intervention projects) and generate transferable insights of relevance to different SEE stakeholders.

Further research should include qualitative and quantitative studies that seek greater understanding of building the SEE overall, as well as studies that focus on particular approaches to developing specific SEE functions. Considering the urgency of sustainability challenges (cf. SDGs) and the various institutional inertia that hinder or slow down SEE development, as demonstrated in this study, a key question for future research ought to be on ways to accelerate SEE function development.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Ethics statement

The studies involving human participants were reviewed and approved by Internal Review Board, Arizona State University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

The research was conceived by NF, AW, and LK, and primarily designed by NF with input from AW. NF performed the data collection through interviews and collation of secondary sources, with participation from AW and LK in interviews. NF analyzed the data. The paper was structured by NF and AW, and was primarily written by NF with a notable writing contribution from AW and review by AW and LK. All authors approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Sustainable production systems of urban agriculture in the future: a case study on the investigation and development countermeasures of the plant factory and vertical farm in China

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Introduction: In recent years, innovative sustainable agricultural production technologies, including vertical farms and plant factories, have been developing rapidly around the world. The development of plant factories and vertical farms is currently receiving a lot of attention from Chinese academia and industry. However, the recognition and satisfaction of the government, producers, sales companies, and consumers are low, and their attitudes are mixed, mainly due to high pre-construction and post-operation costs, low comprehensive utilization of resources, low product diversity, low market share, high prices, and low core competitiveness, which limit its healthy and sustainable development. This paper designed a questionnaire from the perspectives of industrialization, commercialization, and sustainability in order to understand the respondents' level of awareness, doubts and concerns, purchase intentions and consumption expectations, as well as their trust and recognition of branded products in this new agricultural production system.

Method: To determine the diversity of respondents, this paper examines the group structure of participants from management, research and development, manufacturing, sales, consumers, regional development, and other industrial sectors. The survey was conducted using both face-to-face interviews and electronic questionnaires. As an online survey, the questionnaire was distributed to social groups through social media platforms. A total of 729 valid questionnaires were submitted. For the purposes of categorizing, enumerating, compiling statistics, and analyzing the questionnaires used in this study, descriptive statistics, multi-factor cross-analysis, and other statistical methods were employed. The social roles, functions, and interaction styles of various plant factory practitioners are examined from the perspective of social relationships, and pertinent development concepts and suggestions are proposed based on the survey results.

Results and conclusions: The study found that an increasing number of consumers are understanding and accepting this new form of plant production and are willing to purchase plant products from plant factories and vertical farming. Plant factories and vertical farms are widely regarded as one of the most important methods of future urban agricultural production. Awareness, purchase intent, price expectations, brand awareness, and price expectations of plant factories and vertical farms varied significantly by gender, age, education level, occupation, and income. In addition, there are numerous findings that provide governments, producers, marketers, managers, and consumers with great value and assistance.

Development recommendations: We should take the opportunity of developing plant factories to adjust the structure of the plant industry, enrich the "vegetable basket" of urban residents, increase the supply capacity of the market, enhance agricultural modernization and technological innovation, improve the quality of agricultural products from plant factories, strengthen the brand sales of plant products, and develop more functional plant products with high added value. Through the development of plant factories and vertical farms, we can improve the nutrition and healthy diet structure of citizens' diets, increase the modern plant industry's contribution to the national economy, and promote the comprehensive and sustainable development of the urban productive plant industry.

KEYWORDS

sustainable agriculture, plant factory, vertical farm, urban agriculture, precision agriculture, intelligent agriculture, facility agriculture

1. Introduction

1.1. Background analysis

Globally, by 2050, there will be 9.1 billion people on the planet, an increase of 34% from today. About 70% of those people will live in cities, up 21% from the current urban population, and the rate of urbanization will continue to increase (Food and Agriculture Organization, 2009). With the expansion of the global economy, urban dwellers' income levels will double, their consumption levels will dramatically rise, and price will no longer be the primary determinant of food consumption. However, food and vegetable production must be improved economically and efficiently in order to feed this larger, more urbanized, and more affluent population. It is estimated that in order to keep up with the rising consumption of food and vegetables, it will need to rise by at least 70% (Dias, 2015). Additionally, the Food and Agriculture Organization of the United Nations estimates that in 2019, before the COVID-19 pandemic outbreak, close to 690 million people worldwide—or 8.9% of the world's population—were experiencing food shortages (FAO, IFAD, UNICEF, WFP, and WHO, 2020). Localized hunger has become a more pressing issue as a result of the global spread of COVID-19 and successive regional calamities.

Faced with the growth of world population, the expansion of urban scale, the reduction of agricultural land, the shortage of food supply and the loss of agricultural labor force, human beings have to use more and more scarce cultivated land to support the growing population. It is crucial to enhance the working conditions for agricultural workers, the rate at which land is used, and the productivity of food crops. The only option for the sustainable and harmonious growth of the city will be to completely utilize the urban planting area, aggressively expand urban agriculture, and integrate urban agriculture into urban development in order to address the enormous daily food consumption of urban people. Urban agriculture (UA) (De Bon et al., 2010; Pearson et al., 2010; David, 2011; Tracey, 2011; Kozai, 2012; Specht et al., 2014; Lin et al., 2015; Michelon et al., 2019; Appolloni et al., 2020; Ola, 2020; Gómez-Villarino and Ruiz-Garcia, 2021; Marçal et al., 2021) refers to a variety of agricultural planting, breeding and related activities implemented in urban areas and surrounding suburbs. The plant factory (Goto, 2012; Kozai, 2013, 2019; Hu et al., 2014; Graamans et al., 2017, 2018) and the vertical farm (Besthorn, 2013; Despommier, 2013; Al-Chalabi, 2015; Benke and Tomkins, 2017; kaur and Chawla, 2021) are the new development direction of facility agriculture, urban agriculture, intelligent agriculture and modern agriculture, and the advanced mode of fully exploiting and utilizing urban space for facility agriculture production. It is an efficient way to resolve the conflict between the growth of the urban population, the expansion of the urbanization process, and the decline in the amount of arable land per person (Kozai, 2013; Langemeyer et al., 2021; Olvera-Gonzalez et al., 2021). The plant factory, as a high-end type of sustainable development of facility agriculture and urban agriculture (Kozai et al., 2019; Yang, 2019), has the characteristics of modernization and intellectualization and is a part of precision agriculture and intelligent agriculture (Hu et al., 2018). Their advent has changed how humans have farmed for thousands of years and offered a fresh approach to resolving the conflict between the world's population growth and the depletion of available land resources, as well as the current food crisis (Yamori et al., 2014; Kalantari et al., 2018). At present, many countries and regions are actively exploring and developing modern three-dimensional cultivation models to address the shortcomings of traditional agricultural production. Such as Japan, South Korea, Thailand, Singapore, China and Chinese Taiwan in Asia; the United States and Canada in North America; and Poland, Hungary, and the United Kingdom in Europe. Representative examples include Bowery Farming, Plenty, and Oishii Farm in the United States; Future Crops in the Netherlands; SMARTKAS in Hungary; Infarm in Germany; LettUs Grow in the United Kingdom; Techno Farm in Japan; Farmy in Malaysia; and China's Sanan Optoelectronics and JD.com (kaur and Chawla, 2021; Martin and Bustamante, 2021; Perambalam et al., 2021; Silva et al., 2021; Van Delden et al., 2021; Zareba et al., 2021).

1.2. Analysis of the current situation and the necessity of social investigation

China is still in a stage of rapid development due to its larger population and limited land area. It is actively developing urban agriculture and has accumulated rich development experience and made great scientific and technological progress, which can be used as a model by other nations and even the entire world to address the food shortage crisis. This is done in order to effectively address the problem between the rapid population growth and the loss of agricultural labor force, as well as the growing shortage of land resources. The plant factory and vertical farm share many common features in design and substance, commonly known as "Plant factory" in Asia and often called "Vertical farm" in Europe and the Americas, is an intensive industrialized agricultural production system with vertically stacked or inclined shelves (Marks, 2014; Al-Kodmany, 2018; Goldstein, 2018). In fact, the two are current agricultural new technologies and systems that have been created from various academic and practical viewpoints that are both distinct and related (Harbick and Albright, 2016; Kikuchi et al., 2018), and can be seen from Figure 1. This study is not concerned with the concept, and a fine distinction is not intended. However, from the point of view of their common characteristics, both of them are new agricultural production systems integrating information electronics, automatic control, artificial intelligence, mechanical technology, botany, light quality physiology, horticulture, agronomy, and other disciplines (Chen et al., 2013; Ohara et al., 2015; Khan and Ahmed, 2017; Hu et al., 2018; Liu et al., 2019; Wang et al., 2022a). They have realized the accurate and controllable growth environment of crops, the comprehensive reorganization and optimization of resources and energy consumption, and the overall ecological friendliness of environmental contamination (Ioslovich and Gutman, 2000; Brummer et al., 2011; Beacham et al., 2019; Tuomisto, 2019). It is viewed as a methodical initiative for the sustainable development of modern agriculture in the future and is the preferred solution for raising agricultural output to alleviate the burden on food security, local famine, and urban population expansion (Nakayama, 1991; Avgoustaki and Xydis, 2020; Teo and Go, 2021). Their common advantages (Kozai, 2018; Tong et al., 2020) are: (1) the plant growth environment is accurate and controllable, which can achieve high efficiency and energy saving. (2) Plants can be produced continuously all year round, not affected by the sudden epidemic and extreme climate, which improves food safety. (3) It is independent of sunlight and does not require land. It makes the most sense to construct it in a city where it can supply the locals with fresh vegetables. (4) A location with a protracted climate and unsuitable soil for plant development is ideal for construction. (5) It provides the excellent benefit of enhancing product quality by controlling the environment for plant growth. (6) It ensures the sustainable growth of society and significantly raises the rate of land utilization. (7) Plant products can be mass-produced in the workshop on a similar basis to industrial goods. (8) Improve the environment and working circumstances for operators, draw in young professionals, etc.

At the same time, these two new modes of agricultural production have encountered many obstacles and practical difficulties (Kim, 2010; Eaves and Eaves, 2018; Xydis et al., 2020), and have been questioned and worried. The main obstacles are: (1) The price of the construction is too high. (2) Operating expenses are excessive. (3) The production technique is complex. (4) The economic gain is modest. (5) There is insufficient government assistance. (6) The product's level of quality is insufficient. (7) Product diversity alone is insufficient. (8) The level of consumer recognition is low. (9) There is no active marketing. (10) Product development is slow, etc. The primary issues and concerns are: (1) The cost is prohibitively expensive. (2) There is debate over its nutritional worth. (3) Uncertain of its healthfulness. (4) There may or may not be industrial pollution. (5) Uncertain of its cleanliness, lack of contamination, etc.

Despite the fact that academia and business view the plant factory and the vertical farm as sustainable agricultural production systems for addressing the threats posed by climate change, geological conditions, land problems, population problems, food problems, food security problems, energy problems, the aging of agricultural personnel, the environment, and sustainable development. The development of industrial manufacturing, the health sector, the information sector, and other industries can all be driven by these sectors, which are also regarded as intermediate industries for sustainable urban development. Many researchers have made in-depth research in this aspect (Glenna et al., 2011; Rajan et al., 2019). These innovative modern agricultural technologies, however, are insufficient on their own to convince growers or investors to switch to this new way of production. To entice more investment, it is more important to demonstrate their production potential market prospect and profitability through research or other evaluation techniques (Kim et al., 2013; Shao, 2013), which is easy to ignore (Huang, 2019; Yano et al., 2021). Therefore, through the method of questionnaire and interview, this study conducted an extensive social survey on the attitude, cognition, recognition, participation, willingness to pay, and brand awareness of agricultural managers, scholars, producers, sellers, and consumers toward plant factories and vertical farms. The purpose of the survey is to analyze the challenges facing science, technology, and market promotion, as well as to investigate practical solutions and effective coping mechanisms for the sustainable and healthy development of these fields. The findings of this study provide valuable guidance for formulating development strategies that are appropriate for successful marketing, recovering R&D costs through market revenue, attracting additional industrial investment and policy support, and sustaining R&D, production, and sales.

2. Materials and methods

2.1. Analysis of investigated people and their roles

Urban agriculture research has advanced, leading to the development of numerous agricultural sustainable production systems with contemporary high-tech characteristics that are progressively moving toward industrialization, commercialization, and sustainable production. To address the issues and challenges faced in practice, it is essential to conduct focused research and investigation into the social group structures that influence or participate in the growth of the plant factory and vertical farm industries from an economics perspective. Five social groups, namely government management departments, scientific research institutions, production enterprises, sales companies, and consumers, are closely related to the interests of plant

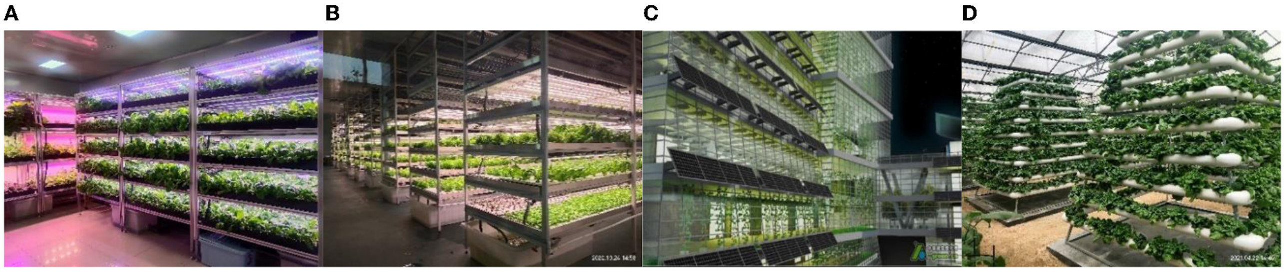

FIGURE 1
Plant Factories [**(A)** plant factory laboratory of our university, **(B)** taken in Xi'an, China] and Vertical Farms [**(C)** selected from network and **(D)** taken in Shouguang, China].

TABLE 1 The first part of the questionnaire (social-demographic characteristics survey).

Number	Question type	Question title	Question options
1	Single Choice	Your gender is:	Male OR Female
2	Single Choice	Your age is:	18–30 years old, 30–45 years old, 45–60 years old OR 60 and above
3	Single Choice	Your highest education (including current education) is:	Senior High School / Technical School and Below, Technical Secondary School / College, Undergraduate College OR Master Degree or above
4	Single Choice	Your recent resident area is:	North China, Northeast China, East China, Central China, Northwest China, Southwest China OR South China
5	Single Choice	Your industry (if not the first four, choose the fifth one):	Government Administration, Scientific Research Institutions or Universities, Agricultural Production Enterprises, Agricultural Products Marketing Company OR Consumers of Agricultural Products
6	Single Choice	Your average monthly income is:	< RMB 3000, RMB 3000-5000, RMB 5000-10000, RMB 10000, and above

factories and vertical farms, respectively. Based on this analysis, the questionnaire design and interview strategy for this study are carried out.

2.2. Sampling

To fully understand the understanding, attitude, recognition, and purchase intention of industry practitioners and different social consumers to the plant factory and vertical farm, as well as the care degree and price acceptance limit of brand products, to ensure the universality and diversity of the sample, this study adopts the multi-stage cluster sampling survey method and face-to-face interview strategy. According to the analysis in Section 2.1, the target population of this survey is the permanent population living in China. According to the sociological characteristics, the respondents are mainly targeted at the following five groups: government administrators from agricultural and rural areas or science and technology management, scientific research personnel from scientific research institutions or universities, production personnel from farm products production enterprises, sales personnel from agricultural products sales companies and consumers of agricultural products. To speed up and shorten the survey process, from the perspective of consumers, the other four groups except potential consumers are also considered as potential consumers. In this way, the survey looks into the opinions and attitudes of these particular groups toward vertical farms and plant factories. To ensure the universality, effectiveness, and timeliness of social survey, according to the situation of using communication tools to Chinese social networks and residents, the online electronic questionnaire is pushed to friends or friend groups through network and instant communication tools software to launch consumers to fill out and write questionnaires online and collect feedback questionnaires automatically through the network. In addition, the survey intends to comprehend the attitude, comprehension, and opinions of government officials, research experts, entrepreneurs, and particular customers through point-to-point voice conversations and in-person interviews, recording the interview contents, and sorting out the survey results. A face-to-face interview is the primary method used in the survey of the managers from the government's agricultural and rural areas and science and technology management departments, with a questionnaire survey serving as a backup. In addition to serving the survey's intended aim, this format offers a great chance to thoroughly comprehend national policies and interact with decision-makers. We mainly use questionnaire surveys in our surveys of academic researchers and college and university professors, with phone calls and in-person interviews serving as supplements. Researchers and agricultural production firm personnel both participate in the investigation. In the survey of potential consumers, we almost all adopt the way of the questionnaire survey, but we also conduct face-to-face interviews

TABLE 2 The second part of the questionnaire (investigation on consumers' understanding and cognitive level).

Number	Question type	Question title	Question options
7	Single Choice	Have you heard of plant factories and vertical farms before?	Yes, I've heard about it before. OR No, I never heard of it. I heard it for the first time today.
8	Single Choice Questions with Illustrations	Plant factories and vertical farm products are shown in the picture. What kinds of things have you seen?	Haven't seen any of them, Have seen 1-3, Have seen 4-6 OR Have seen more than 6
9	Grading Questions	How much do you think you know about plant factories and vertical farms and their agricultural products?	A star - never heard of before, Two stars - know little, Three stars - learn more, Four stars - learn a lot OR Five stars - very understanding
10	Multiple Choice	What do you think is the reason why you know little about plant factories and vertical farms and their crop products?	Too little media coverage, insufficient popularization of scientific and technological knowledge, too few reports on scientific research results, The scale of production is too small to popularize the market, Product marketing activities are too few to know what products come from plant factories or vertical agriculture AND other reasons

TABLE 3 The third part of the questionnaire (investigation of consumers' doubts, concerns, or obstacles).

Number	Question type	Question title	Question options
11	Multiple Choice	What do you think are the main factors that affect the development of plant factories and vertical farms?	Too high construction costs, too high operating costs, complex production technology, Insufficient government support, Not high enough product quality, Not enough product diversity, Consumer recognition, too little marketing, R&D lag, AND Other factors
12	Multiple Choice	What are your concerns about the agricultural products of plant factories and vertical farms?	The price is too high to afford. Its nutritional value cannot be determined. Not sure if it's good for your health, Uncertain whether there is industrial pollution, Uncertain whether it is clean and nuisanceless, other aspects

with as many consumers as possible, to fully understand the actual needs and real ideas of ordinary consumers, and increase the understanding and grasp of the real market.

2.3. Questionnaire design

The design of the questionnaire is crucial for this study since it serves as both the carrier and the cornerstone of the research, as well as a tool for data collection. To help the subjects fully comprehend the pertinent information, the questionnaire takes the form of an online electronic survey with text, images, and video data attached. The questionnaire consists of five parts. Each part includes two or more different questions with a total of 20 questions; all questions are required to be answered. The first section mainly inquired about the social demographic characteristics of the respondents. There are six questions, including their gender, age, education level, area of current home, industry, and monthly income level. See Table 1 for details. The second section aims to ask the subjects about their level of cognitive development and understanding of plant factories, vertical farms, and their products, as shown in Table 2. The third section aims to assess the subjects' reservations, worries, or obstacles regarding the growth of plant factories and vertical farms, as shown in Table 3. The fourth section is mainly used to understand the consumer's willingness to purchase products and price expectations, as shown in Table 4. The fifth part mainly inquires about consumers' trust, awareness, purchase anticipation, and pricing anticipation for brand-name goods, as shown in Table 5.

To ensure that the questionnaire reflects the true thoughts and wishes of the respondents, the questionnaire is anonymous and does not ask for and record sensitive information such as the respondents' names, identifying information and contact information.

According to the analysis in 2.1, the fifth item, a single-choice question, was intended to be in the first section of the questionnaire to help the researcher understand the distribution of the respondents' jobs. Only one of five choices - government officials, academic researchers, producers, sellers and consumers - was available to find out which industry the respondents came from. If a respondent does not fit into one of the first four categories, they are advised to select the fifth category, which is "consumers of agricultural products." These four groups of people are considered to be the actual consumers of agricultural products in this social study.

In this survey, we conducted a questionnaires survey and interviews with government managers, because managers are the people who have the knowledge and formulate policies, and are the macro-regulators of agricultural or scientific and technological development, research, production, sales and even consumption. The direction of development and the rate of building of plant factories and vertical farms are significantly influenced by their level of knowledge, degree of understanding, attitude, and worldview. The reason for the questionnaire survey for scientists is that they are the forerunners and think tanks of this new science and technology. They also set the pace for technological advancement across the board. Understanding the research trends can help you understand and grasp the future development direction and outlook of plant factories and vertical farms. Producers and sellers are the builders of this modern agricultural industry. Investigating and understanding their true thinking is conducive to better identifying problems from practice and improving production and

TABLE 4 The fourth part of the questionnaire (investigation on consumers' purchase intention, price expectation and primary purchase reason).

Number	Question type	Question title	Question options
13	Single Choice	If the price is right, would you like to buy the plant factory and vertical farm" products?	"Certainly," "Maybe" OR "Will not buy."
14	Single choice	Compared with traditional agricultural products, how much higher do you think the prices of agricultural products from plant factories and vertical farms are appropriate?	Slightly higher, not more than 1.50 times, More than 1.5 times but <2 times, More than 2 times but <3 times, Three to five times is acceptable OR More than 5 times, unacceptable.
15	Single choice	What is the primary reason for you to buy products from the plant factory and the vertical farm?	Clean nuisanceless, superior quality, High nutritional index, High freshness, Green health OR Other aspects.

TABLE 5 The fifth part of the questionnaire (investigation on consumers' trust, recognition, brand care, and price expectation of brand products).

Number	Question type	Question title	Question options
16	Single Choice	What do you think of the prospects for plant factories and vertical farms and their crop products?	"Must be," "Maybe" OR "Not"
17	Multiple Choice	What do you think are the advantages of plant factories and vertical farms?	The plant growth environment is accurate and controllable, which can achieve high efficiency and energy saving. Plants can be produced continuously every year to improve food safety (e.g. outbreak, extreme climate impact, etc.), It doesn't need land and sunlight. It's most suitable to be built in the city to supply fresh vegetables for the citizens, It is best for the construction of long climate and poor land areas which are not suitable for plant growth, It has great advantages of improving product quality by regulating plant growth environment, Greatly improve the land-use rate, to ensure the sustainable development of society, So that plant products can be as large-scale production in the workshop as industrial products, AND other aspects.
18	Multiple Choice	What channels do you most want to get information about plant factories and vertical farms and their crop products?	Official news media, We media or social media, Government administration, Research institutions, academic organizations of Universities, Production enterprises or agricultural technology companies, Supermarkets, chain stores or markets for agricultural products and "Other channels."
19	Single Choice	Do you care about the trademarks and brands of agricultural products?	"Very concerned," "More concerned" OR "Don't care
20	Single Choice	How much more do you think it is reasonable to charge for a branded product than a generic one?	"Slightly higher," "No more than 1.50 times, definitely choose branded products," "More than 1.5 times but less than 3 times, preferring to choose branded products," "More than 3 times but less than 5 times, will still consider buying branded products," "More than 5 times, definitely will not choose brand products".

management techniques, processes and methods. Consumers are the end users, and products that are not recognized and accepted by users cannot be developed in the long term. Therefore, it is appropriate and correct to scientifically select the target group and push the electronic questionnaire to them using random sampling in order to make the study general, effective, methodical, scientific and verifiable.

2.4. Statistical analysis method

Descriptive statistical analysis, cross analysis, variance analysis, multivariate regression analysis, and other mathematical statistical analysis methods were used in the study.

The descriptive statistical analysis method is mainly used to analyze the social demographic distribution of the subjects, to objectively understand their understanding, knowledge level, and cognitive depth of this new agricultural production mode, as well as their attitudes, opinions, concerns, recognition, purchase intention, brand care, and price expectation, and to analyze the main reasons why they are willing to buy or unwilling to buy.

Using the cross-analysis method, this paper compares and analyzes the effects of consumers' gender, age, education level, place of residence, occupation, and level of monthly income on their ability to comprehend, level of knowledge, cognitive ability, attitude, view, worry, intention to purchase, price expectation, and brand care of plant factories and vertical farms. The results of the research and analysis are of practical and scientific importance for policymaking, project research and development, industrial planning, resource regulation, production planning, sales planning and health consumption.

Using multiple regression analysis, this study examines and evaluates the impact of consumer social demographics and purchasing behavior on purchasing intentions. Social demography and purchasing behavior are common variables of market segmentation, which enables marketers to accurately identify the most suitable consumer groups and provide them with the most intimate services (Armstrong and Kotler, 2003). The findings

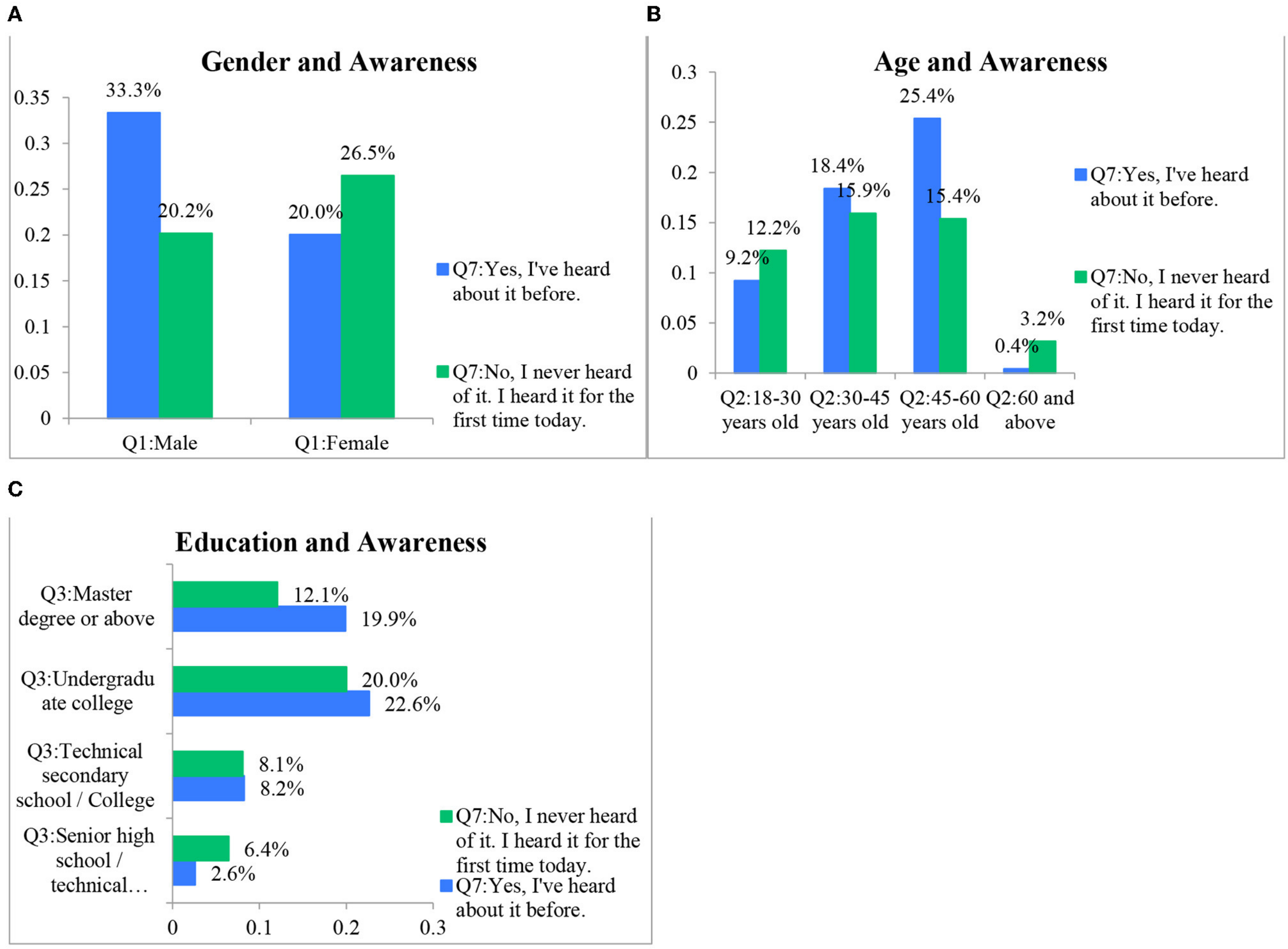

FIGURE 2
Cross analysis of different gender **(A)**, Age **(B)**, Education level **(C)** on Plant factory awareness.

of this analysis can be used by producers to pinpoint the customers most likely to purchase this novel agricultural category and to define their precise requirements. The conclusions help producers better plan construction scale, develop production plans, direct product production, upgrade technical equipment, enhance process flow, upgrade product quality, plan marketing and plan future development prospects.

3. Results and discussion

3.1. Questionnaire collection and statistical analysis

WeChat and QQ are two popular social media platforms in China with a large number of users. The electronic questionnaire, which has the universality of social investigation and research, was sent to respondents *via* WeChat, QQ and other social platforms, with a large base of respondents and random recipients. The design, testing and piloting of the questionnaire was completed in early November 2020. The questionnaire was conducted in three phases. The first phase, referred to as the primary investigation phase, lasted for more than 3 months, starting on December 6, 2020 when the electronic questionnaire was sent out, until March 6, 2021 when the final feedback from the questionnaire was collected. The second phase, a follow-up survey, will be conducted from March 7 to April 9, 2021 to make up for the lack of respondents in the first phase and to broaden the pool of respondents beyond the authors' home regions. The third phase is the voice and on-the-spot interview phase, where key members of government staff and subject matter experts are interviewed directly. More than 800 questionnaires were submitted during the three phases, of which 729 were available for statistical analysis. After extensive testing before the questionnaire was released, simply going through it from start to finish took 20 min, compared with an average response time of 38 min and 33 s for the 729 questionnaires. It can be seen that each questionnaire contains thoughtful responses from the respondents, which effectively reflect their actual cognitive level regarding the plant factory. The sample consisted of 46.5% women and 53.5% men, all of whom were adults over the age of 18 with experience consuming agricultural products. In addition, 74.63 percent of the subjects held a bachelor's degree or higher and possessed high levels of knowledge and cognitive ability. The subjects were from the Chinese mainland, and the number of people in each region was evenly distributed, with high regional representation:

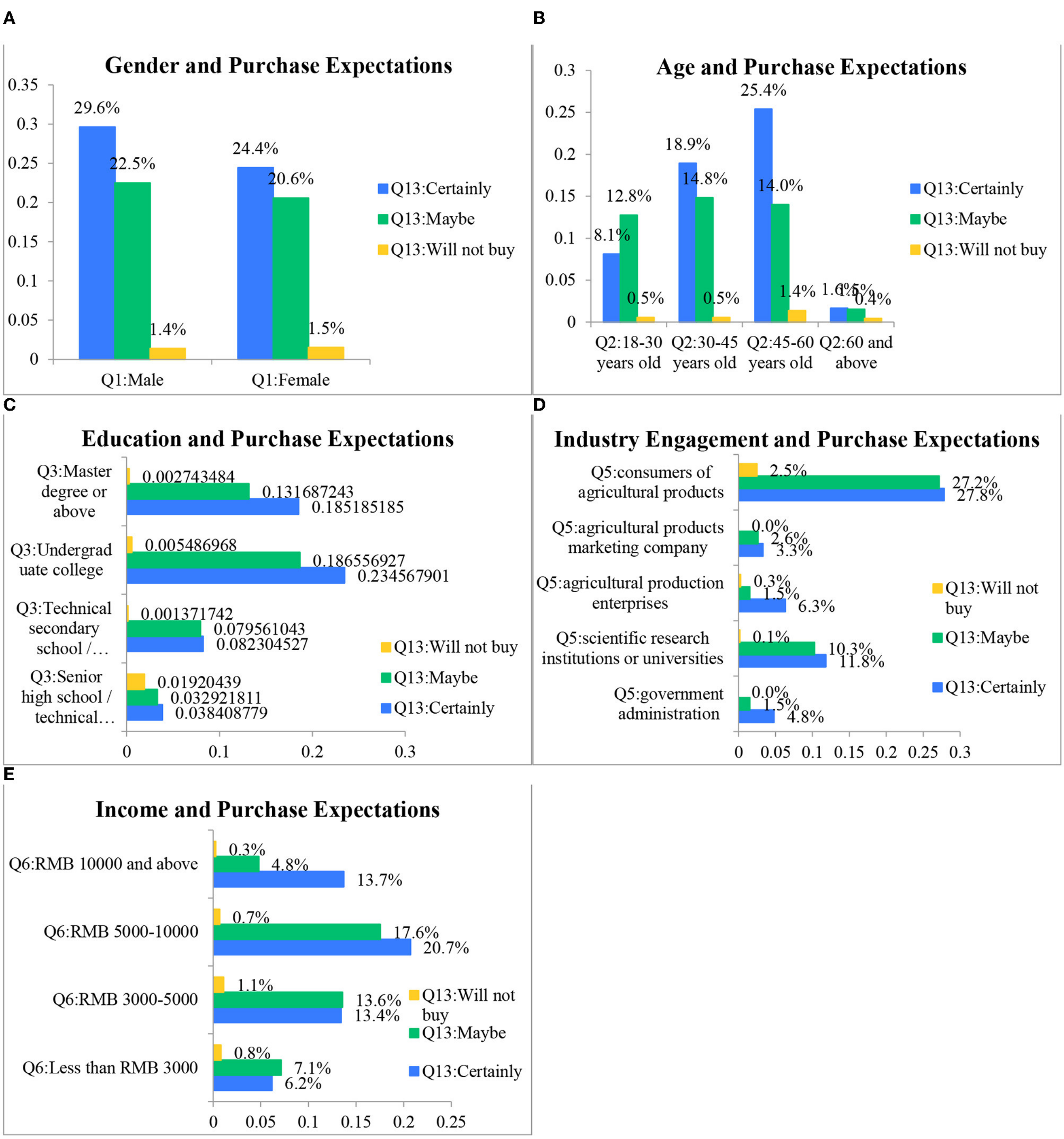

FIGURE 3
Cross analysis of different gender **(A)**, Age **(B)**, Education level **(C)**, Industry engagement **(D)** and Income **(E)** on Purchase expectations of plant factory product.

8.0% were from North China, 8.4% from Northeast China, 44.7% from East China, 8.23% from Central China, 8.37% from Northwest China, 8.6% from the Southwest, and 13.6% from the South. A total of 6.3% of respondents were from government administration, 22.2% from scientific research institutions, 8.1% from production companies, 5.9% from sales companies and 57.5% from consumers. The fact that each respondent is a consumer makes the survey representative of the industry and universal among consumers. High-income respondents accounted for 18.8%, higher-income respondents 39.0%, middle-income respondents 28.1%, and low-income respondents 14.1%. The income levels of the respondents are representative and universal.

These findings demonstrate the relevance, generality and representativeness of this sociological survey. It should be noted that since the authors are from central China and scientific research

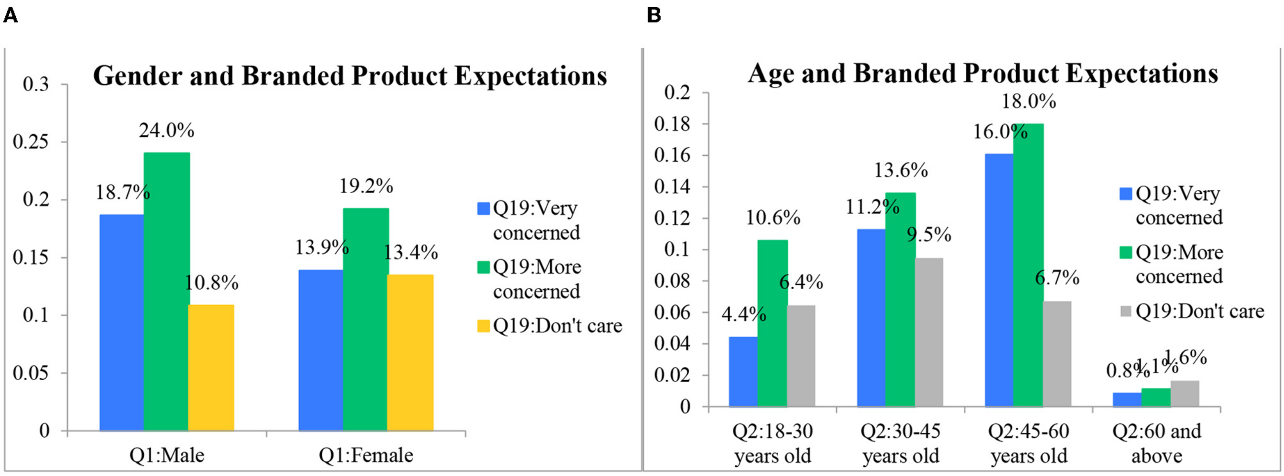

FIGURE 4
Cross analysis of different gender **(A)**, Age **(B)** on Product brand of plant factory.

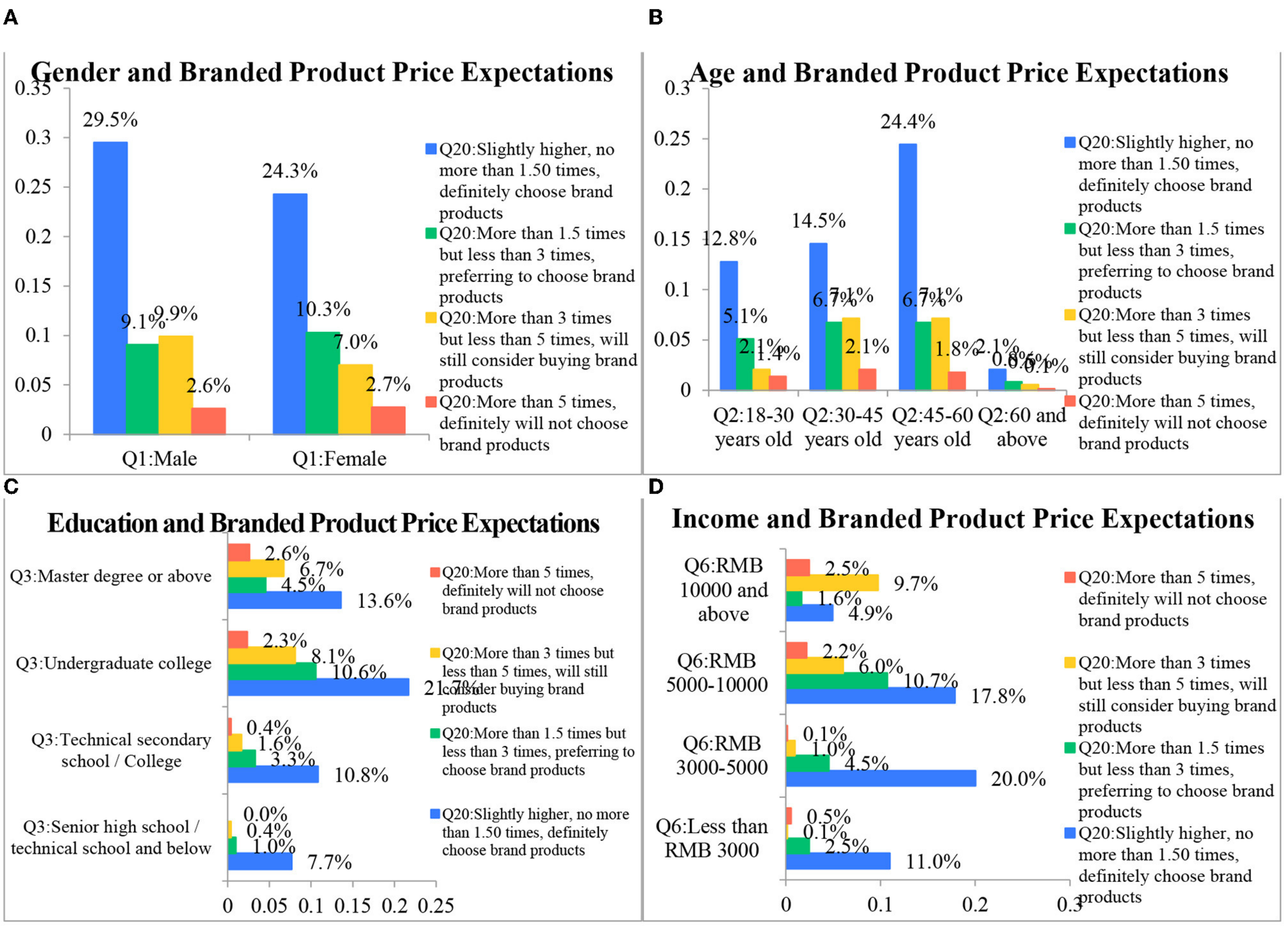

FIGURE 5
Cross analysis of different gender **(A)**, Age **(B)**, Education level **(C)**, Income **(D)** on price expectation of plant factory brand product.

institutions, there are more respondents from central China and scientific research institutions; However, this does not affect the social universality of the survey but rather confirms its universality and validity.

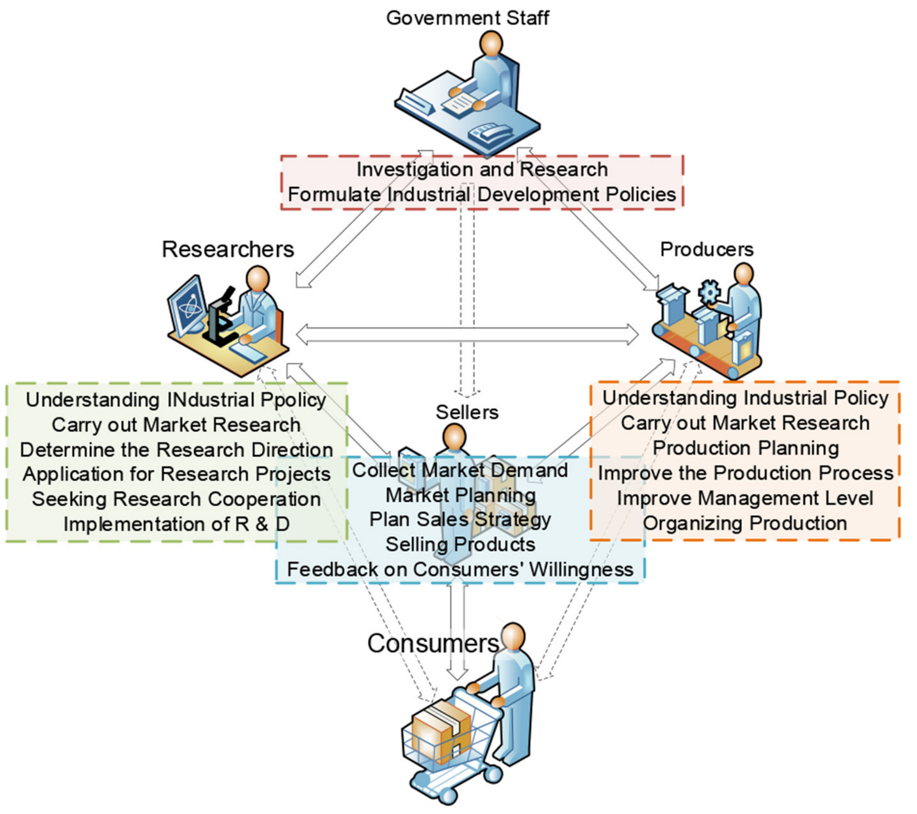

FIGURE 6
Social group role, function, and interaction model.

3.2. Results of the survey

The survey results revealed that 46.6% of customers had never heard of a plant factory or vertical farm and believed they knew nothing about them. 73.3% of respondents believed that the major factor limiting its development is the high construction cost; 66.4% of consumers believe that it is the too-high operation cost; 59.2% believe that it is the lack of consumer recognition; and 56.1% believe that there is not enough marketing promotion. 70.6% of the respondents were concerned with the high price, 59.5% with the low nutritional content, 54.7% with whether it was beneficial to health, 48.6% with industrial pollution, and 48.3% with whether it was clean and pollution-free. Nonetheless, 97.1% of respondents stated they would be interested in purchasing this type of plant product, and 54.5% said they would definitely purchase it. 93.6% of respondents are optimistic about the future of plant factories and vertical farms, and 49.4% of them are extremely optimistic. The main reason they purchase plant products from plant factories is that they are clean and pollution-free, which accounts for 39.3% of the total, followed by green and healthy (30.3%), high freshness (17.6%), high quality (8.8%), a high nutrition index (3.7%), and other reasons (0.3%). 75.7% of the subjects stated that they would be willing to buy brand name agricultural produce for everyday consumption; 32.5% of the subjects indicating that they were very concerned about the product's brand. 76.7% of respondents responded that the price of branded products should not be excessively higher than that of ordinary products, whereas 23.3% of respondents were willing to pay three times or more. The survey also found that 72.8 and 64.3% of respondents intended to learn about a product through official news media and market circulation channels, respectively.

FIGURE 7
New development mode of "Three directions and one entity."

3.3. Analysis of the survey

In China, as the government's investment and policy support for modern agriculture and smart agriculture have increased year by year in recent years, an increasing number of experimental and demonstration plant factories and vertical farms are being built across the country, with approximately 300 such plants having been constructed by the end of 2019 across the country (Data from China Industry Research Network, Research Report on current situation analysis and development trend of plant factory industry in China from 2020 to 2026, 2020,9). The study of survey data reveals that an increasing number of consumers are beginning to comprehend and accept this new form of plant production and are willing to purchase the plant products of plant factories and vertical agriculture. They believe that plant factories and vertical farms will become one of the primary methods of urban agricultural production in the future. This energy-saving, resource-saving, and environmentally friendly sustainable system for plant production has the following advantages: (1) It can be constructed in a region with a long growing season and poor, unsuitable soil for plant growth. (2) It does not require land or sunlight. (3) It is suitable to be constructed in the city to provide residents with fresh vegetables. (4) Plants can be produced year-round to improve food safety in the event of an emergency (such as an outbreak, an extreme climate impact, etc.). (5) It significantly increases the rate of land utilization and promotes the sustainable development of society. (6) By managing the plant's growing environment, it provides many advantages for enhancing product quality. (7) Like industrial products, plant products can be produced on a large scale in the workshop. (8) The plant-growing environment is precise and under control, allowing for excellent efficiency and energy conservation. In addition, some experts noted in the expert interview that the plant factory offers extra advantages, such as increasing employment, improving the working conditions of farmers, and promoting the adjustment and optimization of the agricultural industrial structure. Some scientists have boldly predicted that in the future, more than 60% of leafy vegetable products consumed by urban dwellers will originate from urban plant factories. However, a number of obstacles are impeding the development of the plant factory, such as: (1) its enormous investment in construction and maintenance; (2) its high operating costs; (3) its complex construction technology; (4) its lack of production experience; (5) its small production scale; (6) its subpar product quality; (7) its lagging R&D; (8) its limited product diversity; (9) its weak market competitiveness; (10) its difficult market promotion; (11) its low consumer recognition; and so on. This has also led to considerable consumer concern. The price is the most concerning factor, accounting for 70.6% of the respondents, followed by nutritional value, food safety, industrial pollution, and clean and pollution-free, accounting for 59.5, 54.7, 48.6, 48.2%, etc., which indicates the direction of future work for researchers and plant-factory producers. To accelerate the commercialization of plant factories and vertical farms, it is essential to adopt new energy-saving and emission-reduction technologies to reduce production energy consumption, adopt standardized management and intensive means to improve the comprehensive utilization of resources and production efficiency, and adopt intelligent means to reduce labor costs. In short, the first job is to reduce the cost of products, followed by efforts to enhance their quality and nutritional value. In the future, the income of urban inhabitants will expand dramatically, people's lives will become increasingly affluent and refined, and the need for high-quality, clean, pollution-free, high-fresh plant products will increase. Price will no longer be the primary factor in the purchase and consumption of fresh plant products, and the purchase of big-brand and high-value-added brand products will become a trend in agricultural product consumption in the future, necessitating that the production and management of plant factories and vertical farms devote more attention to brand strategy.

3.4. Cross analysis results

By using the cross-analysis method, the relationship between gender, age, education level, occupation, income level, and cognition level of plant factory and vertical farm, purchase intention and price expectation, brand awareness, and price expectation of brand products were analyzed. The results show that: (1) In terms of understanding and acceptance of plant factory and vertical farms, as illustrated in Figure 2, male consumers are more knowledgeable and accepting of plant factories and vertical farms than female consumers (Figure 2A). Young consumers are more knowledgeable and accepting of plant factories and vertical farms than old consumers (Figure 2B). Consumers with higher education levels are more knowledgeable and accepting of plant factories and vertical farms than those with lower education levels (Figure 2C). (2) In terms of buy intent and price anticipation, as shown in Figure 3, male customers rank higher than female consumers (Figure 3A). Middle-aged consumers rank higher than young consumers, and young consumers rank higher than old consumers (Figure 3B). Consumers with higher education levels rank higher than those with lower education levels (Figure 3C). Consumers from scientific research institutions, universities, and government departments rank higher than those from manufacturing enterprises, sales companies, and ordinary consumers (Figure 3D). High-income consumers rank higher than low-income consumers (Figure 3E). (3) In terms of brand awareness and willingness to buy brand products, as shown in Figure 4, male consumers have stronger brand awareness than female consumers (Figure 4A). Middle-aged consumers have stronger brand awareness than young consumers, and young consumers have stronger brand awareness than old consumers (Figure 4B). (4) In terms of the acceptance of plant factory product prices and brand products, as shown in Figure 5, male consumers are more receptive to higher prices than female consumers (Figure 5A). The price that middle-aged consumers can accept is higher than that of young consumers, and the price that young consumers can accept is higher than that of old consumers (Figure 5B). Consumers with higher education levels can accept higher prices than those with lower education levels (Figure 5C). High-income consumers can accept higher prices than low-income consumers (Figure 5D). From the results of the analysis, we can derive the following insight: in the current planning, construction, and marketing stages of plant factories and vertical farms, we should prioritize the promotion and publicity of target groups such as male consumers, middle-aged consumers, consumers with a high level of education, and consumers with high incomes. Because these consumer groups are more likely to embrace the new high-tech agricultural type of plant factory, to take the lead in purchasing and tasting, and to influence other customers to purchase.

4. Discussion

This social survey and research aims to understand consumers' cognitive level, development concerns, purchase expectations, brand recognition, and purchase intention of plant factory and vertical farm, a new form of modern agricultural production, through an extensive and in-depth social survey to investigate their development prospects, market potential, existing challenges, and sustainable development countermeasures and suggestions. The survey and study results suggest that 93.6% of consumers are aware that this is a new form of urban agriculture production that has the greatest future potential, can be expanded vigorously in urban areas, and is the most high-tech, eco-friendly, and resource-efficient. The majority of consumers are eager to purchase factory plant products because they are clean and pollution-free (39.3%) and green and healthy (30.3%), followed by high-tech freshness (17.6%), high quality (8.8%), and a high nutrition index (3.7%). This result is consistent with the research of You et al. and Huang (You et al., 2013; Huang, 2019). The respondents and interviewees have a better understanding of the value of plant products and the food safety of plant factories and vertical farms as a result of the social survey. In order for them to recognize that the plants grown in the plant factory may increase their taste, nutrition, and quality by precisely regulating the plant development environment factors, they will produce more innovative functional plant products to meet the health and safety requirements of various groups. It also makes them take notice that the plant factory environment is clean and sterile; the production water is strictly purified and meets the drinking standard; the components of the nutrient solution can be absorbed almost entirely by the plants and there are no residues; and the plant products produced are clean, pollution-free, and can be consumed directly without being washed.

The vast majority of consumers (97.12%) stated they would purchase plant-factory products, with 54.1% being extremely certain to purchase, 43.1% willing to purchase, and 2.9 % not purchasing. 70.6% of consumers are concerned about the price of a product, 59.5% about its nutritional content, 54.7% about bad health effects, 48.6% about industrial pollution, and 48.3% about its cleanliness and lack of pollution. The findings are consistent with surveys of consumers in Singapore and Japan (Kurihara et al., 2014). Therefore, new technology and methods should be employed in the scientific research, manufacturing, management, storage and transportation, sales, and other links of plant plants and vertical farms to maximize the complete utilization of resources and reduce operating costs (Graamans et al., 2018; Kikuchi et al., 2018), and gradually improve the comprehensive competitive advantage of products, the recognition of consumers and market occupancy rate, which is the correct choice for the sustainable and healthy development of this new agricultural production system.

Brand items are more convenient for publicity, promotion, sales, and service than non-brand products (Steenkamp, 2017), thus registering trademarks and implementing brand marketing tactics is the best approach to increase consumer recognition and market popularity. The interview, survey, and analysis of consumers' brand awareness indicate that the majority of consumers (76.7%) are more likely to trust and purchase brand products, 43.2% of respondents are more concerned about the brand, and 32.5% of respondents are extremely concerned about the brand. Furthermore, the results of the questionnaire's classification and cross-analysis demonstrate that young people, those with a high level of education, and those with a high income are more likely to accept new things, care more about product brands, and are willing to pay higher prices for brand products. Therefore, plant factory and vertical farm product marketing should focus more on these groups.

5. Conclusions, development countermeasures, and suggestions

5.1. Conclusion

Through the above comprehensive analysis, research, and in-depth discussion of the survey results, we have obtained many valuable findings, which are summarized as follows:

Although a growing number of customers have a basic understanding of the agricultural production system of plant factories and vertical farms, this comprehension is still at a fundamental level. More than half of customers have never heard of this new agricultural technique, and the level of awareness varies by demographic category. Therefore, government employees, researchers, manufacturers, and merchants must continue to collaborate to promote relevant publicity and education.

The survey finds that more than one-third of consumers have never seen one form of factory plant products, and less than one-tenth of consumers are familiar with six or more types of plant products, indicating that this type of plant products has not been introduced in large quantities to the market, and is rare in the market, with rare species and insufficient diversity, and enormous market development space and potential.

The results demonstrate that consumers tend to believe that a lack of news coverage (66.4%), marketing and promotion activities (65.7%), popularization of scientific and technological knowledge (63.8%), large-scale listing (55.1%), reports on scientific research achievements (35.9%), etc. contribute to their lack of knowledge about plant factories and vertical farms. The findings can assist producers and sellers in analyzing market development strategies.

It is found that the main factors that restrict the development of plant factories and vertical farms are high construction cost (73.3%), high operating cost (66.4%), consumer recognition (59.2%), little market promotion (56.1%), complex production technology (45.0%), insufficient government support (40.3%), low product quality (34.9%), insufficient product diversity (30.8%), and lagging R & D (19.8%), etc. Consumers were most concerned about the high price (70.6%), the questionable nutritional content (59.5%), the uncertain health advantages (54.7%), the uncertain industrial pollution (48.6%), and the uncertain cleanliness (48.3%). Clean and pollution-free (39.3%), green health (30.3%), high-tech freshness (17.6%), product quality (8.80%), and nutrition index (3.7%) were the most important purchasing considerations for consumers. These findings indicate that the main tasks of the construction and market development of this new agricultural production system are to reduce the construction and operation costs, to study and verify the comprehensive nutritional value and safety of the products, and to ensure that the harvested products can reach consumers as quickly as possible while retaining the highest level of freshness.

The survey discovered that the vast majority of consumers (93.6%) recognize the benefits of this agricultural production system and are optimistic about its future; Many consumers (97.1%) will purchase this product in the future; and, as long as the price is reasonable or not excessively higher than that of ordinary products; 76.7% of consumers are more likely to purchase branded products. The data indicate that a brand marketing approach is the most effective method for developing this agricultural production system.

The findings of this survey have bolstered our faith in the investigation of plant factories and vertical farms, as well as our resolve to construct a contemporary agricultural production system with strict environmental regulations and high resource sustainability. It will enable us to study, plan, construct, and develop this new type of agricultural production in a scientific, reasonable, and organized manner, promote high-tech agriculture, which is related to the future sustainability and food safety of humanity, to realize scale, industrialization, commercialization, and marketization, and provide immediate benefits to cities with dense populations. It is suggested that multidisciplinary research should be carried out from the perspectives of urban development, modern architecture, commercial economy, environmental protection, and resource sustainability.

5.2. Development countermeasures and suggestions

This social survey offers us with fundamental data and market information, and serves as the foundation for scientific and systematic study on plant factories and vertical farms. On this basis, the author further analyzes the roles, social functions, and interaction models of the government, scientific research institutions, production enterprises, sales companies, and consumers from the perspective of social relations, and then studies the countermeasures for the sustainable development of plant factories and vertical farms.

Because of the complexity of technology and huge investment, plant factories and vertical farms require the guidance of national policies and financial support, the multi-group interaction of the government, scientific research institutions, production enterprises, sales companies and consumers, and even the combined efforts of the whole society. The government is the leader, policymaker, organizer, promoter, and coordinator of the development of national and social undertakings, as well as the largest owner of comprehensive resources. Any fundamental research and large projects are inseparable from the government's policy direction, project driving, financial backing, and land policy, particularly the establishment of plant factories and vertical farms in urban areas. Scientific research institutes are the pioneers of scientific research, technology development, and policy theory research, and they represent the cutting edge of academic research and the highest levels of output. Obviously, the continued efforts of scientific research institutions and university researchers are also necessary for the sustainable growth of plant factories and vertical farms. The production enterprise is the principal participant in the construction, production, and operation of plant factories and vertical farms, as well as the key force and market body in its sustainable development. The sustainable development of plant factories and vertical farms is unachievable without the active engagement of sales companies, which are essential to push production means and products to the market and maintain market circulation. The recognition and attitude of consumers are also significant. It is impossible to accomplish sustainable development if their feelings, preferences, and anticipations are ignored. Figure 6 depicts the roles, functions, and interaction models of social groups.

On the basis of investigation and analysis aimed at the collected problems, doubts, and concerns, combined with the analysis of the social group role, function, and interaction model directly related to the plant factory and vertical farm industry, some coping strategies and suggestions were presented, with the purpose of mobilizing the initiative of all parties in society and uniting to pursue the sustainable development of modern agriculture.

For a nation or country, we must first reexamine the status and role of plant factories and vertical farms in modern agriculture, the national economy, social development, and human sustainable development, and define their strategic positioning. When necessary, it should be incorporated into the national strategic development plan, the medium- and long-term development plan, the national top-level design should be strengthened, urban development and major construction projects should be coordinated, national support should be increased, and a comprehensive and flawless policy support system should be established.

Mobilize the collaboration and cooperation of diverse research institutions, academic groups, multi-disciplinary experts, and industrial production enterprises to the fullest extent, conduct extensive academic discussions, carry out comprehensive and interdisciplinary theoretical research and technical development on plant factories and vertical farms, and implement a comprehensive theoretical and technical system for the entire discipline.

We should increase the scope and intensity of government support and the participation of scientific research institutions, build demonstration projects with production enterprises as the main body, strengthen product research and development from point to area, develop more, better and low-cost equipment and facilities, expand production scale and product diversity, improve product quality, and build complete technical standards, production specifications, process standards, and product standards, improve the technology system, standard system and the quality supervision system.

We will strengthen the supporting construction of network, intelligent and information-based environment monitoring platform, growth characteristics monitoring platform, production control platform, tracing and tracing platform, marketing expresses information service platform and big data analysis platform, carry out various technical training, industrial promotion, and market development, expand the marketing channels and establish a comprehensive and perfect marketing system.

Establish professional research direction or discipline of plant factory and vertical farm, include it in the teaching syllabus of environmental engineering, facility horticulture, and other disciplines and vocational education, cultivate a large number of professional scientific and technological talents and marketing managers, expand publicity and increase marketing efforts, improve consumers' awareness and recognition, enhance brand influence, and promote the improvement of food culture.

Explore the new development strategy of "3 Positions and 1 Entity." Wang et al. (2022b) The smart plant factory with skyscrapers is expensive, technologically advanced, and systemically complex. To expand healthily and industrialize rapidly in a market environment, an appropriate development mode is required. "3 Positions and 1 Entity" is a novel form of production, operation, and management integrating "factory production, corporate management, and brand marketing" with "modern company + intelligent skyscraper" as the business and production entity. See Figure 7. The modern corporation is the originator of production and the market, and the intelligent skyscraper is the production entity of the urban plant factory's solid foundation. Factory production, business management, and brand marketing are the three components of the plant factory that face the market, satisfy the high-quality lifestyle requirements of customers, and lead the modern smart agricultural sector. The four are interconnected and interdependent. Without modern companies to fully utilize the creativity of market players and intelligent skyscrapers to serve as the production "workshop" of plant factories, there will be no foundation for the year-round, large-scale, high-capacity, high-quality, intelligent, informational, and industrialization of plant production, making it difficult to achieve the construction goal comprehensively. Factory production, company management, and brand marketing are sharp tools for the rapid growth and development of urban plant factories, which largely guarantee the industrialization of urban agricultural production, the modernization of management, the achievement of enterprise development, and the high quality of plant products.

To integrate a plant factory into urban development and feed the large-scale urban population, we must fully mobilize the enthusiasm of government agencies, scientific research institutions, production enterprises, sales companies, and consumers, so that all parties can form a joint force, maximize their role, promote the overall joint linkage, tap the potential power, integrate superior resources, and be market-oriented. With scientific and technological innovation as the support and achievement transformation as the link, we should adhere to a plant factory and vertical farm as the development orientation of urban productive agriculture. We should use the opportunity of developing plant factories to adjust the structure of the plant industry. We should take the safety supervision of plant products as the guarantee, enrich the "vegetable basket" of urban residents, increase the market supply capacity, enhance the scientific and technological innovation of agricultural modernization, improve the quality of agricultural products of plant factories, and strengthen the brand marketing of plant products, and develop more functional plant products with high added value. We should take advantage of the opportunity presented by the development of plant factories to improve the diet nutrition and healthy diet structure of citizens, boost the contribution rate of the modern plant industry to the national economy, and comprehensively promote the sustainable development of the urban productive plant industry.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

Informed consent was obtained from all participants included in the study and a separation of personal and factual data was always guaranteed. All persons and institutions involved in the production of this manuscript are informed and familiar with the results and this publication.

Author contributions

XW: data collection, designed the study, and peer-reviewed drafts. XW, VO, VZ, ZW, and MZ: research collaborator and peer-reviewed drafts. ZW: research collaborator, data collection, and data analysis, and first draft of manuscript. VO and VZ: research collaborator. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Strengthening food security through alternative carbohydrates in the city-state of Singapore

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Strengthening food security, in places where land and natural resources are limited or no longer available, is challenging. This is especially true for the production of staple food carbohydrates. Unlike some alternative foods, such as cultured meats, producing food carbohydrates using conventional agri-food approaches requires many natural resources, which are not available in some regions such as Singapore. Therefore, we must develop new, sustainable methods to enhance the quantity and nutritional quality of foods rich in carbohydrates. In this article, we review current developments in food security in the city-state of Singapore and emphasize the essential role of food carbohydrates in the food security plan. We discuss technology developments (i.e., indoor vertical farming, urban farming) used to enhance crop quality and production. We also make a few recommendations such as exploring underutilized and unconventional crops that are resilient and nutrient-dense, identifying hidden resources in local ecosystems (i.e., revalorizing agri-food processing by-products), and producing alternative carbohydrates (i.e., microbial and synthetic carbohydrates). Experience and approaches developed in Singapore provide an example to other regions and may inspire creativity in securing food availability.

KEYWORDS

food security, Singapore, food availability, alternative carbohydrates, microbial carbohydrate, indoor farm, synthetic carbohydrate, urban farming

1. Introduction

The world today faces an increasing demand for food. Nearly 9–10% (approximately 720 to 810 million) of the global population went hungry in 2020 (FAO, IFAD, UNICEF, WFP, and WHO, 2021). The world's population is expected to increase to 9.9 billion by 2050 (Population Reference Bureau, 2020). At its current food consumption pattern, the world will have a 70% increase in food demand in 50 years (Food and Agriculture Organization, 2009). However, food production and supply are not rising sufficiently to meet the projected need. In addition, environmental challenges, such as climate change, further put food production at risk. In the absence of effective adaptation, the global yield of food crops (Bichetti et al., 2021) could decline by nearly 30% by 2050 (Hobert and Negra, 2020).

The rapid increase of urbanization also raises challenges in food security. More than 55% of the global population lives in urban areas (United Nations Department of Economic and Social Affairs, 2018), and nearly 80% of the population worldwide uses imported foods for at least a portion of their meals. The value of food imports has tripled since the beginning of the century (Bichetti et al., 2021). However, the high cost does not guarantee food availability. The reliance on foreign supplies for major nutrients is risky for food security. The COVID-19 pandemic and the war between Russia and Ukraine have interrupted the global food supply chain and threaten food security in many countries. In addition to the concern of food availability, nutrition security in urban areas involves tackling the coexistence of overnutrition (i.e., overweight) and malnutrition (i.e., deficiency of micronutrients). Urbanization influences food systems and diets, which tend to include a high proportion of unhealthy foods and sugar-based beverages (Nguyen et al., 2021). A sedentary lifestyle further elevates health risks. As a result, city-states, such as Singapore, face the challenge of stabilizing food availability and nutrition quality.

Singapore currently produces less than 10% of its food supply due to limited natural resources (Singapore Food Agency, 2020). Aside from growing food locally, the country diversifies its importing sources and also produces food overseas to secure the food supply chain. Singapore's approaches have been very successful. The country was ranked first in 2018 and 2019 by the Global Food Security Index (GFSI), which examined food affordability, accessibility, and quality (Economist Intelligence Unit, 2018, 2019). However, when natural resources and resilience were added to the score criteria, the rank of Singapore dropped to 29th out of 100 countries (Economist Intelligence Unit, 2020).

To strengthen its food security and resiliency, Singapore has set a national goal ("30 by 30") to increase its local food production from less than 10 to 30% by 2030 to meet nutritional needs. The government also implemented the Singapore Food Story R&D Plan to develop technologies in areas of sustainable urban food production, sustainable future foods such as advanced biotech-based protein production, and for food science safety and innovation (Singapore Food Agency, 2022). A significant effort has been invested in technology development. Stakeholders have quickly accelerated the transformation of the food industry into advanced manufacturing, particularly in producing plant and cultivated meat and dairy alternatives to formulate alternative proteins into popular local cuisines that stimulate consumers' interest and acceptance (Quek, 2022). In addition to prioritizing production, Singapore took regulatory leadership and became the first nation to approve the commercial sale of cultivated meat products (International Trade Administration, 2021). The approval enables the availability of alternative proteins for the consumers in Singapore. Singapore demonstrates a successful case in implementing these advances through the integration of science, technology, economics, consumer education, and novel food regulations and policies.

Perhaps a more significant challenge to increasing food security in Singapore is obtaining alternative sources of vital energy and nutrients. This article recommends and discusses a few potential solutions to support food carbohydrate security, including developing innovative food production technology, exploring underutilized crops with greater resilience and nutrients, identifying hidden resources in local agri-food systems, and producing alternative carbohydrates, such as microbial carbohydrates and synthetic glucans. The adaption of new food systems and the initiatives taken in Singapore could be applied to other regions and inspire more innovative approaches to strengthen food security in the world.

2. Role of carbohydrates in food security

Carbohydrates, proteins, and lipids are macronutrients, which provide the human body with vital energy, and carbohydrate-based foods are recognized as nutritious and healthy. Carbohydrates first appear in our life as part of complementary feeding during weaning (Lin and Nichols, 2017). Rice is given to young children in a great quantity in Asia and Africa. Western India has a tradition of feeding infants with arrowroot. In the United States, infant cereals or baby finger foods made of rice, oats, maize, and wheat are popular. Parents observe the benefits of complementary feeding with starch-based foods as they see their children grow (Lin and Nichols, 2017). The Eatwell Guide in England comments that starchy foods are a good source of energy and the main source of a range of nutrients in our diet (Public Health England, 2019). The dietary guideline encourages "choosing higher fiber or wholegrain varieties, such as wholewheat pasta and brown rice, or [to] simply leave the skins on potatoes" (Public Health England, 2019). Glycemic carbohydrates are the primary caloric energy for our brain, central nervous system, kidneys, and heart muscles (Vannucci and Vannucci, 2000; Myers et al., 2021). Some indigestible and non-digestible carbohydrates, such as dietary fiber, are substrates of gut microbial fermentation and are essential to human health. Carbohydrate-based foods also provide non-carbohydrate nutrients, including proteins, vitamins B, C, and E (Kulp and Ponte, 2000), minerals (i.e., potassium, iron, magnesium, zinc, and selenium), and phytochemicals (e.g., β-carotene, polyphenols; McKevith, 2004; Zaheer and Akhtar, 2016; Saini et al., 2021). For example, grains supply carbohydrates and are also a primary protein source in human diets. Wheat is a popular grain and offers nearly one-fifth of the calories and proteins consumed worldwide (Daba et al., 2020; Poutanen et al., 2021). However, excessive consumption of carbohydrates creates health concerns in some populations. The long-term overconsumption of sugars and rapidly digestible starch-based foods is associated with some hyperglycemia-related diseases, such as type 2 diabetes and obesity. Low-carbohydrate diets, which restrict the energy supply received from carbohydrates and lead to quick weight loss, are popular with some groups (Gómez-Maqueo et al., 2023). However, the nutritional functions of carbohydrates go beyond their role as energy sources and involve providing some biological functions. Glycoconjugates (e.g., glycoproteins and glycolipids) operate as messengers of critical information and are involved in receptor structure, recognition sites, blood clotting regulation, and lectin interactions (Murray, 2003). Long-term carbohydrate restriction is linked to complications such as heart arrhythmias, impairment of cardiac contractile function, kidney damage, lipid abnormalities, increased cancer risk, impairment of physical activity, osteoporosis, and sudden death (Bilsborough and Crowe, 2003). Removing carbohydrates from regular diets or overconsuming carbohydrates with poor nutritional quality contributes to health risks.

According to the Food and Agriculture Organization of the United Nations, "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious foods that meet their dietary needs and food preferences for an active and healthy lifestyle" (Food and Agriculture Organization, 2006). Historically, carbohydrate staple foods (e.g., rice, wheat, potatoes) have played a fundamental role in food security. Rice, maize, and wheat make up 2/3 of global human food consumption, and rice alone provides more than 21% of global caloric needs. Besides grain-based staple foods, root (i.e., potato) and fruit (i.e., banana and plantain) crops are consumed by over 3 billion people in developing countries (Scott, 2021). Cultivating carbohydrate staples transformed nomadic hunter-gatherers into settled farmers, spawned the first urban centers, and built empires and dynasties (Callaway, 2014). Existing challenges today involve effectively producing sufficient carbohydrate foods and processing them in such a way that would support healthy diets.

3. Challenges in strengthening carbohydrate food security with limited natural resources in Singapore

In the 1970s, 9% of Singapore's total population (approximately 175,000 people) was engaged in agricultural activities. Due to urbanization and industrialization, the food system was gradually restructured with limited self-production (Singapore Food Agency, 2020). Currently, Singapore produces few staple carbohydrate foods; the primary self-produced products are eggs, fish, and leafy vegetables (Singapore Food Agency, 2020). Less than 1% of Singapore's land, which is only approximately 72 square kilometers, is available for food production (Mullen, 2020). However, conventional cultivation of carbohydrate-rich crops requires the luxury of land space. Furthermore, the long planting season of staple crops restricts the use of land from multiple production cycles. There are also many difficulties in terms of climate. Typical tropical weather consistently has high temperatures and abundant rainfall. In recent years, Singapore has experienced hotter temperatures with increased amounts of rain (Adeline et al., 2021), which further challenges the agronomic management of maintaining crop quality, yields, and disease resilience. The self-production cost (e.g., energy and space renting) in Singapore is often much higher than that in neighboring countries, such as Malaysia, Indonesia, and India. The production cost is reflected in the product price, which is less competitive than imported crops.

Like many urban regions, Singapore faces challenges in nutrition security. Nearly 28% of the elderly (above 55 years old) were at risk of malnutrition in Singapore due to low mobility and poor health (Nagpaul et al., 2020). Some migrant workers suffer from hidden hunger. One study found that the long-term imbalanced diets of migrant workers in Singapore, consisting primarily of white rice with few other foods, resulted in a deficiency of vitamins A and B, iron, zinc, and folic acid (BBC, 2016). The Singapore Ministry of Health declared "war on diabetes" in 2016. Singapore's high prevalence of diabetes was once only next to the United States among developed countries. The disease is projected to affect one in two residents in Singapore by 2050 (Ministry of Health, 2019). A food-focused strategy was promoted to increase the accessibility to healthier food options, such as brown rice and low-sugar beverages (Ministry of Health, 2019).

Despite many obstacles to local production, Singapore continues to prioritize the increase in self-production as a vital buffer for when the global food supply chain is interrupted (Teng, 2020). Non-conventional approaches are needed to produce accessible, affordable, and nutrient-rich carbohydrates. Figure 1 illustrates Singapore's strategies and the recommendations from this article.

4. Production with innovative technology

Singapore is globally recognized in innovation and technology. Beyond its leadership in digital competitiveness (e.g., artificial intelligence, cloud computing, and quantum computing), developing innovative farming technologies is crucial for growing food in a productive, sustainable, and climate-resilient manner. Indoor farming and urban farming have continued to advance in Singapore with the support of innovative technologies.

4.1. Indoor vertical farming

Indoor farming is a resource-conserving method where food is produced in closed recycling and controlled systems with a minimized negative impact on the environment. It is immune to environmental stresses (e.g., rainfalls, drought) and is sustainable in that it utilizes water and energy with advanced technology. Hydroponics, aeroponics, and aquaponics are popular farming methods, which either recycle or minimize the use of water. A hydroponic system supplies plants with nutrients *via* a thin stream of water running through the roots. An aeroponic system sprays a nutrient-containing mist onto the roots in an enclosed root chamber, using 70% less water than hydroponics (Masyk and Fritz, 2017). In aquaponics, fresh-water fish, such as tilapia, generate nitrogen-based waste to supply plant growth. One kilogram of fish can produce approximately seven kilograms of vegetables in such a system. Vertical farming has rapidly developed in Western countries, such as the United States. It is projected to grow approximately 24% between 2018 and 2024 and is expected to be worth $3 billion in US dollars by 2024 (Arizton, 2019; LeBlanc, 2020). Vertical farming, unlike conventional, horizontally constructed greenhouses, is particularly favorable to urban areas like Singapore. Vertical farming can potentially expand food production on ships or offshore landfilled areas. Therefore, Singapore is one of several Asian countries (i.e., Japan, China, South Korea, Taiwan, and Thailand) with a significant number of vertical farms (Piechowiak, 2022).

Indoor farming requires much science and technology development to close the knowledge gap for elevating yield, quality, and sustainability. Much technology development is invested in lighting, temperature control, irrigation systems, and water recycling. Lighting is costly, but the development of LED lighting has decreased energy consumption by at least 75% and lasts 25 times longer than incandescent and fluorescent lighting (Breene, 2016; Energy, 2022). Supplementing artificial light with natural light further decreases the cost and excess heat generated from LED lights (Asiabanpour et al., 2018). Manipulating light wavelengths (blue, red, and white) impacts the photosynthesis rate and maximizes crop growth (Lin et al., 2013). Furthermore, modular towers designed with rotating growing racks improves and evenly distributes light, irrigation, and airflow (Al-Kodmany, 2018). In addition, the application of infrared-light-absorbing curtains mitigates heat (Panasonic, 2021). Novel techniques can manipulate plant growth and, therefore, can also alter crop quality. Moisture sensors, for example, are used to gage the degree of photosynthesis (Panasonic, 2021), which directly impacts crop growth. Researchers, such as those at the newly established Research Center on Sustainable Urban Farming in Singapore, have begun genetically modifying crops to become more suitable for an indoor growing environment while also enhancing the nutritional quality.

Indoor farms in Singapore are primarily used to grow vegetables that have a short turnover and adapt well to a hydroponic system without soil. Cultivating staple food crops is more challenging than vegetables. However, research has shown great yields of some staple

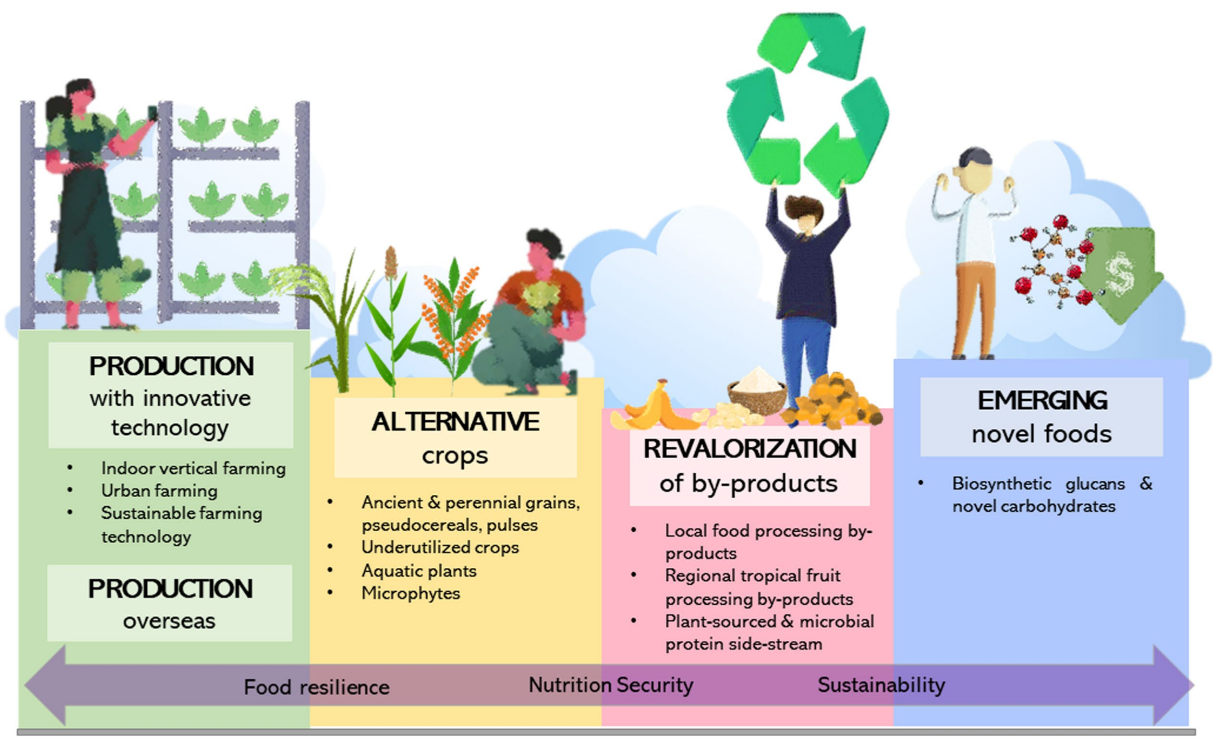

FIGURE 1
Strategies in producing food carbohydrates with limited natural resources.

crops cultivated *via* advanced technology. Rice is an essential crop that provides up to 76% of the caloric intake of Southern Asians. The yield of indoor-farmed rice may be elevated to five times that of the traditional paddy-grown rice through increased harvest cycles (Kiernan, 2018). Potatoes are an environmentally sustainable crop. Research has shown potatoes provide more food energy, require less water and land, and their production involves fewer greenhouse gas emissions than most other crops (Food and Agriculture Organization of the United Nations, 2009). Utilizing indoor farms, the US National Aeronautics and Space Administration (NASA) produced potatoes (175 t/ha) with twice the best yield of potatoes grown in traditional fields (89 t/ha) or greenhouses. Indoor vertical farmed wheat is also projected to reach 600 times (~700 t/ha) more grains than traditional farming (3.2 t/ha) through the crop simulation tool DSSAT-NWheat, which simulates field conditions of one hectare of land and optimizes temperature, light, carbon dioxide levels to obtain a maximum harvest for a 10-floor vertical farm (Asseng et al., 2020). The success of indoor farming opens a new era of sustainable food production on a grand scale.

4.2. Urban farming

Urban farming is a food production strategy conducted in household and commercial settings. Residents are encouraged to grow food at home and in the community for self-supply. Some policies have been implemented for commercialization in Singapore to promote sustainable production. For example, the first standard requires agronomic management to grow farm products that can be labeled as clean and green (Enterprise Singapore, 2020). Approximately 36 urban commercial farms with an average of 5.2 hectares have been established in Singapore. In addition, schools, backyards, and rooftop gardens are utilized for more planting for consumption and education (AgriFarming, 2021).

Leafy vegetables, herbs, and fruits are popular crops; carrots, bananas, sapodilla, guava, custard apple, and ginger are also grown at these farms. Some urban farms (e.g., Bollywood Veggies in Singapore) are experimenting with staple crops, such as rice, sweet potato, cassava, and pumpkin (The Smart Local, 2019). Technology development can further turn urban farming into a significant source of production. For example, using recycled rainfall in a drip irrigation system enables three harvest cycles of rice in one year. With advanced technology, it is projected that Singapore could supply some of its own rice needs as early as 2030 (Temasek Foundation, 2021).

Despite the efforts and advances made in urban farming and indoor farming development in Singapore, some challenges remain. Urban farming production is not economically competitive with the imported foods produced in a conventional food system. Production quantity is rising, but its sustainability (i.e., water usage) and efficiency (i.e., production per literate of water) require comprehensive and standardized assessments. For example, some hidden costs (e.g., post-harvesting management with a small-scale production) and product quality (e.g., nutrition density, sensory attributes) need to be considered along with labor, water, electricity, infrastructure, etc. In addition, urban farming outdoors in a tropical region is highly vulnerable to diseases and infections that requires additional agronomic management to maintain crop health. Nevertheless, recent assessment reports demonstrate the promising future of urban farming and indoor farming to strengthen food security in Singapore (Wood et al., 2020; Song et al., 2022). Governmental support along with funds and collaboration from the private sector promotes increased participation. Furthermore, urban farming raises awareness of food resilience and increases food production in a small area. In Singapore, urban farming also provides social benefits, such as education, youth development, and skills and workforce training. Expanding current urban and indoor farming development to include carbohydrate-based crops would increase the availability of these essential food sources.

5. Future potential for Singapore

5.1. Production of underutilized and unconventional crops

The world production of staple crops focuses primarily on maize, rice, and wheat. These staple crops supply caloric energy. They are also the primary materials of carbohydrate-based ingredients, such as maltodextrin and syrups. Non-conventional (alternative) carbohydrates offer a way to increase self-supplied nutrients and ingredients. Unlike rice, many alternative crops have high sustainability, high resilience to harsh environments, and significant nutritional value. These crops include ancient grains, pseudocereals, perennial grains, pulses, and unconventional tropical crops (Li et al., 2020; Table 1). Ancient grains refer to grains with few changes over the last few hundred years. Pseudocereals are plants with starch-rich seeds and function similarly to cereal grains in food applications. Pseudocereals such as buckwheat, quinoa, and amaranth (Table 1) are less frequently utilized in Western countries and are often included in the ancient grain category. However, many are not new to South Asians, such as buckwheat and amaranth. Perennial crops offer a higher level of ecological intensification in agriculture. In contrast to modern wheat and other grains, perennial crops do not need to be re-seeded or re-planted every year. Therefore, the planting method of perennial crops protects soil from erosion, nutrition loss, and damage due to microorganisms. In terms of nutritional values, whole grains offer higher nutritional quality with rich dietary fiber, lower starch digestibility, and greater micronutrients. Most of these grains are rich in essential amino acids, essential fatty acids, minerals, and vitamins and are free of gluten (Schoenlechner and Bender, 2020). Overconsuming rapidly digestible starchy food is associated with some health risks, such as diabetes and obesity. Increasing the consumption ratio from rapidly digestible carbohydrates (e.g., polished white rice, sweet bread) to carbohydrate-based foods with great nutritional quality, such as whole grains, will strengthen nutrition security in Singapore. The food applications of alternative grains are simple since many are similar to modern grains, such as wheat, barley, and rice. Table 1 tabulated some applications of ancient grains as well as other underutilized and unconventional crops. Some of these grains (e.g., millet, and quinoa) are found in local grocery stores, indicating the acceptance and demand of those grains in Singapore.

Singapore is humid, with consistently high temperatures, which makes cultivating tropical crops feasible. Some underutilized or unconventional tropical root and rhizome crops are resilient to environmental change and require minimal agronomic management. Starches produced from canna (*Canna edulis*), chufa sedge (*Cyperus esculentus*), air yam (*Dioscorea bulbifera*), white ginger lily (*Hedychium coronarium*), malanga (*Xanthosoma sagittifolium*), and kithul (*Caryota urens*) are candidates as substitutes for some commercial starches and chemically modified starches (Sudheesh et al., 2019; Dos Santos and De Francisco, 2020; Table 1). Canna starch has been broadly used in oriental desserts as a thickening agent, and the starch of white ginger lily has a high amount of amylose with low paste viscosity. Kithul stem has abundant starch, which has been broadly studied to promote the rural economy in Sir Lanka. Unlike alternative grains, tropical crops greatly vary from one to another. Therefore, much research is required to commercialize these underutilized crops into novel or alternative foods and ingredients desirable to consumers. Starches in these alternative crops are worth researching for novel functionalities or properties. These unconventional starches may be good candidates for replacing conventional chemically modified starches and may be used as "clean label" starch ingredients.

Tropical regions also have a high diversity of nutritious fruits with abundant carbohydrates and micronutrients, such as vitamins, minerals, and antioxidants. Breadfruit (*Artocarpus altilis* S. Park. Fosb), wood apple (*Limonia acidissima* L.), monkey jack (*Artocarpus lakoocha* Roxb.), marang fruit (*Artocarpus odoratissimus*), gumihan (*Artocarpus sericarpus*), and nam-nam (*Cynometra cauliflora*) have the potential to provide alternative carbohydrates (Table 1). Breadfruit is native in Malaysia and Indonesia. Nearly 75% of the dry weight of breadfruit is starch. Both breadfruit starch and breadfruit flour could be commercialized to replace some chemically modified starch (Adebowale et al., 2005; Nwokocha and Williams, 2011). Wood apple trees are able to grow on saline waste and neglected lands (Kumar and Deen, 2017), and wood apple is suitable for processing into jam, jellies, and preserves. Monkey jack is another crop containing abundant carbohydrates and also rich in proteins, vitamins (e.g., vitamin C and vitamin A precursor, β-carotene), and minerals (e.g., sodium, potassium, iron, copper, manganese, and phosphorus; Yadav et al., 2018). Marang fruit is often referred to as an "athlete's fruit" due to the abundance of starch and micronutrients, which are essential for athletic performance and muscle growth. Gumihan is a very sweet fruit that grows well in humid tropical weather. Nam-nam is native to Malaysia and is used for preparing sambal, compote, or fruit salad.

Pulse-based foods are excellent sources of proteins and carbohydrates, which generally have slowly digestible carbohydrates and are rich in dietary fiber. Pulses also contain abundant micronutrients, such as flavonoids, polyphenols, terpenes, and lectins (Reynoso-Camacho et al., 2006). Despite its popularity, only a few legumes (i.e., pea, soybean) are introduced to the global market. There are many varieties of pulses that are native or cultivated in the South Asian continent and Indo-Pacific regions (Nayak et al., 2022), and many of them are nutritious to humans and resilient in harsh environments (Table 1). The winged bean (*Psophocarpus tetragonolobus*) is a tropical legume that grows well in hot and humid equatorial regions, such as the Philippines, Indonesia, Thailand, and Sri Lanka. The immature pod of the winged bean is consumed raw, pickled, or cooked (e.g., stir-fried, boiled). Horse gram (*Macrotyloma uniflorum*) is tolerant to drought and salinity (Reddy and Reddy, 2005) and is easily found in Malaysia and India. Horse gram, which is similar to other legumes, consists of nearly 60% carbohydrates and 18–25% protein and also contains abundant minerals (i.e., iron, molybdenum, phosphorus) and other micronutrients (i.e., carotene, thiamine, riboflavin, niacin, and vitamin C; Prasad and Singh, 2015).

Black gram (*Vigna mungo*) and rice bean (*Vigna umbellatta*) also have a high nutritional value, and mung bean (*Vigna mungo*), which has been a part of Chinese diets for over 2,000 years, is consumed in sprouts, soups, or desserts. Singapore is experienced in overseas farming and is very active in researching product and ingredient development with sustainable manufacturing techniques. Converting these underutilized roots (or rhizomes), fruit, and legumes into alternative ingredients for Asian foods would not only supply Singapore but benefit others.

Aquatic plants are another alternative approach to increasing food production. Many aquatic plants have abundant carbohydrates and are popular food materials in oriental cuisines, such as lotus (*Nelumbo nucifera*), wild rice (genus *Zizania*), water chestnuts (*Eleocharis dulcis*), water caltrop (*Trapa natans, Trapa bicornis*, or *Trapa rossica*) and duckweed (*Lemna minor*; Table 1). Lotus has a high economic value due to its demand in Chinese communities. The entire lotus plant, including the seed, rhizome, stem, and flowers, are valuable in oriental cuisines, for medical use, and beverages (e.g., lotus flower tea, lotus flour drink). Wild rice is an ancient grain and has become popular in Western countries due to its nutrients and taste, and its stem, known as jiāobái, serves as a vegetable in oriental meals. Water chestnut is not a "nut" but is a bulbotuber with a crisp texture. Water chestnuts are consumed in salads or with fruit, or they are cooked with other food materials. Water caltrop, which is prevalent in China and Taiwan is another ancient crop and has been part of human diets for over 3,000 years (Lu et al., 2021). The fruit of water caltrop contains a single, large (averaging 5–7 centimeters in diameter), edible starchy seed with a unique tapered shape and two elongated, curved, dropping spines. Duckweed (*Lemna minor*), a small aquatic plant, grows rapidly and densely. It serves as an alternative protein source as well as an alternative carbohydrate. Duckweed is suitable for humans and livestock, and various varieties have different ratios of macronutrients.

TABLE 1 Examples of applications of underutilized or unconventional crops.

Category	Crops	Scientific name	Selected applications
Ancient grains	Sorghum	*Sorghum bicolor*	Porridge, soups, and stews
	Teff	*Eragrostis tef*	Porridge
	Millet	*Pennisetum glaucum*	Porridge, sauces, and stews
	Quinoa	*Chenopodium quinoa*	Salads, beverages, snacks
	Amaranth	Genus *Amaranthus*	Porridge, patties (tikki), and stews
Roots and rhizomes	Canna	*Canna edulis*	Consumed raw, boiled, and baked
	Chufa sedge	*Cyperus esculentus*	Beverages and bread
	Air yam	*Dioscorea bulbifera*	Chips, fries, stews
	White ginger lily	*Hedychium coronarium*	Stews
	Malanga	*Xanthosoma sagittifolium*	Mashed, roasted, and fried, and used in soups
	Kithul	*Caryota urens*	Flour is used in porridge and desserts
Pulses	Winged bean	*Psophocarpus tetragonolobus*	Stews and salads
	Horse gram	*Macrotyloma uniflorum*	Porridge, soups, and salads
	Mung bean	*Vigna radiata*	Soups, sauces, stews, and salads
	Black gram	*Vigna mungo*	Soups, sauces, stews, and salads
	Rice bean	*Vigna umbellatta*	Soups, sauces, and stews
Aquatic plants	Lotus	*Nelumbo nucifera*	Stews, soups, tea, and used as a vegetable in meals
	Wild rice	Genus *Zizania*	Consumed as a vegetable (starchy vegetable)
	Water chestnuts	*Eleocharis dulcis*	Consumed raw and stir-fried, and used for drinks, stews, and soups, salads, pickled, and candied
	Water caltrop	*Trapa natans*, *Trapa bicornis* or *Trapa rossica*	Cooked snacks, stir-fries, dumpling stuffing, stirred into rice, and in vegetable dishes
	Duckweed	*Lemna minor*	Boiled or roasted
Fruits	Breadfruit	*Artocarpus altilis*	Processed into flour and consumed boiled, steamed, baked, and fried
	Wood apple	*Limonia acidissima*	Juice, chutney, ice cream, and jams
	Monkey jack	*Artocarpus lakoocha*	Curry, pickled, and consumed fresh
	Marang fruit	*Artocarpus odoratissimus*	Jams and consumed fresh
	Gumihan	*Artocarpus sericarpus*	Consumed fresh
	Nam-nam	*Cynometra cauliflora*	Pickled and consumed fresh

5.2. Development of microbial carbohydrates

Microphytes, such as algae, are another potential alternative crop source. Although it is not yet fit for human consumption, producing starch from photosynthetic microorganisms (e.g., microalgae) has been an alternative way to substitute maize for biofuel production (Chen et al., 2013). Microalgae grow rapidly in various aquatic environments, such as fresh-water, saline water, and wastewater. It has a high capacity to absorb carbon dioxide and is highly efficient at using light energy for photosynthesis (Guimarães, 2012). Therefore, microalgae accumulate and produce starch rapidly, and their starch content depends on species and cultivation conditions. Red algae are a microalgae that produces a unique polysaccharide, Floridian starch, which has a high degree of branched molecular structures. Floridian starch has a low gelatinization temperature, low viscosity, and high resistance to retrogradation, which are all of interest to the processed food industry (Yu et al., 2002). Microalgae starch may have comparable characteristics to commercial products (e.g., maize starch). Starch extracted from *Klebsormidium flaccidum* is similar to maize starch in its ratio of amylose to amylopectin, swelling capability, and solubility, despite its small granule size of approximately 1 μm (Ramli et al., 2020).

Marine photosynthetic bacteria, such as cyanobacteria, have been used for centuries to produce high-value ingredients and nutritional supplements. Although most cyanobacteria produce glycogen, several species (e.g., *Cyanobacterium* sp. NBRC 102756, *Cyanothece* sp. ATCC 51142, *Caynobacterium* sp. CLg1) produce insoluble polysaccharide granules (Nakamura et al., 2005; Deschamps et al., 2008), which is highly analogous to cereal amylopectin with its tandem–cluster structure (Suzuki et al., 2013). From a sustainability perspective, phylum, such as cyanobacteria, could have a distinct advantage for large-scale cultivation as they can be cultivated in seawater.

Yeast strictly produces glycogen, which is a branched glucose polymer, unlike amylopectin, without cluster structure and cannot form insoluble granules like starch. These microorganisms store glycogen in tiny soluble particles in the cytoplasm rather than in large insoluble granules, as with photosynthetic organisms. However, a recent study showed the feasibility of recreating the synthesis of starch granules in a common yeast culture (*Saccharomyces cerevisiae*; Pfister et al., 2016). Genetically engineered yeast was purged of its endogenous glycogen-metabolic enzymes to be able to express the core Arabidopsis starch-biosynthesis pathway. The result produced dense, insoluble granules with a starch-like semi-crystalline organization.

Among non-conventional carbohydrate resources, microphytes may best suit Singapore and similar environments. Its vigorous aquaculture industry has abundant resources for supporting the cultivation of microphytes suitable for saline water. Technology, which has been developed to enhance microbial protein production, has rapidly advanced in Singapore and therefore, can facilitate the indoor cultivation of microbial carbohydrates. With limited land space and natural resources to grow conventional higher plants, novel microbial carbohydrates would have unlimited potential for developing alternative foods and ingredients. However, some macrophytes and microbial carbohydrates are new to human diets. Substantial research on food safety, regulatory processes, and consumer acceptance must be conducted.

5.3. Development of synthetic carbohydrates

Starch is the primary glycemic carbohydrate in human diets. However, the structure of starch granules is complicated in that, even today, a successful synthesis of a starch granule has not been documented. Nevertheless, carbohydrate biosynthesis is not a new science, and some glucans with relatively small molecules were developed and commercialized as food ingredients. Most synthetic glucans are developed by modifying starch, starch derivatives (e.g., maltodextrins), and sucrose. Isomaltulose, dextrans, neo-amylose, alternans, and alternan-oligosaccharides are either commercially or bio-technically modified or synthesized from sucrose (Xue et al., 2022). Pullulan and cyclic cluster dextrins are produced from starch, and cyclodextrins are made from melt condensation of glucose and sorbitol in an acidic environment (Miao et al., 2018). Some α-glucans are produced from non-starch sources. Naturally, isomaltooligosaccharides are found in various fermented foods, such as miso, sake, and soy sauce, although commercial isomaltooligosaccharides are produced from starch hydrolysates through enzymatic modifications (Gangoiti et al., 2020). Agricultural post-harvest and food processing by-products, such as corn stalks, rice brans, and fruit skins, are carbon-rich materials for developing novel food carbohydrates. Xylitol, a non-cariogenic sweetener, is primarily produced by the chemical hydrogenation of xylose, which is obtained from natural resources, such as nutshells, wood hydrolysates (e.g., sulfite waste liquor), or corn cobs hydrolyzed in acid (Vandamme and Soetaert, 1995).

Novel glucans cannot yet replace starch in providing caloric energy, but they provide different technical properties and nutritional functionalities needed in the processed food industry (Table 2). Low-calorie foods, prebiotics, resistant or slowly digestible starch, and immunity-related functions (e.g., fungal β-glucans) are essential from a health perspective. Oligomers or polysaccharides generated from biotechnical production are often used as texture stabilizers in food applications, such as thickeners (xanthan gum–produced by bacteria), gelling agents (gallant gum–produced by bacteria), and glazing agents (e.g., polydextrose–synthesized through melt condensation reaction). Fermentation techniques and biotechnology are primary tools for developing novel (biosynthesis) glucans, and many reactions rely on enzymes and catalysts. Researchers recently reported the synthesis of glucans toward the goal of producing artificial starch (Cai et al., 2021). The researchers successfully used an inorganic catalyst and engineered recombinant enzymes to convert inorganic carbon sources into glucans. Although, much research is still needed to create a starch granule, the study demonstrated the necessity of exploring novel enzymes for alternative food production. These carbohydrate sources show great promise and may be key to providing cost-effective and accessible alternative carbohydrate sources. Nevertheless, the production of alternative carbohydrates and the use of novel enzymes must meet consumer health regulations, and safety and toxicology examinations must be incorporated into the research plan.

5.4. Revalorization of agri-food processing by-products

Many food processing by-products are landfilled even though many nutrients (i.e., starch, lipids, proteins) are retained in those by-products. Even a small island state like Singapore has a great quantity of nutrient-rich by-products. In 2021, Singapore produced almost 800,000 tons of food waste and recycled approximately 20% of it (Figure 2). The top four waste streams in Singapore are spent grains, okara, bread, and spent coffee waste (National Environment Agency, 2021). Singapore actively researches innovative solutions to revalorize food processing by-products (National Environment Agency, 2021), and some food applications have become available on the market (Table 2). Okara is a soybean processing by-product consisting of approximately 4% carbohydrates, 6% proteins, and 2% lipids, and the quantity produced in Singapore yearly is around 83,000 tons (National Environment Agency, 2021). Okara is blended into food formulation ingredients for beverages, confectionery, mock meat products, soy cheese, energy bars, crackers, bread, and noodles. Okara is also directly processed into probiotic beverages through fermentation with various biocatalysts (Vong and Liu, 2019). Coffee ground waste can be converted into alcoholic drinks (Liu et al., 2021). Food processing by-products are generated in small food processors throughout Singapore under hot (25–32°C) and humid conditions (~80%, sometimes 100% during prolonged periods of rains), and the main challenge to utilizing food processing by-products is contamination and pasteurization. Another difficulty is that many processors cannot immediately process or adequately store the by-products. On-site cost- and space-saving processing to conserve the materials for further processing is essential for utilizing those materials (Table 3).

Singapore is located close to countries with active agricultural industries (i.e., Thailand), especially those with tropical fruit production, such as banana, pineapple, durian, rambutan, and jackfruit. Technology development utilizing fruit processing by-products in Singapore creates an opportunity to partner with processors to strengthen food security as well as to enhance sustainable manufacturing. Typical by-products are seeds, peels, husks, stems, leaves, and immature fruits, and these portions of fruit usually contain much carbohydrate as well as proteins, lipids, and micronutrients. Seeds from jackfruits, durians, and rambutans are large, and contain approximately 26–80% carbohydrates (Eiamwat et al., 2016; Baraheng and Karrila, 2019). The starch in jackfruit seed offers a firm and elastic

TABLE 2 Technological and nutritional functionality of α-glucans in foods.

Ingredients	Functionality
Isomaltulose	Sweetener
Isomaltooligosaccharides	Sweetener, anti-caries, prebiotic, soluble dietary fiber
Resistant maltodextrins	Bulking agent, soluble dietary fiber
Polydextrose	Bulking agent, glazing agent, humectant, stabilizer, thickener, soluble dietary fiber
Pullulan	Filler, glazing agent, film-forming, thickener, binder
Cyclodextrins	Encapsulating agent, masking taste
Dextran	Thickener, cholesterol-lowering agent, emulsifier, stabilizer, humectant, texture agent, anti-crystallizing agent
Neo-amylose	Insoluble dietary fiber
Cyclic cluster dextrins	Spray-drying aid, slowly digestible carbohydrate, taste improver
Alternan	Bulking agent, binder
Alternan-oligosaccharides	Prebiotic, modulating blood sugar
Low-amylose starch	Gelling agent, texture stabilizer
Low-digestible starch	Prebiotic, modulating blood sugar

Vandamme and Soetaert (1995), Miao et al. (2018), Gangoiti et al. (2020), and Xue et al. (2022).

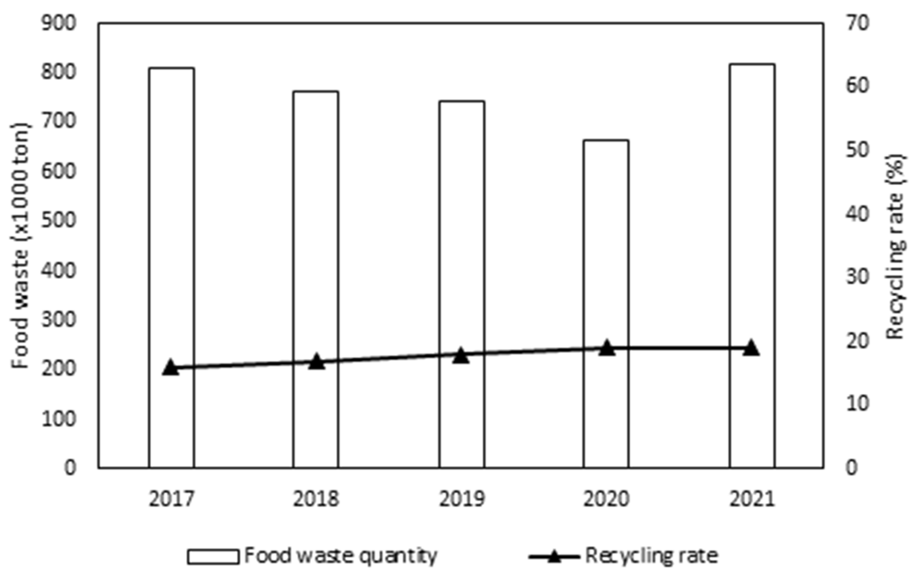

FIGURE 2
Food waste generated (×1,000 ton) and recycling rate (% of total food waste from total generated food waste) in Singapore from 2017 to 2021. Recreated based on data in (National Environment Agency, 2021).

TABLE 3 Commercial products made from the revalorization of agri-food processing by-products in the Singapore region.

By-products	Commercial products	Product highlights	Ref
Spent grains	Noodles	High-protein noodles made of spent barley	Neo (2021)
	Yeast substrate	Beer yeast substrate made of spent brewery grains	Evans (2022)
	Snack	High-protein chip snack made of spent brewery grains	Lee (2021)
Okara	Beverage	Non-dairy probiotic drink	Lim (2021)
	Bakery	Ingredient high in dietary fiber for baking	The Straits Times (2017)
	Energy bars	Granola bars made with okara and oats	Bean My Day (2022)
	Crackers	Baked crackers made with okara and rice	ZenMarket (2021)
	Noodles		Good Food World (2022)
Bread and spent coffee waste	Beer	Ale infused with surplus bread and upcycled coffee grounds	Tan (2022)
Jackfruit seeds	Flour	Ingredient used for baking and soups	Nature Loc (2022)
Pineapple stems and peels	Supplements	Supplement rich in dietary fiber	Cheng (2022)
Green banana	Flour	Ingredient for cooking, baking, and making smoothies.	

texture, while flours made from green bananas have slow starch digestibility (Vatanasuchart et al., 2012; Kumar et al., 2019). Noodles made from jackfruit seed flour and green banana flour have received much positive response, and green banana flour has been distributed in local markets in Singapore. Pineapple stems and peels are very nutritious, with sugars and vitamins as well as dietary fiber and polyphenols, which both aid in the healthy growth of gut microbiota (Campos et al., 2020). Much research is in progress studying how to utilize these hidden food resources in functional foods and ingredients in Singapore. A challenge in revalorizing unconventional portions of fruit is coping with undesirable components, such as endogenous toxic compounds (e.g., alkaloids), chemicals from agronomy practices (e.g., pesticides), or compounds with unpleasant taste (e.g., bitterness). Fermentation and other biotechnology are helpful in removing undesirable components. Food safety and toxicology must be considered while developing products from non-conventional materials.

Singapore invests a significant effort in alternative protein production, and both microbial and plant-based protein production generate a substantial amount of carbohydrates. Protein extract from legumes (e.g., peas, chickpeas) generates a considerable portion of starch and fiber. In addition, carbohydrates generated from microbial protein production, such as β-glucans and chitin, have much potential for functional ingredient development. Technology development to extract and modify these carbohydrate-rich by-products will effectively enhance their functionality and application for local food development.

6. Conclusion

Hunger is real; hidden hunger is not negligible, and food carbohydrates are essential to both. Whether the location is on an island like Singapore or a vast territory, natural resources are not unlimited. The current agri-food system and consumption patterns are not sustainable for feeding a growing global population. Conventional local production faces many limitations, and innovative approaches outside local agri-food systems may unearth some solutions. Sustainably utilizing local resources with novel technology can build basic production infrastructure. Collaboration with local stakeholders and partnerships with global food suppliers create a greater chance of success in strengthening food resilience and nutrition security.

Author contributions

AL: conceptualization, supervision, writing–original draft, and reviewing and editing. AG-M: conceptualization and writing–original draft. All authors have read and agreed to the published version of the manuscript.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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