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Transdisciplinary research for understanding and transforming food systems

Edited by
Alexandros Gasparatos, Laura M. Pereira and Cyrille Rigolot

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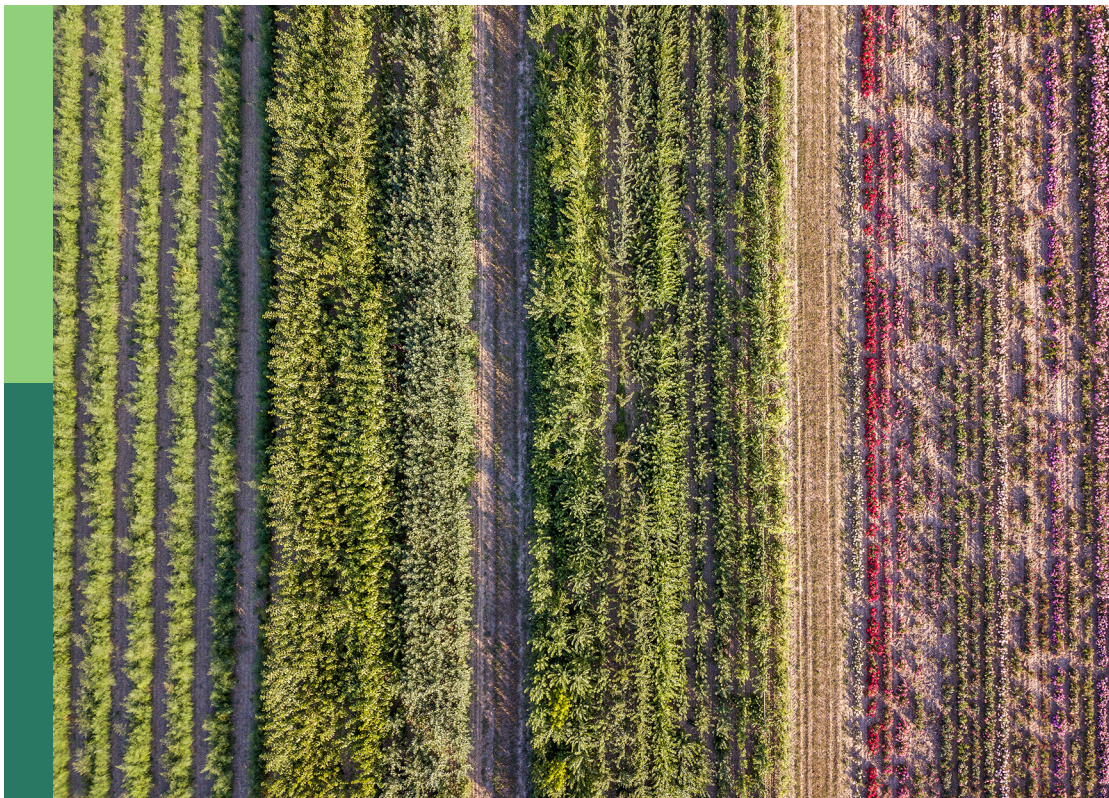

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Transdisciplinary research for understanding and transforming food systems

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Editorial: Transdisciplinary research for understanding and transforming food systems

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stakeholders, transdisciplinary, food system, participatory, sustainability

Editorial on the Research Topic
Transdisciplinary research for understanding and transforming food systems

Fostering the sustainable transformation of food systems is one of the biggest bets for meeting the Sustainable Development Goals (SDGs) (Willett et al., 2019). As diets and food production have radically transformed in the past decades, the industrialized and globalized food systems that are notably prevalent across the global North have become major causes of poor health and environmental degradation (IPES-Food, 2016; Willett et al., 2019). At the same time, malnutrition, food insecurity and underperforming food production systems are still the reality in many parts of the global South (FAO et al., 2023). The expected population growth, accelerated urbanization, and increased affluence in much of the global South are likely to further catalyze unsustainable dietary shifts and food systems transformation in the coming decades (FAO et al., 2023).

However, understanding food systems and transforming them in a sustainable manner is far from straightforward, especially when considering their multiple intersecting economic, social, technological, and cultural dimensions. This typically corresponds to a "wicked problem," without any single individual simple and definitive solution. To further complicate things, food systems encompass different stakeholders operating at different levels with enormously different worldviews and vested interests (UNEP et al., 2023). However, food system transformations must be arguably context-specific, as the production and consumption of food must reflect the socioeconomic, environmental and governance characteristics of their geographical and temporal contexts (Pereira et al., 2020).

In this context, it has been argued that transdisciplinary research (TDR) approaches offer promising opportunities for sustainable food systems transformations. Although there is no single consensual definition of transdisciplinary research (TDR), it is generally agreed that its key characteristics are the integration of multiple disciplinary perspectives (inter-disciplinarity) and the engagement of stakeholders at all stages of the knowledge production process (Lang et al., 2023). In practice, there is a wide diversity of TDR approaches. Yet much remains to be done to better understand their conditions of success (and failure) for food systems transformations, which has become a rapidly evolving research field.

The goal of this Research Topic is to offer a forum for gathering and critically synthesizing new up-to-date insights on how TDR approaches, methods and processes can be mobilized to understand better and transform sustainably and inclusively food systems. The Research Topic collects nine papers that mobilize very diverse TDR approaches for equally diverse applications in Asia, Africa, the Americas and Europe (Table 1).

Berthet et al. report the initial experiences gained from the implementation of a large-scale and long-term transdisciplinary project in France. The study focuses particularly on four types of actions within this project, namely backdrop, targeted, assessment, and communication and dissemination actions. It critically discusses how these actions aim to co-produce knowledge, raise awareness about challenges in the local food system, envision new interactions between stakeholders, and collectively generate innovative ideas and catalyze actions toward agri-food system transformation.

Calla et al. present the experiences gained from the implementation of transdisciplinary approaches such as the Community Voice Method (CVM), film-making, Transformation Labs (T-Labs) and stakeholder engagement processes. In particular the study focuses on how such approaches can be used to elicit and convey the perceptions of very diverse stakeholders, with the overall aim of reducing pesticide use and related conflicts in France.

Dernat et al. study the outcomes of a participatory foresight exercise, in the context of a Protected Designation of Origin (PDO) cheese area in France. The study argues that the continuous engagement of farmers in the collective dynamic needs to be continuously re-negotiated over time in order to overcome the risks and insecurity that farmers have to face in the transformation process.

Gasparatos et al. critically discuss how participatory engagement processes can help introduce transdisciplinary research elements, using insights from five research projects on commodity crop production in Sub-Saharan Africa. In particular, they show how such participatory processes can help (a) identify research priorities, knowledge gaps, and underlying phenomena, (b) formalize impact mechanisms and develop methodology, and (c) interpret data and validate findings.

Guzman Luna et al. present the experiences gained from a 3-year participatory action research (PAR) project with coffee smallholders in Mexico and Nicaragua that leverage diversification practices for a transformative agroecology. They critically discuss how this project helped achieve change through capacity-building, co-creation of questions/knowledge, farmer-to-farmer sharing of pedagogies and co-production of popular education material.

Hermesse et al. outline the experiences gained from the implementation of six research projects using different transdisciplinary research approaches and the concept of co-creation. These projects collectively sought to create more sustainable urban agri-food systems in Brussels (Belgium). Notably the study illustrates how these projects brought together different actors in Brussels, creating a shared awareness about the need for change of the city's agri-food system.

Jarzebski et al. discuss the process, thematic focus and lessons learned from the design and implementation of six SDG-Labs that developed biodiversity-based solutions for sustainable food systems transformations in Armenia, China, Japan, Madagascar, Thailand, and Uganda. The study argues the great potential of SDG-Labs to develop solutions at the biodiversity-food-climate nexus, reflecting critically their strengths, weaknesses, opportunities and threats.

Juri et al. report the process and lessons learned from an international transdisciplinary community of practice that co-designed and implemented a 3-year multi-stakeholder process for food system transformation in Uruguay. The study describes the design, structure, and facilitation of this transdisciplinary process through the principles of knowledge co-production, as well as its potential for uptake in other contexts.

McGreevy et al. argue how soft scenarios can contribute to transdisciplinary processes for sustainable food system transformation. The study draws from a 5-year transdisciplinary action research project in different parts of Asia and critically discusses how soft scenarios can (a) question widely held assumptions about the future, (b) be inclusive to multiple perspectives/worldviews, (c) foster receptiveness to unimaginable futures and (d) develop futures literacy.

Some of the studies in this Research Topic focus on the in-depth analysis of one or several TDR project(s) in a single national context (Berthet et al.; Juri et al.; Hermesse et al.; Calla et al.; Dernat et al.), while others draw lessons after critically synthesizing insights from case studies in different countries (Gasparatos et al.; Jarzebski et al.; McGreevy et al.; Guzman Luna et al.). Whereas, some studies consider food systems (and related solutions) as a whole in a given locality or national context (e.g., Berthet et al.; Juri et al.; Calla et al.), others focus on specific value chains (Guzman Luna et al.; Gasparatos et al.; Dernat et al.), aspects of food systems (Hermesse et al.) or response options (e.g., biodiversity-based solutions) (Jarzebski et al.). The studies also focus on different time frames within the TDR cycle, ranging from the initiating stages of TDR projects (Calla et al.) or their recent conclusion (Juri et al.; Jarzebski et al.), to the reflexive analysis following the conclusion of TDR processes (Berthet et al.; Gasparatos et al.; Hermesse et al.; McGreevy et al.).

Each study within the Research Topic proposes a unique, situated TDR approach to connect researchers and stakeholders for food systems transformations. Depending on the timing and stage of the TDR process, different methodological innovations are discussed in each study. Some of these methodologies are rather forward-looking such as soft scenarios (McGreevy et al.) and the co-creation of visions and transition pathways (Juri et al.). Calla et al. link a visioning exercise ("miracle questions") with other TDR methodologies (Community Voice Method, Film-making and T-Labs) to address conflicts between stakeholders as a preliminary step to a lasting transdisciplinary process. But what happens after shared visions have been designed, and some consensus has been reached (or not)? Dernat et al. show that the link between participatory foresight and action is far from linear, and explore the "New World Kirkpatrick Model" as a framework for monitoring and adjusting agri-food system transitions in the making. Finally, some papers propose a broader reflexive view on the whole TDR process, from system diagnosis to actions' implementation, assessment and dissemination (Berthet et al.; Guzman Luna et al.; Jarzebski et al.; Gasparatos et al.).

TABLE 1 Main characteristics of the studies included in the Research Topic.

Study	Countries	Target food systems	Transdisciplinary approaches and methods	Transdisciplinary research outcomes
Berthet et al.	France	Food systems (local), Food practices	Place-based Research, Real-World lab ("Zone Atelier")	- Raise awareness; - Envision new interaction between stakeholders; -Develop innovative ideas; - Catalyze action
McGreevy et al.	Japan Thailand	Food systems	Futures literacy, Soft scenario, "Learning, Playing, Experimenting"	- Question widely held assumptions about the future; - Enhance inclusiveness to multiple perspectives and worldviews; - Foster receptiveness to unimaginable futures
Juri et al.	Uruguay	Food systems (national)	Bridging organizations, Knowledge co-production, Community of practice, Multi-stakeholder processes	- Generate a language of collaboration, dialogue and imagination
Hermesse et al.	Belgium	Food systems (urban, peri-urban)	Participatory Action Research, Co-creation	- Place agri-food system transitions on the political agenda; - Identify future challenges for food systems transformations
Calla et al.	France	Food systems (local)	Community Voice Method, Film-making, "Miracle Question", T-Labs, Workshops	- Understand the complexity of food systems transformations from conflictual perspectives; - Build long-term trust between researchers and other stakeholders; - Open up dialogue; - Develop long-term solutions
Guzman Luna et al.	Mexico Nicaragua	Smallholder coffee production systems (local)	Participatory Action Research	- Build capacity with community facilitators; - Co-create relevant knowledge for strategic planning; - Share farmer-to-farmer and popular pedagogies across territories
Gasparatos et al.	Eswatini Ghana Guinea Kenya Malawi Mozambique Kenya	Commodity crop production systems (local)	Participatory methodologies	- Identify research priorities; - Develop methodologies; - Interpret data and validate findings; - Enhance research credibility, relevance, legitimacy, and effectiveness
Dernat et al.	France	Dairy-cheese value chains (local)	Foresight, Participatory observation	- Encourage farmers into action; - Maintain engagement over time; - Overcome the risks and insecurity facing farmers in transition
Jarzebski et al.	Armenia, China Japan Madagascar Thailand Uganda	Biodiversity-based practices (local)	SDG-Labs	- Accumulate knowledge from local communities; - Leverage local biodiversity for food security and income generation; - Raise awareness; - Foster stakeholders' participation in decision-making processes

Some of the common major TDR outcomes observed in the nine studies include (albeit to different extents) building trust between stakeholders (including researchers) and raising awareness. In some studies, stimulating the imagination among actors appears to be a major component of TDR, with imagination being essential for finding innovative ideas, enhancing inclusivity to multiple perspectives and increasing openness to disruptive futures (Berthet et al.; McGreevy et al.; Juri et al.; Calla et al.). Other studies highlight the interest of TDR processes to foster tangible actions on the ground (Dernat et al.), play an advocacy role by placing agri-food system transitions on the political agenda (Hermesse et al.), assist strategic planning and capacity-building (Guzman Luna et al.), enhance the credibility, relevance legitimacy and effectiveness of research (Gasparatos et al.) or harness knowledge from local communities for developing solutions and fostering stakeholders' participation to decision-making (Jarzebski et al.).

Collectively the nine studies collected in this Research Topic highlight the major opportunities that TDR processes offer for understanding and transforming food systems, but also the multiple challenges affecting their effective design and implementation. Some of the commonly articulated challenges include the long timescales necessary for effective TDR implementation and the constraints posed by the

prevailing sociotechnical and governance landscapes. However, all studies agree that TDR processes can indeed become a springboard for the co-design of innovative solutions for food system transformation, not the least by empowering multiple stakeholders to engage more deeply in transformation processes.

Author contributions

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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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Advancing Food System Transformation and Addressing Conflicts Through Transdisciplinary Methodologies: Strengths and Limitations of the Community Voice Method, T-Labs, Film-Making and the Miracle Question

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Food systems are changing through various socioeconomic and policy processes. For example, in France, following concerns over the effects of pesticides on ecosystems and health, the French government launched the "Ecophyto II+" plan in 2019 that aims for a 50% reduction in the use of pesticides by 2025. This top-down food system transformation is leading to conflicts between stakeholders over how to enact such a policy, and its implications for farmers and their practices. By adopting a transdisciplinary research approach, we explore conflicts linked to food system transformations in the context of three case studies in France. The case studies revolve around conflicts over pesticide use and reduction in three agricultural settings in Bourgogne Franche-Comté, namely (a) water management near Auxerre, (b) apiculture-agriculture relations in the Jura, and (c) viticulture-local resident relationships near Macon. We use four innovative transdisciplinary techniques to integrate inclusively the viewpoints of diverse stakeholders with the aim of generating actionable responses to transform food systems. First, the Community Voice Method (CVM) includes filmed semi-structured interviews and integrates a number of opportunities for participation and successive rounds of data analysis. Second, the interviewees were asked a "miracle question" that encouraged them to step back from conflicts and practices toward their ideal vision of agriculture and food systems. Third, the CVM resulted in the production of four films that relate the visions and perception of each case study interviewees in their own words and in their own setting. Finally, Transformation Labs (T-Labs) conveyed the main results of the CVM knowledge synthesis through the films produced and opened a dialogue toward the development of solutions. We review the four techniques, how they were implemented in the three case studies, and with which outcomes. Thus the aim of this paper is to offer reflections and lessons learnt from different transdisciplinary processes as a means of strengthening their application in other contexts. We argue

that such methodologies, whilst resource-consuming, are essential to fully understand the complexity of food system transformations from the often-conflictual perspectives and competing knowledge claims of the multiple actors involved. In addition, we highlight the role of these techniques in building long-term trust between researchers and other stakeholders, and the benefits in terms of opening up dialogue and developing long-term solutions, as determined by the stakeholders themselves.

Keywords: agriculture, Community Voice Method, films, transformation, participation, Transformation Labs, workshop, conflict

INTRODUCTION

In light of the importance of tackling the current crisis relating to biodiversity, a number of political commitments have been made. One of the most important ones is the UN General Assembly's adoption of the 2030 Agenda for Sustainable Development in 2015, where governments are committing to achieving 17 Sustainable Development Goals (SDGs) over the next 15 years. However ambitious the SDGs are, it is clear that by missing so many previous political commitments to address the biodiversity crisis, there is an urgent need for a fundamental transformation in the way in which we tackle the issue. This is particularly relevant to the agricultural sector, which covers ∼40% of the EU in terms of land coverage (EUROSTAT, 2018). This sector is considered a main driver of environmental degradation (Stoate et al., 2009; Pe'er et al., 2020) due to the extensive adoption of intensive, mechanized, and chemically-based farming to meet the growing global demand for agricultural commodities (Henle et al., 2008; Stoate et al., 2009; Zabel et al., 2019; Vanbergen et al., 2020). Governments are putting measures in place to respond to the challenge of maintaining biodiversity while ensuring food security (Tilman et al., 2011; Kastner et al., 2012). This aims at achieving a general movement of sustainable agricultural transformations, defined here as processes that "imply changes in cognitive, relational, structural and/or functional aspects of agricultural systems aiming at new qualitative and/or physical outcomes that contribute to social justice and environmental integrity in agriculture and beyond" (Skrimizea et al., 2020, p. 257). This is the case in France, where the "Ecophyto II+" plan was launched in 2019 aiming for a 50% reduction in the use of pesticides by 2025.

The trade-off between productive agriculture and farmland biodiversity can, however, lead to conflicts, which are understood here as social conflicts among actors with different, and often conflicting, attitudes, and where power asymmetries between actors occur (Redpath et al., 2013). In the case of the dramatic and rapid change in France over pesticide use—here perceived as a top-down food system transformation—conflicts between stakeholders are emerging over how to enact such a policy, and its implications for farmers and their practices (Lecuyer et al., 2022). Viewing such conflicts as expressions of more systemic issues and symptoms of unsatisfied needs and marginalization of certain stakeholders (Skrimizea et al., 2020), it becomes clear that sustainable (agricultural) transformations are complex and contested governance challenges.

Addressing the sustainable agriculture transformations challenge requires changing how decisions are made and strategies are developed by bringing together the competing knowledge claims of "experts," academics, practitioners, policy makers and citizens (Kenter et al., 2019; Wyborn et al., 2019; Ainsworth et al., 2020). Researchers have considerable agency and responsibility in participating in or creating conditions for transformations (Pereira et al., 2020; Whitfield et al., 2021). In this respect, many alternative types of research processes that aim at being more participatory and thus more democratic, inclusive and transdisciplinary have emerged (Wyborn et al., 2019; Pereira et al., 2020). Transdisciplinarity refers to a "reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge" (Lang et al., 2012, p. 26). "Knowledge co-production" is a form of participatory transdisciplinary process that has gained momentum in sustainability science and practice. Knowledge coproduction is defined here as an "iterative and collaborative process(es) involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways toward a sustainable future" (Norström et al., 2020, p. 2). Such a process is particularly important (and challenging) in conflict situations around transformative change, where many actors have a stake in the issue (not always solely at the local level), where stakeholder values and practices are central to both conflict development and management, and where stakeholders can use knowledge as a form of power—either to strengthen their own positions, or undermine others (Hodgson et al., 2018). Nevertheless, while a growing body of literature shows that knowledge co-production in an action research setting is fundamental to achieve sustainable transformations, co-production discourse and practice has also been critiqued for insufficiently attending to conflicts and power relations overlooking what we previously described as unsatisfied needs and marginalization of certain stakeholders (Blythe et al., 2018; Chambers et al., 2022). Chambers et al. (2022) recently argued for the need of engaging with co-production methodologies that address this gap by embracing the tensions of transformative processes and jointly elevating, questioning, exploring and navigating conflicting agendas within. In this paper, we contribute toward these gaps related to

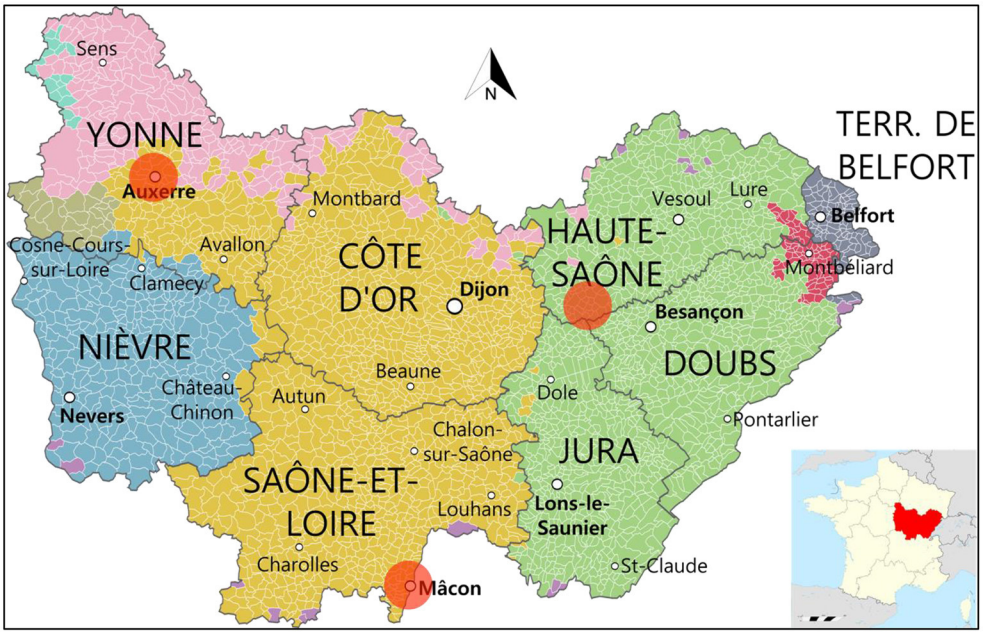

FIGURE 1 | Map of Bourgogne Franche-Comté region of France and the locations of the study sites (red dots). Source: Authors.

transdisciplinary methodologies capable of addressing conflicts and power relations in the context of transformative change.

The aim of this paper is to offer reflections and lessons learnt from different transdisciplinary processes as a means of strengthening their application in other contexts. In particular we focus on the lessons learnt from a participatory approach seeking to address the conflicts linked to food system transformation in three French localities. The case studies we used in our research all revolved around conflicts over pesticide use and reduction in three distinct agricultural settings in Bourgogne Franche-Comté: water management near Auxerre, apiculture-agriculture relations in the Haute-Saone and viticulture-local resident relationships near Macon. We used four innovative techniques, (a) a Community Voice Method, (b) a miracle question, (c) films and (d) a Transformative Labs approach. The focus was to integrate inclusively the viewpoints of academics and societal stakeholders (considering power relations) and translate the outcomes of this transdisciplinary process into actionable responses to transform food systems, namely context-specific knowledge, and pathways toward a sustainable future. We review each method in turn before reflecting on their applicability and outcomes, and on how future methodologies can be evaluated and improved upon in the context of transformative change.

METHODS

Case Studies

Three case studies were selected for this study (see **Figure 1**; **Table 1**), all of which are in the Bourgogne Franche-Comté (BFC) region in the east of France. The selection of the region was dictated by the funding source, as the project was funded by the French National Research Agency as part of a wider programme called I-SITE-BFC ("Initiatives Science Innovation Territoire Economie en Bourgogne-Franche-Comté"). This programme aimed to bring in more knowledge, cultures and international exchanges to Bourgogne-Franche-Comté by appealing to foreign scientists, and in turn, use this knowledge and exchange to enhance research contributing to knowledge of the BFC. As part of the funding programme, the topics suggested in the proposals were very open, with a general guideline that projects should contribute to knowledge on socio-ecological and food transitions.

The Bourgogne Franche-Comté (BFC) region covers 47,800 km^2, and it is the fifth largest region of France. At the same time with 2.8 million inhabitants (2017) it is one of the least populated regions in France (59 inhabitants/km^2). Agriculture occupies almost 50% of the regional surface area, with a diversified sector that includes arable land, grasslands, dairy and livestock (mainly cattle) production, viticulture, and polyculture. In 2018, the total value of production in the agricultural sector was around €5.6 billion, subsidies excluded, with crop production accounting for over 18% of the value, 37% of which was for wine production, cattle production (14%) and dairy production (13%) (Agreste, 2019). It is worth noting that some of its agricultural output such as Burgundy wine and Comté cheese are world-renowned.

The selection of the three case studies within the BFC region followed an iterative process that built on informal interviews with key stakeholders of the region, including scientists, union representatives, NGO representatives and elected representatives. Together they suggested a range of key themes and case studies. We then focused on those case studies that demonstrated conflicts, and where a transformative change approach could be possible. We then liaised closely with key collaborators in

TABLE 1 | General characteristics of the three case studies.

	Case study 1	Case study 2	Cade study 3
Main conflict focus	- Contested impact of pesticide use on bees	- Contested impact of pesticides on local communities	- Contested approaches to mitigate pesticide impacts on water quality
Key stakeholders	- Beekeepers (professionals and amateur); - Arable farmers	- Wine producers (organic and conventional) - Local communities (individuals and associations) - Elected representatives	- Arable farmers (organic, conventional, soil conservation) - Elected representatives - Environmental organizations
Current efforts to address conflicts	- Experiments and workshops with key stakeholders organized by the ADABFC	- Communication pamphlets aimed at local communities for improved understanding of wine production - Local charter developed by wine production associations to set guidelines on pesticide use	- Local water charter signed by a number of local farmers

each case study area, including (a) the Association pour le développement de l'apiculture en Bourgogne-Franche-Comté (ADABFC), (b) the Confédération des Appellations et des Vignerons de Bourgogne (CAVB) and, (c) the Communauté d'agglomération de l'Auxerrois. This process, which consisted of in-depth discussions with our collaborators prior to the start of the research but also at regular intervals during it, was essential to ensure the initial and continued relevance of the research to the challenges faced in each case study area. The characteristics of the three case studies are outlined below and in **Table 1**.

The first case study explored conflicts between beekeepers and (other) farmers (as many beekeepers consider themselves farmers) in the region, focusing on the use of pesticides around the towns of Dole, Besancon and Vesoul. With over 4000 beekeepers and 105,000 hives, BFC is the 5th largest beekeeping region in France (Agreste, 2019). This case study is essentially embedded within the broader context of the natural and important relationship between beekeepers and other farmers. Beekeeping requires areas that are managed by other farmers where bees can forage to collect nectar and pollen, and produce honey and other hive products. Conversely, bees ensure pollination, thus contributing to the production and quality of many crops. However, simplified crop rotations, a scarcity of agro-ecological infrastructures (e.g., hedges, field margins), and the use of crop protection products, medicines or other chemicals used in agriculture that are toxic for bees (domestic and wild) can lead to episodes of bee mortality, or at least a lack of abundant and diverse food resources for bees (Vanbergen and The Insect Pollinator Initiative, 2013). This alters the "win-win" relationship that may exist between beekeeping and farming, and leads to conflicts. As a result, various European and French legislative tools have restricted and banned the use of insecticides believed to be harmful to bees and other pollinating insects. This fragile balance between beekeeping and other farming activities (and the associated legal changes imposed on farmers' practices) have often mobilized the latter, who claim to lack alternatives, while finding themselves amidst scientific uncertainty about the degree to which their practices are indeed to blame for bee loss (Cailloce, 2016). In the context of our case study, and to address such issues, the "Association pour le Développement de l'Apiculture en Bourgogne-Franche-Comté" (ADABFC) has initiated technical experiments and dialogue between beekeepers and other farmers, as part of a wider research project aiming at promoting mutual understanding and cooperation.

The second case study explored conflicts between wine producers and local communities over concerns regarding pesticide drift from vineyards to local schools and homes. Our study sites were located around the towns of Chalon-sur-Saone and Mâcon, which form the renowned viticulture areas of the Côte Chalonnaise and Le Mâconnais. Due to its climate, Bourgogne is highly susceptible to agriculture-related diseases. For example, between April and July, whenever there is a risk of disease outbreak, wine producers spray pesticides to control disease and pests, particularly mildew and powdery mildew. As in other parts of France (as well as other parts of the world), the aerial spraying of pesticides has met resistance from local communities (especially neo-rurals) but also tourists in Saône-et-Loire. Considering that this type of conflict concerns diverse agricultural practices and is prevalent in many parts of France, in December 2019, the French government reinforced related measures with a decree (Décret n°2019-1500 du 27 décembre 2019) on Zones Non Traitables or "buffer zones." This prohibits the spraying of pesticides within 10 meters from settlements for crops over 50 cm high (e.g., vineyards) and within 5 m for others. Since its draft proposal, the decree has raised concerns among Burgundian wine producers, who fear that such a buffer zone could affect the area of vineyards, impacting negatively their annual turnover. In addition to these existing concerns, a new study was launched in November 2021 by Santé France Publique to study the health impacts of pesticides on humans, using wine production as its case study. This is concerning for wine producers who feel they have been targeted and that results of that study may worsen relationships between them and local communities.

Our third case study was around the Auxerrois water catchment area, where there is a conflict between stakeholders on how to manage water quality (Calla et al., 2022). This is associated with problems arising from the past use and resulting high concentrations of nitrates and residues of phytosanitary products associated with cereal farming in the area. The conflict started as far back as the 1990s, when the services in charge of monitoring the quality of the water distributed in the catchment area's

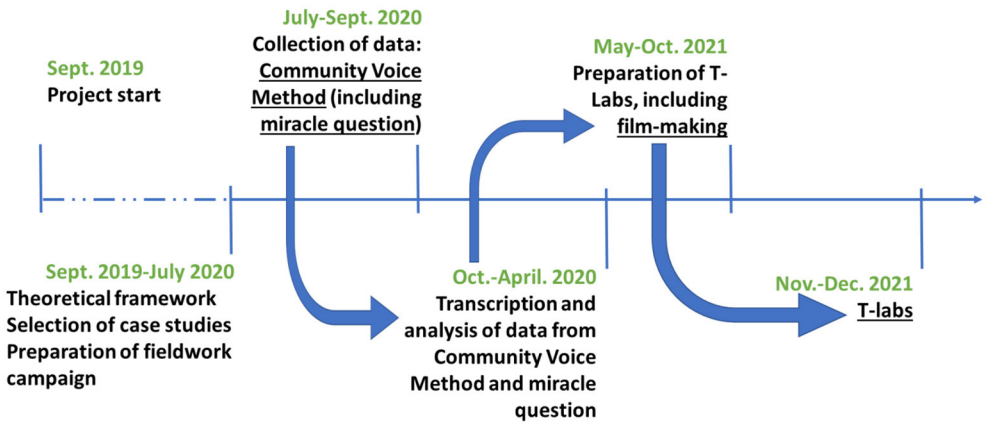

FIGURE 2 | General research approach and timings.

networks, observed that the maximum threshold for nitrates was exceeded (Calla et al., 2022). The situation became so strained that in 2018, the Regional Health Agency was asked to consider emergency scenarios, including the distribution of bottled water for 70,000 inhabitants. Whilst "curative" approaches such as the construction of a treatment plant were considered, eventually a "preventive" solution was selected. This consisted of working with farmers by transforming agricultural practices through systems that use fewer inputs (mainly fertilizers and plant protection products), if not abandoning synthetic inputs altogether. Farmers have reacted in different ways to this approach. Some have chosen to convert to organic farming and do without chemical inputs, others have opted for soil conservation agriculture which works through a limited use of chemical inputs (but above all the abandonment of plowing); while others have preferred to take a "reasoned" approach by signing up to agri-environmental measures. The results, however, are perhaps slower to emerge than was anticipated, and a new administration is now pushing for the curative approach. The issues that collaborators were keen to focus on were how to ensure the greater compatibility between the curative and preventive approaches, and how to maintain collaborative relationships in the long-term.

General Research Approach

Our research followed a qualitative multi-method research design (Fetters and Molina-Azorin, 2017). Four main techniques were used in this study. First, a Community Voice Method (CVM) where interviewees were filmed (Community Voice Method and the Miracle Question section). Second, as part of the interviews, participants were asked a "miracle question," to encourage them to step back from conflicts and practices to their ideal vision of agriculture in terms of individual, relational, structural and cultural transformations (Community Voice Method and the Miracle Question section). Third, the result of the CVM resulted in the production of four films that relate the visions and perception of each case study participants in their own words and in their own context (Films and Transformation Labs section). Fourth, the films were screened as part of Transformation Labs (T-Labs) to convey the main results from the knowledge synthesis approach, and to open dialogue toward the development of pathways (Films and Transformation Labs section).

Figure 2 outlines the succession and timing of the four techniques, while Data Collection and Analysis section provides more information about the implementation of each of these four techniques. Finally we elicit the main lessons learnt from the design and implementation of these techniques through a SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats). Our research was carried out with ethical clearances obtained from the Université de Bourgogne Franche-Comté (CERUBFC 2021-06-15-017-2) and prior written consent given by each participant.

Data Collection and Analysis

Community Voice Method and the Miracle Question

The Community Voice Method (CVM), based on filmed semi-structured interviews, is an approach to public participation and participatory research that integrates a number of opportunities for participation and successive rounds of data analysis (Ainsworth et al., 2019). In the context of conflicts and transformative change, CVM has a number of strengths and opportunities. A CVM follows a step-wise process, consisting of in-depth interviews and analysis, which we followed in our research:

Initially in-depth recorded and filmed interviews were conducted with stakeholders to understand the underlying discourses in each site. We designed a guide for semi-structured interviews (see Box S1 in **Supplementary Material**) (Young et al., 2018) as a basis. In the context of this study, the interview guide was designed to allow interviewees to share their experiences and express their values, perceptions, and knowledge related to agriculture and its past, present and future evolution in their territory (Questions 2–5). We focused on exploring the interviewees' vision of an ideal (future) agriculture and their perceptions with regard to enablers and disablers for a

transformation to take place toward this ideal vision (Questions 3 and 5).

As part of the interview, interviewees were asked a "miracle question," inspired by solution-focused therapy (de Shazer, 1985). We asked interviewees to imagine that, after their normal working day, they went to bed and during the night a miracle happened, that resulted in a transformed and ideal agriculture. The slight particularity was that no one told them that the miracle had happened. So the question becomes how would they know this miracle had happened, and what would it look like. What is important is not the miracle question itself, but what it triggers at the intrapsychic and relational levels. The miracle question allows a shift, freeing the interviewees from the discourse of complaint. In other words, (s)he leaves the position of victim to become active, and (s)he finds solutions to implement in their emotional and professional environment, and their relations (de Shazer et al., 2007).

We purposively selected interviewees through a combination of stakeholder analysis and snowballing that aimed at identifying key informants. Once the case study was selected (see section Case Studies), we carried out a stakeholder analysis based on the analysis of policy documentation, scientific literature, local press, and other reports. This enabled the compilation of potential key informants, as well as the identification of three key collaborators, one for each case study, who were the first to open the field to other relevant participants (see section Case Studies). Once these collaborators identified potential interviewees, we followed a snowball sampling approach to recruit more interviewees. We also checked this list against our initial stakeholder analysis to add other interviewees and reduce any potential bias from the identification of stakeholders by the collaborators and their suggested interviewees. Interviewees were engaged in, cared about, or were directly impacted by agricultural practices (and tensions) in the respective study sites. We sought interviewees that could provide rich information and represented a diversity of interests and socio-cultural aspects within (and across) the three case study regions (Patton, 2002). We also aimed to include key actors who have an impact on the territories under study, but who may operate at different scales, from the local to the national level. We were especially interested in including the voices of people who were relevant to the issue but less heard and marginalized from decision-making processes. The profiles of the interviewees are summarized in the **Supplementary Material** (Box S2).

We carried out a total of 55 interviews, filmed from July to September 2020: 21 interviews for case study 1, 17 for case study 2, and 17 for case study 3. Considering that the appropriate sample size in qualitative research is determined by data saturation (Patton, 2002), these interviewees were found to be sufficient for the needs of each case. The interviews lasted for an average of 1 h each and were conducted in French. For the interview analysis, we transcribed each interview and the transcripts were corrected and imported into New NVivo (QSR International Pty) for coding. The interviews were analyzed using thematic analysis adapting the steps suggested by Braun and Clarke (2006). First, the transcripts were analyzed by the authors breaking down the data and re-organizing it through coding. The codebook derived both from the analytical framework (Skrimizea et al., 2020) and from the recurring themes emerging from the data which were not evident in the existing framework (see Box S3 in **Supplementary Material**) (Fereday and Muir-Cochrane, 2006). The codebook was used to sort concepts within the interview text according to one or more sub-codes. Text coded within each sub-code could then be quantified and cross-tabulated in NVivo to identify common themes. To mitigate individual researcher bias and increase consistency, inter-coder comparison analyses were conducted until an acceptable level of agreement was achieved (Landis and Koch, 1977).

Films and Transformation Labs

Four films were developed through the interviews, with the support of a professional film-maker. One film was on the visions of an ideal agriculture based on the results from the "miracle question" across all case studies; the remaining three films described each of the case studies. The aim of the films was to summarize the main discourses conveyed by the interviewees in their own words and in their chosen contexts. To develop each film, a coding analysis was conducted based on coding (section Community Voice Method and the Miracle Question), to identify quotes representing the most frequently occurring perspectives from each section of the interviews. Discussions then took place between the authors to ensure that each film included: (a) each interviewee at least once (for the case study films), (b) all key discourses identified by interviewees, and (c) a wide range of perspectives. The script was sent to the film-maker for a first draft, and an iterative process between the filmmaker and the authors ensured that the film was of a relevant length for use in workshops (see below). The script was sent to all interviewees for their approval prior to the video editing, together with the clip of their appearance. As such, each interviewee was provided with the extract of their interview selected for the film, and where that extract would be placed in the overall film. This was key to ensure that each interviewee's quote was placed in context with the rest of the film. Three interviewees opted not to be included due to personal reasons or concerns that their message(s) had not come across as expected.

An important step in the CVM process is the feedback on the interviews' results (through the films, in our case), their reflexive evaluation, and their reintegration into public discourses. A key issue from our perspective was also to allow for the results of our study to lead to in-depth discussions and pathways toward transformation. As such, we adopted an approach that merged CVM with Transformation Labs (or T-Labs), as the two approaches have a number of similarities.

T-Labs build on the methods and approaches outlined in the Social Innovation Lab Guide (Westley et al., 2015). "Labs" bring together diverse groups of people working on complex challenges to see the system through different perspectives, redefine problems and identify opportunities for innovations to make a difference. T-Labs consist of three steps: The first is "Research and Preparation" (Step 1). Research activities that aim to identify and frame the question (Research In) and explore across scales and across a diversity of stakeholders (Research Out) were captured through the interviews (section Community Voice Method and the Miracle Question). The second is the workshop

itself (Step 2). In this case we held 1-day workshops that had three main components: (a) allowing participants, including "agents of change" or stakeholders in the systems that have the ability to change the system, to "see" the system in which the problem has arisen, (b) to identify the criteria for an innovation in the context of this problem domain, and (c) to identify points of leverage. The third is Taking Action after the T-Lab (Step 3), with the writing up of strategies identified in each case study (including how they will be implemented, and by whom), the implementation of strategies by change-makers, and the evaluation of impact across scales in the system (Pereira et al., 2021). The integration of T-Labs and CVM allowed for films to be a prominent feature of the workshop, and to add the transformative dimension more explicitly into the overall methodological design.

One workshop was organized in each site at the end of the second year of our 3-year project, to ensure that there would be sufficient time afterwards for the research team to support the stakeholders in their choice of transformative solutions. The three workshops were planned in close cooperation with our key stakeholders to ensure that the dates suited them, that the place chosen for the workshops was suitable, and that the topic corresponded with their expectations. A list of potential attendees was developed by the authors, and shared with key stakeholders in each study site. Potential attendees included previous interviewees (see section Community Voice Method and the Miracle Question), but also additional key local actors that could have a role in developing and implementing any solutions identified during the workshop. A professional facilitator was hired to ensure safe and constructive discussions. Whilst the researchers were observers during the workshops to evaluate the process and the outcomes of each workshop, we acknowledge of course that the researchers had a prior steering role, in terms of organizing the workshops, selecting the participants, structuring the workshops and preparing the videos (Whitfield et al., 2021). At the start of each workshop, participants were also asked to complete and sign a consent form, which described the aims/process of the research, and asked for specific permission to use photos during the day and to contact them after the workshop for an evaluation. The workshop agenda followed the three-step process of a T-Lab (see Box S4 in **Supplementary Material**).

The workshop allowed for a range of participatory approaches to be used, including:

- Reciprocal presentations of participants, where each person presents another person after a conversation;
- Focused conversations in trios to stimulate active listening and address specific questions related to the films, with one person speaking, one reformulating and one taking notes, and participants asked before the films to prepare post-its answering certain questions (i.e. "what is important for you/for the relationship between W and Y?" and/or "what makes you react?");
- Instant vision, with a large poster entitled "a vision of the future relationship" that is open for all participants to contribute to with drawings, keywords, or symbols (see **Figure 3**);

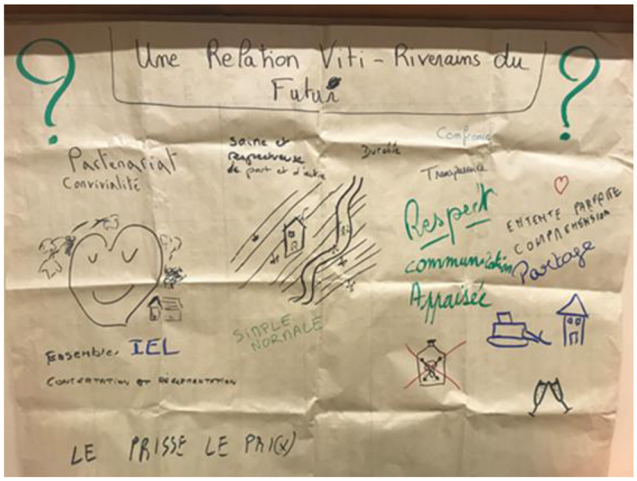

FIGURE 3 | Instant vision during the transformation lab portraying the future relationship between wine producers and local communities.

- Keep-Drop-Create analysis in small groups where participants reflect on the improvement of the current situation through structured thinking (i.e., questions such as "what works and should be continued?," "what should be dropped?" and "what could be created/would be an innovative solution?") (**Figure 4**);
- Open brainstorming for idea generation, where all participants can contribute an idea captured on a post-it note, and the facilitator grouping related ideas in clusters to highlight main themes;
- Structured action plan, where for each identified solution, participants explore in small groups ways to implement it [i.e., questions such as "who should be involved?," "what should be done?," "how could this be done (resources)?," or "when (schedule/timing)?"];
- Samoa circles (also called fish bowls) with concentric circles, where participants who want to speak join the inner circle. Allows for active listening, equality amongst speakers and trust-building.

We developed three strands of evaluation during and after the workshop: (a) evaluation of the CVM results (through evaluation from the participants of the films during the workshop); (b) evaluation of the workshop process and outcomes (through feedback at the end of the day and follow-up questionnaires with workshop participants—see Box S5 in **Supplementary Material**); and (c) self-reflection through observation sheets during the workshop and a project team debrief after the workshop. Following each workshop, a report synthesizing the ideas generated was compiled and disseminated to participants.

RESULTS

CVM and the Miracle Question

Interviewees largely agreed to be filmed (only two refused for personal reasons). It is important to note that the interviewees

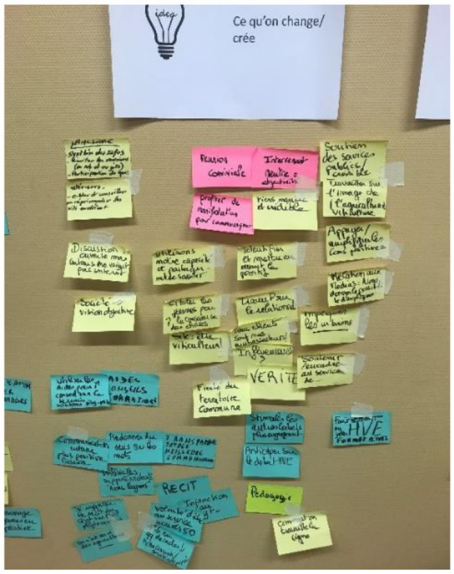

FIGURE 4 | Example of the Keep-Drop-Create analysis in the T-Lab.

were informed well in advance that interviews would be filmed and could reflect on whether they would give consent to be filmed and on the location of the interview. This resulted in filming taking place in diverse settings, including, among others, in fields, in front of bee hives, on river banks. Whilst the setup of the filming was initially a little unusual for the interviewees, their self-consciousness dissipated within the first few seconds of the filming, with interviewees focused on the interviewer, rather than the filming material. The interview questions were generally easy for the interviewees to respond to.

Our sample was heavily biased toward men (with only 12 female interviewees), despite efforts to identify and interview more women. In addition, the average age of our interviewees was about 50 years old (**Supplementary Material S2**). Snowball sampling was useful in accessing perhaps less well represented groups such as farmers, as it was generally much easier to identify interviewees and initiate contact by mentioning that a fellow farmer had suggested them.

The "miracle question" worked well in the majority of interviews, with only 3 interviewees either not able, or choosing not, to engage in the miracle question. The miracle question had to be introduced gently and it was common for interviewees to be initially a little confused by the required response. Once they were reassured that there no right or wrong answers, interviewees often had very wide-ranging responses, and highlighted a number of issues and perspectives that we had not considered when developing the rest of the interview guide, and indeed perspectives that did not reoccur over the remainder of the interview.

Following coding, the key themes to emerge from interviewees, and used to structure the vision film, were as follows:

- Change in environmental conditions;
- Fulfilled, valued and recognized agriculture (including better understanding of agriculture and food value, fulfilled farmers, institutional support, and productive agriculture);
- More localized agriculture (including improved relationships and a re-localized agriculture);
- Scientific and technological future pathways;
- Small and more diverse and respectful agriculture (including the improved relationship between humans and nature, smaller and more diverse farms, and an agriculture more in tune with the environment).

In effect, the above themes were pathways toward more sustainable food systems, as identified by interviewees without prompting from the interviewer. By keeping the question open, and talking about "an ideal agriculture," interviewees were free in their interpretation. For some interviewees, this happened through their senses. For example, one interviewee perceived the miracle through his hearing: "*I think the first thing we'll notice is that there will be no more noise. If it was really a miracle in relation to nature, we have no more engine noises. There's no more noise. And when we wake up, that's what it's going to be: Silence.*" For another it was with what he could see when we woke up to the miracle: "*hedges, and flowers, and butterflies [laughs].*"

Interviewees also responded with regards to how the miracle would make people feel. For example one interviewee suggested that: "*People would be happier, in my opinion, more fulfilled. We wouldn't have this malaise, I think, in the agricultural world. And everyone could perhaps live more equitably. And then, in addition, it would also be beneficial, well for our health, for us, and also for all the biodiversity.*" The question allowed for very deep feelings to emerge such as well-being, pride in their jobs, recognition and legacy. As one interviewee attested: "*It's a very good question. The miracle in agriculture, well, that would be that all the farmers in France earn their living. That there are no more suicides in agriculture, that there are no more families torn apart, that there are no more inheritance problems, that there is no more agri-bashing. That farmers be proud of their profession, and be able to proudly pass it on to their children, to their wives, to their husbands.*"

Overall, the two techniques have diverse strengths and weaknesses, as well opportunities and threats for their implementation as outlined in **Table 2**.

Films and Transformation Labs

The development of the films was iterative and intensive—especially in terms of selecting the quotes based on our inclusion criteria, following our previous coding and gaining participant approvals (see **Table 2**). We relied on a professional filmmaker, who accompanied us during the interviewing and edited the films to create a high-quality documentary. The involvement of a professional filmmaker also allowed us to have quality pictures of interviewees and their settings, which we sent to interviewees at Christmas to share our best wishes. These contributed to building a continued and trusting relationship with them. The films were presented to all interviewees (and other stakeholders) during the workshops held in November–December 2021 (see **Figure 5**).

TABLE 2 | SWOT analysis of the four transdisciplinary techniques used in the context of transformative change and conflicts.

	Strengths	Weaknesses	Opportunities	Threats
Community Voice Method	Differentiated research from what interviewees had experienced Created a bond with the interviewees, especially through sharing of photos after the interviews Led to the development of films rather than written quotes	Costly in terms of time and resources to set up filmed interviews Requires additional ethical approvals as interviewees cannot be anonymized Some interviewees may refuse to be filmed	Allows researchers to address challenges of representation and power Allows interviewees to convey their perspectives in a setting of their choosing Addresses the potential power and bias gap between researchers and interviewees	Interviewees may feel intimidated by the filming and less open in their responses Long process that needs to be followed through, not just with the interviews, but the dissemination of results back to interviewees and the integration of their feedback
Miracle question	Easy to integrate in interview guides Allows for broader themes and perspectives to emerge Helpful in terms of constructing pathways toward transformation	Requires proper introduction to avoid being confusing to interviewee Needs to be embedded within a broader context, to create pathways to reach the miracle	Allows interviewees to move from a discourse of complaint to a discourse of solutions Allows the interviewees to create a reality and bring it to life.	When relaying the results of the miracle question, stakeholders may feel it is too disconnected from reality, conveying a utopia
Films	Offer powerful research summaries, that bring out emotions as well as content Useful in terms of starting dialogue amongst stakeholders	Costly in terms of time and resources to edit films Require substantial effort for developing films that will only be used in one workshop	Reduce the power gap between researchers and interviewees Reduce an element of bias in terms of how the results are conveyed (compared to written quotes)	Remaining bias in terms of the selection of quotes Lack of anonymity, which needs to be carefully communicated to participants
Transformation Labs	Allow for in-depth discussions and social learning between stakeholders with different perspectives Allow for solutions and innovations to emerge within a short time-span	Require a trained facilitator that needs to both adapt to each T-Lab, and be accepted by the participants Require resources (e.g. good facilities, facilitator) Require time to organize and prepare Difficult to reach solutions within a day, as a lot of time needs to be spent on sharing positions and needs of stakeholders before moving on	Allow participants to better understand the viewpoints, worldviews and values of others Allow a safe space for reflection, sharing and development of solutions amongst stakeholders Address power asymmetries between stakeholders Provide a different and unusual approach for participants that may be experiencing stakeholder fatigue	Difficult to implement in cases of high inter-personal conflict, where the conflicts need to be addressed before moving on to solutions Require resources (e.g. excellent facilitator, organization of the T-Lab, identifying, inviting and chasing up the relevant participants) Rely on having the relevant participants attending, and in sufficient numbers

The strengths and weaknesses relate to the lessons learnt from our application of each technique, whereas the opportunities and threats apply to future potential applications in other contexts based on our experiences.

FIGURE 5 | Setting during the viewing of films in the T-Lab.

The workshops were held in locations suggested by our three key collaborators, and known to interviewees. The importance of the setting cannot be emphasized enough. In two of the workshops, the setting had comfortable spaces for participants to work in, flexibility for the organizers in terms of setting up small discussion groups, and enough space to add materials on the walls, among others. In one setting, the space was very large and sparse, and despite efforts to make the space more comfortable to participants, the setting impacted negatively on the overall discussions and engagement.

Whilst we aimed to have around 20 participants in each workshop, the workshops comprised 13 participants in the apiculture case study, 21 in the viticulture case study, and 16 in the water case study. The ratio of those invited to those attending was about 3:1. In all workshops, participants expressed that they would have appreciated more diversity among the participants (e.g., more farmers in the water case study, more representatives of consumer associations in the apiculture case study, and more local community associations in the viticulture case study). In addition, in some workshops, some participants could only attend the morning or the afternoon session, which disrupted the dynamics and required the facilitator to adapt.

The evaluation of the films was positive, with feedback shared in plenary, and through feedback cards. The participants appreciated the format of the films, and expressed diverse emotions based on the viewing (e.g., "moving," "comforting," "sad," "passionate"). One participant noted that the films should be disseminated more broadly, as they showed a dimension to farming that was rarely communicated: "*Passion is what drives farmers, but it's rarely conveyed.*" The workshop participants also identified a number of themes that emerged in the films. These include, among others, the lack of recognition of farmers, poor image and communication of farming practices, lack of alternatives to pesticides, change of narratives around farming, lack of collective initiatives and thinking among and between farming groups and others, shifting societal demands around food price and quality, and administrative burdens. These were themes that were also identified in our analysis and the resulting films, but which were reinforced through the participants' feedback.

The evaluation of the workshop at the end of the day was broadly positive, with participants appreciating the quality of the facilitator's work, the opportunity for exchanges between the participants that increased understanding and trust-building, and the new questions raised by the process. As one participant expressed it: "*The more you learn, the more you wonder.*" These were captured when asked for their one word describing how they felt about the day (**Figure 6**). Limitations of the T-Labs as perceived by participants included the lack of diversity of participants, unclear perspectives and diverse expectations in terms of next steps, and timing (either with time too short on certain activities, or the day feeling too long). The evaluation of the techniques was also carried out by the research team, through a SWOT analysis (**Table 2**).

DISCUSSION

Lessons Learnt From the Application of the Different Techniques

The research presented here responds to the urgent need to advance and promote transformative change in food systems, as well as address the conflicts such change can trigger. This is achieved through the use of transdisciplinary knowledge coproduction methodologies that are inclusive and fair (i.e., involve diverse types of expertise, knowledge and actors—and take account of and try to address power imbalances), and lead to outcomes (i.e., context-specific knowledge and pathways toward a sustainable future). Below, we highlight the main lessons learned in terms of the extent to which CVM, the miracle question, films and T-Labs contributed to these two aspirations.

Lessons Learned for Promoting Inclusiveness and Fairness

In our work we built on a combination of methodological pathways suggested by Chambers et al. (2022), focusing on (a) exploring diverse agendas, (b) elevating marginalized agendas, and (c) navigating conflicting agendas. Thus, the approaches used were selected in large part to address the need for inclusive and fair integration of diverse types of knowledge, expertise and actors with a first aim of exploring diverse agendas and fostering mutual understanding and respect for a plurality of perspectives (Chambers et al., 2022). As stated in the introduction, a key challenge of transdisciplinary approaches, which is even more acute in conflict situations, are the potential power imbalances between actors (Blythe et al., 2018). As such, methodologies need to take account of these imbalances, and provide a voice for those actors that are less often heard, and often absent from decision-making processes (Ainsworth et al., 2020). In the case of our research, the emphasis was to ensure that farmers (often small scale) were at the heart of our research and that diverse channels for recruiting interviewees and participants were mobilized in order to attempt to reach possibly less "networked," more marginalized actors. Although the entry point through our key stakeholders initially prioritized more networked farmers, the stakeholder analysis and snowball approach for interviews then allowed for a broader representation. The selection of the case studies based on the presence of conflict and the final inclusion of

FIGURE 6 | Word cloud based on one-word evaluation of the day across the three T-Labs.

a diversity of actors permitted to navigate the conflictual agendas that played out during all the steps of the transdisciplinary process from the initial interviews to the workshops.

The CVM and resulting films ensured that not only were the voices heard through quotes that would be conveyed by researchers, but that the interviewees were directly communicating their concerns and aspirations. This was continued during the workshops through the methodologies used, which encouraged participants to listen to others, even reformulating their concerns and views. The iterative exchange between the authors and film-maker, and between the authors and interviewees ensured that interviewees were kept fully updated on the progress of the films, their role in them, and how they would be portrayed, thereby building trust between researchers and participants. The process also ensured that all actors were heard: each interviewee who gave us approval for the use of his image has at least one appearance in the films. The viewing of the film at the workshop, and resulting discussions also allowed for a triangulation of our results from the interviews themselves, checking that no new themes emerged.

The T-Labs were also key in ensuring an inclusive and fair process—both in terms of who was invited and who turned up on the day, but also in terms of how the stakeholders were engaged during the workshop. The invitations to the workshops were very broad and included not only our interviewees, but also all other relevant actors recommended by interviewees during interviews, and others that we had identified in our stakeholder analysis. The activities conducted during the T-labs were carefully designed to foster spaces of "humility," where all actors possessed legitimate views and could contribute to and question knowledge (Latulippe and Klenk, 2020; Chambers et al., 2022). The fact that the workshops were facilitated by an independent professional facilitator trained in conflict mediation was key to ensuring that processes during the workshop aimed at reducing conflicts and power imbalances between stakeholders and that all participants felt heard in their personal perspectives and emotions in sufficiently safe/"safe-enough" spaces (Ely et al., 2021)—thereby contributing to building a trusting environment. This is a key aspect in conflict transformation, that sees power dynamics as one of the main underlying cause of conflict and aims at providing more agency to actors and structures (Rodríguez and Inturias, 2018). Food system transformation will be supported by any process, including such transdisciplinary methods, that can overcome power asymmetries and reposition power as a force for conflict transformation (Skrimizea et al., 2020; Lecuyer et al., 2022). The choice of an independent professional facilitator was also a conscious decision taken after reflecting our own positionality as researchers; it permitted to distance ourselves from the process of the T-labs and avoid the risk of bias and power imbalances between researchers and participants (Ely, 2021).

The above focus on reducing power imbalances also contributed to trust-building, a key outcome of transdisciplinary processes, and highly relevant in the context of transformative change and conflict (Young et al., 2016; Whitfield et al., 2021). The trust-building between researchers and other actors was a process that evolved and made use of opportunities. For example, sending professional personalized photographs with all participants at Christmas led to a number of correspondences between researchers and other actors, and a building of trust which led to more open and easy dialogue, with interviewees regularly calling researchers to update them with news. This was also apparent after the T-Labs, when researchers received a number of calls and emails from participants, following up on discussions started in the T-Labs. The trust-building between actors was also apparent, with often very emotional sharing of perspectives at T-Labs, which were acknowledged by the group. More research will need to be carried out in the final year of the project to better understand the more long-term impact of the methodologies on trust-building and the intensity of conflict in the case studies.

Lessons Learned for Promoting Outcomes Relevant to Stakeholders

In terms of ensuring relevance, much of this was done ahead of any research taking place—as it should in transdisciplinary

research. Indeed, the first 6 months of the research were spent developing a theoretical framework for the research, but also ensuring, through our close collaborations with key stakeholders, that our research was relevant and useful. As seen in the Methods section, the selection of case studies was also carried out in collaboration with and based on the suggestions of stakeholders. Enough time for preparation was key also for the identification of the right combination of actors to be included in the transdisciplinary process: experience has shown that time pressure can result in the rapid creation of a large, seemingly inclusive pool of stakeholders that however lacks sensitivity to representation and can lead to outcomes serving only the most "evident" social groups and individuals (Chambers et al., 2022).

The greatest benefit of the methodologies used was the context-specific knowledge and coproduced pathways toward a collectively defined sustainable future developed as a result. The miracle question was key in identifying pathways toward a sustainable future, as determined by interviewees. The unusual nature of the question allowed participants to project themselves, whilst remaining grounded in a reality. The miracle question is in fact conceived to get out of the problem space and to think differently, thus facilitating problem solving and allowing a renewed perspective outside the usual framework in which people operate (de Shazer, 1985). From there, new meanings can be conceived, allowing many to access a playful, childlike, joking and pretend state, breaking out of the habitual thought pattern that has created a problem that cannot be solved. The pathways identified by interviewees were realistic, but also allowed them to "think outside the box." The question also led them to build their pathways in a layered approach. Many of the interviewees walked us through their vision. For example, starting with what they saw when they opened the window, to the people they interacted with as they walked into town, and how the landscape looked around them. This meant that the pathways were often incredibly detailed and spanned different scales (individual to structural and even cultural). The resulting film is often very moving, as we hear and see the aspirations of interviewees, within the setting of their choice. We believe they can contribute to influence power and conflict transformation by modifying the dominant narratives (Rodríguez and Inturias, 2018; Skrimizea et al., 2020), and support the creation of positives narratives, both collectively and individually from diverse perspectives that could act on the status quo and enable transformation (Pereira et al., 2018; Raudsepp-Hearne et al., 2019). Following on from the films, the workshops were set up in a way that allowed participants to develop possible joint solutions. This was very important to the research team, as a number of interviewees had told us that the workshops needed to be more than "talking shops." The process of getting to solutions, and the types of solutions identified varied significantly across workshops, depending on the context. Indeed, in one case study where the institutional context had changed radically since we had carried out the interviews, the facilitator quickly established that it was too soon to encourage participants to think of solutions, and that the priority was on re-building trust between participants in this new context. Reading the room, and building in some flexibility is key in these processes, as an abrupt focus on solutions could have exacerbated tensions. In the other workshops, the development of solutions was achieved, and in one workshop, leverage points were also established.

Limitations and Suggestions for Improvement

The main limitations of the methodologies used were their cost, the difficulty of targeting the relevant stakeholders in both the CVM and the T-Labs, the need for experienced facilitators to support the T-Lab process, and the need to adapt to change.

The resourcing of the process, both in terms of time and money, was a challenge in our research. The decision to film interviews was taken after the project was funded, and therefore budgets had to be amended to allow for this extra cost. Perhaps what was most challenging in terms of resources was the time spent developing the film scripts. For future processes, it would be timelier to start with the development of the film scripts before carrying out the more detailed coding. Having said this, the detailed coding did help the authors better identify the key issues to bring to the fore in the films. In addition, the research team was also acutely aware of the time we were asking of participants—for the interviews, but also in the making of the films, and time spent at the workshops—and were keen to ensure that that time was not seen as being wasted by participants. In future processes, costs associated with transdisciplinary approaches should ideally be integrated from the set-up of the research. However, as with many transdisciplinary projects, flexibility is needed, which can impact on the subsequent use of resources (Ely et al., 2021). In our case, our funders did not require us to have settled on case studies or methodologies when our project proposal was submitted. This flexibility, which we acknowledge is not a given in all funding mechanisms, allowed for a co-development of the research and the methodologies used with stakeholders, which in turn allowed for greater relevance of our research.

A second limitation of the approaches was the difficulties in engaging with the relevant stakeholders in the case studies. It was disappointing in all workshops, for example, that certain groups were under-represented (e.g., farmers in the water management case study, or local community associations in the viticulture case study). In addition, we could have included researchers (other than the research team) to ensure greater transdisciplinarity in the workshop discussions in terms of a science-policy-society dialogue. A suggestion for addressing this could be to carry out a two-workshop process (resources allowing), where the first workshop would be only with the interviewees, who could comment on the films, suggest a theme for a follow-up workshop, and identify key people to invite, which they would take responsibility for inviting themselves (with the support of the research team when needed). By doing so, the participants of the first workshop could engage in the process as "agents of change," integrating different domains (science, practice and social movement) and creating bridges between top-down and bottom-up approaches that can support food transformations at the territory level by developing social networks and recognizing or creating and seizing windows of opportunity (Westley et al., 2013; Butler et al., 2015; Caron et al., 2018; Skrimizea et al., 2020).

A third limitation was the reliance on an experienced facilitator in our transdisciplinary methodologies. The T-Lab required a facilitator that (a) understood the methodology and

its aims, (b) had experience of dealing with stakeholders in conflictual situations, and able to be flexible in terms of changing the T-Lab structure when needed, while keeping to the general aims and approaches of the methodology; and (c) was acceptable and accepted by the group of stakeholders. The facilitator was invaluable in our research, both in terms of developing the workshop agenda and process with the research team ahead of the workshops, and adapting methodologies and approaches on the day depending on the group dynamics. Indeed, while the agenda was the same for all three case studies, adaptations were needed. For example, at the start of one workshop, a participant expressed concern over the aim of the workshop, and the limited number of farmers and other stakeholders present. This comment sparked a debate, which needed to be managed by the facilitator, who had to adapt the day significantly in order to accommodate these concerns. Despite this adaptation, the group still managed to identify solutions and leverage points. Such facilitation expertise and capacity are not always accessible. Our suggestion, based on our experience, would be to consider the issue of selecting a facilitator ahead of any decision to organize a T-Lab, or communication to stakeholders of a potential workshop. In addition, time needs to be spent with the facilitator ahead of the workshops to explain the process of the T-Lab, its aims, and to develop a tailored programme. Finally, good inter-personal relations with the facilitator are essential. During the workshop, the facilitator regularly checked in with the researchers to ensure the aims of the workshop were being reached.

A fourth and final limitation was adapting to change. This adaptation could be at the scale of the individual T-Lab organization. For example, in one T-Lab we discovered at the last minute that there was no material for viewing the films. We had to use our own equipment, which had a negative impact on the quality of the viewing, and made it difficult for participants to understand the film. A recommendation for future process would be to check the settings in advance of the workshops to ensure the most fit for purpose spaces, where participants feel safe but also able to think outside of their usual settings; and where all the necessary material allows for the methodologies used to work. Adapting to change also impacted on the timing and format of the T-Labs. For example, initial dates set for T-Labs clashed with an important farming practice. We had to amend the date to better suit the farmers attending the workshop. Adaptability was also required with regards to the Covid pandemic, which meant that we could not meet stakeholders in large groups over extended periods of time. This resulted in us needing to be even more adaptable, for example organizing workshops during those times when they were allowed by law, and then adapting to the changing regulations, for example insisting that all participants wear masks and checking their sanitary passes on their arrival. There were, however, some advantages to the pandemic: thanks to the COVID pandemic, the film-maker we hired to film the interviews had spare time to edit the subsequent films. A final adaptation to change, which we had not anticipated, was in terms of our changing roles as researchers during the course of this transdisciplinary research. At the start of the process we saw ourselves very much as reflective scientists (collecting and analyzing data from the CVM, and observing the resulting actions of the T-Labs for example), as well as process facilitators (initiating a process, selecting participants and encouraging the expression of all viewpoints) (Wittmayer and Schäpke, 2014). As the process has evolved, however, we are increasingly seeing our role changing into one of change agents, empowering participants to own their processes. In the apiculture case study, for example, the final year of the project will focus on coaching the ADABFC to build their future capacity. In the viticulture case study, we will be supporting them in creating their narrative of past and future transformation. Whilst this new role is likely to build closer relationships and trust with the local communities and provide new avenues for future action; we are acutely aware of the need to be transparent with ourselves but also with other stakeholders (including our own institutions) about our changing role, but also its limitations. For example, whilst we still have funding to work on the project for 1 year, we cannot guarantee involvement as part of an ongoing process—an issue faced in other transdisciplinary research (Ely et al., 2021). These considerations around the roles of researchers need to be discussed with the communities with whom we work in transdisciplinary research, including the potential benefits and limitations of changing roles (Whitfield et al., 2021).

CONCLUSIONS

Our aim in this paper is to offer reflections and lessons learnt from different transdisciplinary techniques (Community Voice Method, the miracle question, films and T-Labs) as a means of strengthening their application in other contexts of transformational change, especially in addressing conflicts and power asymmetries.

Beyond the above reflections on the use of transdisciplinary knowledge coproduction methodologies to create transformative solution spaces in food systems, three key final reflections emerged from our experience. The first is the dynamic context of the case studies, which impacted on the use and outcomes of the techniques. In one case study in particular, the institutional context had changed radically between the time when we carried out our interviews, and the time we held the workshop following a local election. This changed context meant that the theme we had initially identified for the workshop was no longer as relevant, because participants had to rebuild trust with the new institution in place before being able to think of solutions. The T-Lab methodology may assume a continuum, but the realities of time taken to analyze data and plan a workshop means that many changes can happen that need to be incorporated in the overall methodology.

The second point is the need for resources. In our case we could hire a professional film maker and a professional facilitator to increase the quality of our films, and ensure constructive and tailored workshops. This also meant that we could free up time for the researchers to analyze data and evaluate workshops. Having trusted professionals that invest in the work, and become part of the research team was invaluable.

The third key learning point was that beyond the methodologies, the solution-focused participatory approach

throughout the project permitted a continued process of deliberative engagement with the key collaborators, interviewees and workshop participants, and created bonds that have been fundamental for and profoundly shaped our roles as reflective scientists, process facilitators, and change agents creating transformative spaces in the three cases.

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.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Comité sur l'Éthique des Recherches de l'Université de Bourgogne Franche Comté. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JY, ES, and LL participated in the development of the research. JY, SC, and LL contributed to the data analysis. SC and JY led on the initial draft of the manuscript with all other authors contributing to the writing of this paper. All authors participated in the data gathering. 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.2022.835203/full#supplementary-material

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Toward Food Sovereignty: Transformative Agroecology and Participatory Action Research With Coffee Smallholder Cooperatives in Mexico and Nicaragua

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The challenges that coffee smallholder livelihoods face suggest the need to move beyond incremental changes in production. Transformative agroecology offers a potential approach to guide systemic change to achieve food sovereignty among coffee smallholders and cooperatives. This work aims to understand the extent to which diversification practices among coffee smallholders can contribute to a transformative agroecology, and to what extent, participatory action research (PAR) projects may support related transformative processes. The PAR projects described in this paper took place over 3 years with participants associated with two smallholder cooperatives in Mexico, and Nicaragua. After establishing long-term partnerships among cooperatives and universities, we used a PAR approach to guide a mixed methods study that included 338 household surveys, 96 interviews, 44 focus group discussions, and participant observation during farmer-to-farmers exchanges. We found that, although coffee-producing households in both study sites report several diversification activities, more than 50% still face some period of food scarcity each year. In our reflections with farmers and staff from the participating cooperatives, that are also included as co-authors in this study, we conclude that coffee smallholders and cooperatives in both locations are in the early stages of developing a transformative agroecology, as a path toward food sovereignty. Several leverage points to achieve this include land access, native seed conservation, cultural attachment to certain diversification practices, and traditional diets. Some of the more significant challenges to advancing a more transformative agroecology are the prioritization of coffee as a crop (i.e., coffee specialization), and dependency on coffee income. Our PAR project also aimed to contribute to achieving change in the

prevailing system through 1) capacity building with community facilitators/promoters, 2) co-creation of questions and knowledge relevant to the strategic planning by coffee cooperatives, 3) sharing farmer-to-farmer pedagogies across territories, and 4) the co-production of popular education material. We conclude that diversification remains an important agroecological strategy for smallholder commodity producers, as a way of achieving food sovereignty. Most of all, we find that achieving diversification is not a linear process, as there are many trade-offs, feedback loops, obstacles and opportunities that should be considered through long-term and collective approaches.

Keywords: livelihoods, agroecological diversification, seed sovereignty, land access, farmer-to-farmer, traditional diets

INTRODUCTION

The processes of neoliberalization in the coffee sector of Latin America, initiated in 1989, resulted in the closure of national institutes that oversaw technical training and coordinated marketing with smallholder coffee producers, among other activities (McCook, 2017). This trend exacerbated existing drivers of food insecurity, such as food price fluctuations, unsustainable land and water management, pre-existing social vulnerabilities, and precarious livelihoods (Johansson et al., 2016). Despite improvements in some regions, smallholder coffee producers continue to experience various negative socio-economic and climatic impacts (Jaffee, 2014). In addition to these existing challenges, the recent COVID-19 pandemic has exposed new vulnerabilities in the food system (Altieri and Nicholls, 2020; Gliessman, 2020). Stronger theoretical and empirical research is needed to understand, communicate, and contribute to transforming agrifood systems and bringing us closer to solving these persistent challenges (Adger et al., 2013). Furthermore, there is a need to move beyond incremental changes toward through transformative processes (De Schutter, 2011), which are not limited to minor adaptations, but reduce vulnerability and build pathways toward food sovereignty and more dignified livelihoods (La Vía Campesina, 2015; Anderson et al., 2019).

As an alternative to these multiple threats and conditions that leave rural populations exposed and vulnerable, a growing number of scientists, farmers, social movement leaders and some politicians are recognizing and promoting agroecological principles for transformation, with a strong focus on diversity and diversification (IPES Food, 2016). Transformative agroecology can be an approach for redesigning food systems toward achieving food sovereignty, seeking to also achieve ecological sustainability, and economic and social justice in the process. Through transdisciplinary, participatory, and action-oriented research, agroecology links science, practice, and movements focused on transforming food systems (Méndez et al., 2013; Gliessman, 2016).

Diversification is an important principle within agroecology-based transitions. Diversification helps to reduce risks, improve soil fertility, optimize productivity, generate alternative sources of income, and improve diets (Gliessman, 2015). Many studies show that agroecological diversification strengthens farmers' resilience to different shocks such as hurricanes (Holt-Giménez, 2002), coffee price declines (Bacon et al., 2014), long-term drought (Bacon et al., 2017), or access to land (Sauer, 2020). However, there remains a lack of published empirical research on important issues affecting the benefits and challenges of diversification as a means of strengthening food sovereignty. In a context where different types of stressors intersect, more research is needed to better understand the limitations and/or contributions of diversification as part of agroecological transformative processes and its relationships to food sovereignty. This study aims to fill this gap in the literature.

There are several reasons why smallholder-based coffee systems in Mesoamerica are ideal to study transformative agroecology processes, with an emphasis on diversification and through Participatory Action Research (PAR). First, shaded coffee systems are an example of diverse agroecosystems that tend to conserve higher levels of biodiversity, generate higher amounts of ecosystem services and be more resilient to disturbance, than less diverse coffee plantations (Jha et al., 2011; Perfecto and Vandermeer, 2015). Second, studies in coffee systems show that in addition to coffee, smallholders often manage diversified farms that contribute to food security and income, including milpa plots (i.e., corn, beans, and associated crops)[1], home gardens (for vegetables, backyard animals, and fruit trees) and apiaries for honey production (Soto-Pinto et al., 2000; Bacon et al., 2014; Jaffee, 2014; Anderzén et al., 2020), all contributing to food sovereignty. Third, there is a long history of PAR with smallholder coffee farmers in Mesoamerica, which has focused on different aspects of diversification (Bacon et al., 2005, 2008, 2017; Bacon, 2010; Méndez et al., 2010a; Caswell et al., 2012; Fernandez and Méndez, 2018; Anderzén et al., 2020). Fourth, coffee is a complex export-oriented cash crop, which is linked to traditional small-scale agriculture and to a large-scale value chain that involves over 100 million people globally (Tucker, 2011). Fifth, coffee systems have pioneered innovations that advance sustainability in coffee-growing communities (Jaffee, 2014). Finally, there are strong peasant and/or indigenous community-based organizations and cooperatives with whom the research team has relationships to support long-term research.

[1]The *Milpa* is an Indigenous agricultural system originating in Mesoamerica that involves intercropping of several crops, usually different combinations of different varieties of corn, beans and squash (Gliessman, 2015).

In this paper, we report some of the major insights generated through a four-year PAR process in partnership with local organizations in Mexico and Nicaragua. This PAR process sought to co-create knowledge and develop agroecological strategies, based on diversification, to manage high environmental risk, changing market conditions, and other structural factors. Our work addressed two key objectives, as follows. The first objective was to analyze and document different diversification pathways and assess the extent to which they were part of transformative agroecological processes, which contribute to food sovereignty. The second was to examine the role of PAR itself, which is often seen as central to enabling food sovereignty in transformative agroecology processes. Specifically, this work was driven by the following research questions: 1) to what extent do current diversification activities contribute to transformative agroecology that advances food sovereignty in two coffee regions of Nicaragua and Mexico? 2) how can PAR support smallholder diversification with cooperatives, as part of transformative agroecology? 3) what are the obstacles and opportunities for smallholder coffee cooperatives to use diversification as part of processes focused on food sovereignty and transformative agroecology?

CONCEPTUAL APPROACH

This section presents the theoretical pillars that inform our research and how they weave together to shape our conceptual approach. In particular, we draw from and integrate the concepts of 1) food sovereignty, 2) transformative agroecology, and 3) participatory action research (PAR).

Food sovereignty is the collective path toward the development of autonomous food systems, which stand in opposition to a neoliberal and neo-colonial model characterized broadly by plantation-based and large-scale industrialized monocultures (Chappell et al., 2013; Grey and Patel, 2015). Food sovereignty is a precondition to genuine food security, which also addresses the social and political control of the food system (La Vía Campesina, 1996; Patel, 2009). Some of the guiding principles for food sovereignty identified in the Nyéléni declaration[2] (2007) (Schiavoni, 2009; European Coordination European Coordination Vía Campesina, 2018) are to value food providers, by 1) honoring and supporting all their identities and their livelihoods; 2) supporting food providers to have control over their territory and the natural resources on it (i.e., land, water, seeds, livestock, and fish); 3) building food sovereignty on local knowledge, skills, and nature; and 4) rejecting technologies that undermine them (i.e., genetic engineering). In that regard, seed sovereignty and agrobiodiversity[3] are key components for achieving food sovereignty (Kloppenburg, 2014; García López et al., 2019). In ecological terms, agrobiodiversity (as well as on-farm diversification established and managed through the use of agroecological principles), may reduce the use of external inputs, attract pollinators, enrich, and protect the soil, reduce water consumption and transpiration, and increase the quality and amount of the harvest (Ponisio et al., 2015; Isbell et al., 2017). Agroecology has been broadly recognized as an approach with high potential to achieve food sovereignty (Jansen, 2015; La Vía Campesina, 2015; Martínez Torres and Rosset, 2017; Bezner Kerr et al., 2019; Altieri and Nicholls, 2020).

Although plurality is a key element of agroecology, we consider it especially important to highlight the transformative component of our approach, especially in a context in which agroecology is at risk of being stripped of its political content (Giraldo and Rosset, 2017). In that sense, transformative agroecology can be a synergistic strategy with other political and social goals (i.e., gender equity or agrarian reforms) that are the basis for processes that seek to achieve food sovereignty. For the purposes of this paper, we will focus on the role of transformative agroecology processes in achieving food sovereignty.

To better characterize transformative agroecology, we identified 24 indicators (also referred to as elements, parameters, or principles) through an extensive review of the literature (La Vía Campesina, 2015; Gliessman, 2016; Anderson et al., 2019; Biovision, 2019; FAO, 2019; Galab et al., 2019; HLPE, 2019; Hernández et al., 2020). Following the objectives of this study, we ranked and organized the indicators into four deeply interconnected dimensions, as follows: 1) environmental and productive, 2) economic, 3) socio-political and 4) food sovereignty (**Table 1**). Beyond the different dimensions and indicators, **Table 1** also outlined in which phase of the research process (Phase 1 or 2), data for each indicator was collected (Section Data Collection).

In this work, we emphasize on-farm diversification as a food sovereignty indicator and an integral component of agroecology (Altieri et al., 2015). In fact, as diversification can have a strong impact on farmers' diets, it can be considered one of the most important agroecological principles for household nutrition (Bezner Kerr et al., 2021), and thus a key element of food sovereignty. In that regard, we differentiated between two forms of on-farm diversification. The first includes diversified farms conducting certain agricultural activities motivated primarily by cultural and traditional reasons. For instance, one study found that Zapotec indigenous households in Mexico continued to grow traditional maize varieties even when the mean total production costs exceeded the market price of maize by 400% (Chappell et al., 2013). The second is a process of diversification in which households add new strategies into their "portfolio of activities" as a proactive or reactive measure (Ellis, 2000). These often involve agricultural activities that are promoted by external actors, including governmental or nongovernmental organizations.

The last theoretical pillar is agroecology's strong linkages to PAR, which is also deeply rooted in Latin America (Rosset et al., 2020; López García et al., 2021). The link between agroecology and PAR can constitute a virtuous cycle with transformative potential (Levidow et al., 2014; Méndez et al., 2017; Sevilla Guzmán, 2017; Anderson et al., 2019; Rosset et al., 2020). Méndez et al. (2013) summarized these linkages in common principles between PAR and agroecology, which include empowerment of local communities, context dependency, contributions to positive local change, deepening of long-term relationships, and

[2]Created with the participation of more than 500 social movement leaders from nearly 80 countries.

[3]Expresses the number of species and their abundance in the agricultural plots.

TABLE 1 | Dimensions and indicators of transformative agroecology in coffee socio-ecological systems.

Dimension	Indicators	Data sources by phase (P1 or P2)
1. Environment and productivity	Landscape connectivity***	P2: interviews, farm mapping; participant observation
	Water management and access**	P1: surveys; P2: interviews, focus groups; participant observation
	Resilience to climate change and extreme weather events**	P2: surveys, focus groups, focus groups
	Synergies and recycling**	P2: surveys, focus groups; participant observation
	Pest Management*	P2: surveys, farmers' exchanges
	Animal welfare*	P2: focus group, farmers' exchanges
	Soil Health*	P2: surveys
2. Economic	Financial empowerment and solidarity economy***	P2: surveys, focus groups, farmers' exchanges
	Labor force***	P1: surveys P2: surveys; participant observation
	On-farm income diversity***	P1: surveys P2: surveys, interviews, focus groups, farmers' exchanges
3. Socio-political	Responsible governance***	P2: interviews, farmers' exchanges; participant observation
	Ability to challenge and transform structure of power***	Farmers' exchanges, participant observation
	Impact on policies plus producer and producer-consumers links***	Participant observation
	Awareness and analysis of structural and historical context*	P2: farmers' exchanges; participant observation
4. Food sovereignty[a]	Co-creation of knowledge***	P2: interviews, focus groups, farmers' exchanges; participant observation
	Agro/diversity***	P2: surveys; participant observation
	Seed sovereignty***	P2: Focus groups, farmers' exchanges; participant observation
	On-farm diversity***	P1: surveys P2: surveys, farm mapping
	Traditional diet attachment***	P2: surveys, interviews, focus groups, farmers' exchanges; participant observation
	Ability to cope with food scarcity**	P1: surveys P2: surveys, farm mapping, interviews; participant observation
	Short and fair food chain distribution**	P2: surveys, interviews; participant observation
	Dietary diversity**	P2: surveys, farm mapping, focus groups; participant observation
	Agricultural practices that are culturally meaningful*	P2: farm mapping, interviews, focus groups, farmers' exchanges; participant observation
	Intergenerational and gender equity*	P2: surveys, interviews, focus groups, farmers' exchanges; participant observation

[a]*Including social and cultural indicators from other frameworks; *denotes lower relevance for the specific indicator; **denotes average relevance for the specific indicator; ***denotes high relevance for the specific indicator.*

incorporation of diverse voices and knowledge systems. PAR processes can also influence systems of agricultural products and input exchange among different users and consumers, as well as networks with various actors involved in markets, agroecological practices, farmer organizations, and/or allied NGOs, or "agroecological lighthouses", representing iconic cases that can inspire others (Anderson and McLachlan, 2015; Mier y Terán Giménez Cacho et al., 2018; Nicholls and Altieri, 2018). Finally, PAR can be a driving force to question and highlight elements that communities were not aware of and generate alternatives in the face of different inequities.

METHODOLOGY

Study Site

Here we introduce some of the structural and historical features of the two cooperatives with whom we partnered in this study: 1) Campesinos Ecológicos de la Sierra Madre de Chiapas (CESMACH) in southern Mexico, and 2) the Promotora de Desarrollo Cooperativo de Las Segovias (PRODECOOP) in northwest Nicaragua (see **Figure 1**).

In previous decades, agrarian reforms provided land to smallholder and farmer organizations that were institutionalized as cooperatives in Central America, or *ejidos* and agrarian communities in Mexico[4] (Bacon, 2010; Jaffee, 2014; McCook, 2017). Agrarian reforms implied national land redistribution through a variety of processes. Notwithstanding this historical favorable condition in terms of land access, the contemporary crises that coffee producers are experiencing has its roots in the neoliberalization that began in the region in the late 1980s (Bacon, 2010). Its beginning was marked by the collapse of the International Coffee Agreement in 1989, which regulated exports and prices (Jaffee, 2014; McCook, 2017). In the following years, governmental institutions that provided technical training, credit, and that controlled quality, sales, and export of coffee were dismantled (Bacon, 2010; Méndez et al., 2010b; Jaffee, 2014; McCook, 2017). That was the case of INMECAFE in Mexico and UNICAFE in Nicaragua. These changes meant that "an entire sector of peasant producers was exposed to the effects of a deregulated market (...) over the next 3 years, due to the 70 percent drop in the prices, the small producers of coffee were plunged into poverty, indebtedness and even bankruptcy" (Jaffee, 2014: 59). This context led to the surge of many cooperatives that organized smallholder coffee producers, allowing them to access better markets, quality control, and technical training. The demand for quality coffees with "sustainability certifications" (e.g., organic or Rainforest Alliance), mainly by consumers in the United States and Europe (McCook, 2017), have favored international interactions with coffee grower organizations. As a result, international Non-Governmental Organizations (NGOs), buyers, and certifiers replaced the role of governmental agencies in providing technical training, guaranteeing minimum prices, coordinating exports, and financing development projects

[4]Collective land tenure assigned by the state to a group of farmers who demanded it. This was possible in the context of the agrarian reform that took place between 1934 and 1992 (Morett-Sánchez and Cosío-Ruiz, 2017).

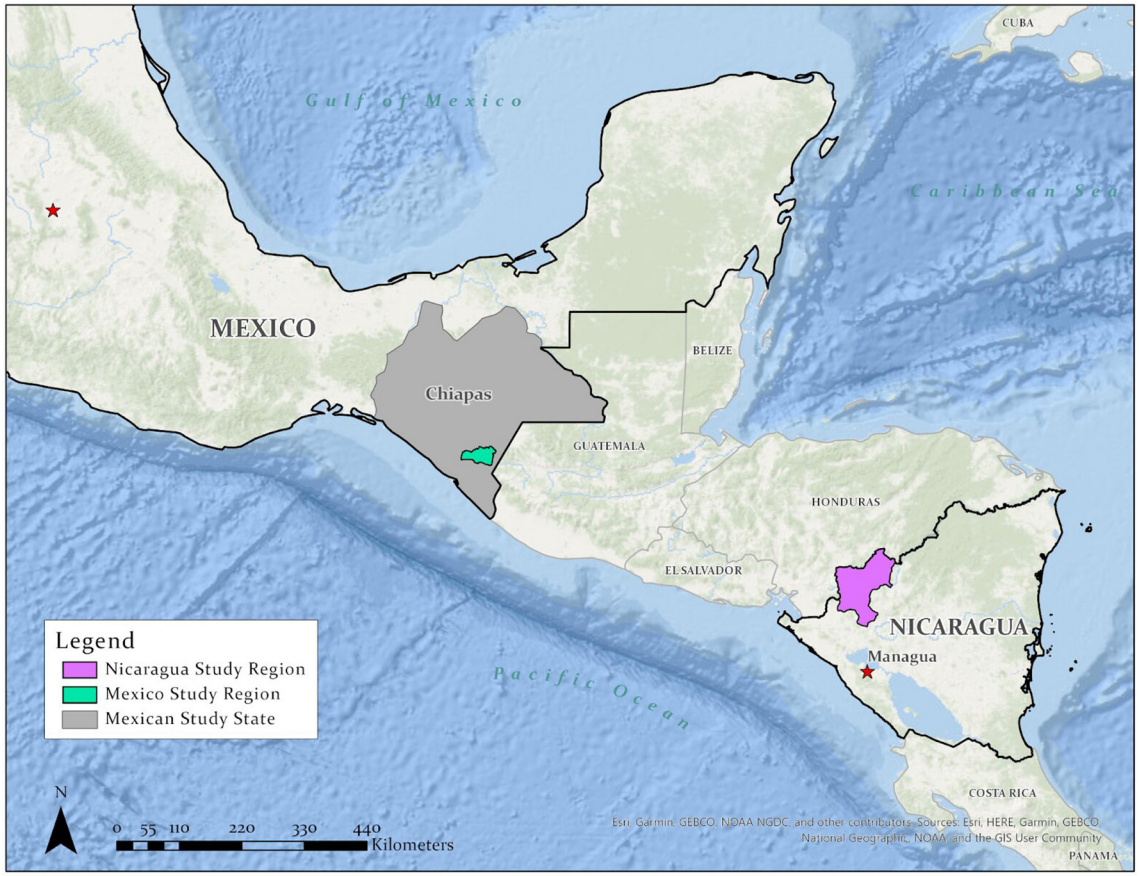

FIGURE 1 | Location of CESMACH (Mexico) and PRODECOOP (Nicaragua). Created by Emma McCurry, Santa Clara University.

with cooperatives. These relationships could be a double-edged sword for organizations, as they could also generate dependent relationships.

Beyond their common structural context, both cooperatives have features that have defined their path toward food sovereignty. Key to this analysis is that they both have a history with institutions and projects that promote diversification.

CESMACH is a coffee cooperative in Mexico founded in 1992 that currently has 689 members, of which 30% are women. Most of its members are part of *ejidos*, distributed in 46 communities, located in the northern side of the Sierra Madre de Chiapas Mountain range in southern Mexico. CESMACH is positioned within the buffer zone of the "El Triunfo" Natural Protected Area (Fernandez and Méndez, 2018), a biodiversity hotspot with an abundance of wild foods that grow in the forests and managed plots. By 2000, the cooperative had registered its trademark as "Café Campesino", and in 2001, it obtained its Fair Trade (FLO-International) and organic (CERTIMEX – IMO control) certifications.

CESMACH has always expressed a commitment to the social wellbeing of its members. Since the early history of the cooperative, they have promoted projects to support sustainable agriculture, family health, nutrition, housing, and food security. All of this has been done with the support of diverse institutions, including governmental (e.g., CONABIO), NGOs (e.g., Heifer International, Food 4 Farmers, Edhuca), solidarity buyers (e.g., Equal Exchange) and international universities following PAR principles (e.g., University of Vermont). Some of the main achievements in this regard have been obtaining a women-inclusive registered trademark called Café Femenino (2006) and also establishing Miel Real del Triunfo (2019), a smaller and parallel cooperative to process and sell honey.

PRODECOOP is a coffee cooperative union in Nicaragua founded in 1993. It integrates 38 affiliated grassroots cooperatives made up of 2,300 member families, of which 28% are women (PRODECOOP, 2020). The organic and conventional production units are located in three departments in northern Nicaragua that contain three mountain ranges running east to west with topographical variation between ∼800 to 1,600 m above sea level (Kelley et al., 2018). PRODECOOP members obtained land tenure in the 1980s agrarian reform, during the 1990s and early 2000s (Bacon et al., 2017). PRODECOOP has developed sophisticated quality control and trained professional staff to market their smallholders' coffee to premium organic, fair trade, and specialty markets.

PRODECOOP's long-term commitment is to improve the quality of life of its members and promote cooperative development in the Segovias region. PRODECOOP started to invest in farm diversification as a key strategy to eliminate seasonal hunger, launching their Food Security and Sovereignty Program (SSAN). This initiative began with a diagnosis in 2010, through which an action plan with project initiatives and activities emerged. These integrated the gender policy and community-based action research approach in partnership with local and international universities following PAR principles (i.e., Universidad Nacional Agraria and Santa Clara University), farmers' movements, and NGOs (i.e., Community Agroecology Network (CAN), based in California). Another important element is capacity building, where farmer leaders of on-farm diversification experimentation and farmer promoter networks are the backbones of all technical assistance in coordination with nine agricultural extension agents. This motivated family participation, increasing from 30 to 1,500 families involved in Good Agricultural Practices on Diversification (GAPD) over the last 11 years.

Participatory Action Research Partnerships

In 2016, researchers and practitioners[5] joined PRODECOOP and CESMACH to design the project "Assessment of Diversification Strategies in Smallholder Coffee Systems of Mesoamerica". PAR and shared methodologies (i.e., criteria for selecting participants; surveys, interviews, and focus groups) were important components of the project from the beginning. This included collective planning and coordination with in-country teams (including local researchers and community facilitators/promoters), cooperative leadership and farmers to define specific goals, design and implement research tools, validate and share results, and define next steps for research and action.

In CESMACH, we worked with five community facilitators (young cooperative members or sons or daughters of members), and the cooperative-based project coordinator (a biologist/agroecologist). In Nicaragua, which had an established longer-term PAR process (Bacon, 2015), the dialogue was carried out with 14 community promoters, and two agroecologists/technical assistance teams. The selection of facilitators/promoters and assistance teams was carried out according to the cooperatives' criteria for hiring personnel, based on their regulations and as a way to contribute with their local governance. Although facilitators/promoters were part of each phase of the project, their leadership in designing research tools, managing focus groups, and making decisions grew throughout the process, with a change being particularly noticeable for female promoters. This led to group reflections and adjustments to finalize research tools, methods, program implementation, community validation, co-authorship, and dissemination of findings for different audiences.

[5]Researchers came from the Agroecology and Livelihoods Collaborative (ALC) at the University of Vermont (UVM), Santa Clara University (SCU), and the Community Agroecology Network (CAN) in the USA, El Colegio de la Frontera Sur in Mexico (ECOSUR), and the Universidad Nacional Agraria (UNA) in Nicaragua.

Data Collection

We used a variety of research methods and instruments throughout the PAR project. In Phase 1 (P1; early 2017), we conducted a survey with 167 households in Mexico and 171 in Nicaragua, with the objective of getting an overview of farmer households' livelihoods, including characteristics of on-farm diversification, food security, and sources of income. For an analysis of this data the interested reader is referred to Anderzén et al. (2020) and Bacon et al. (2021). In Mexico, the households were selected with the support of the cooperative leadership, from five groups (30 farmers from each group) representing different types of diversification: 1) beekeepers, 2) farmers with milpa plots, 3) farmers who had participated in diversification projects, 4) farmers participating in specialty coffee initiatives, and 5) farmers who had not participated in any diversification projects. A similar set of criteria was used for Nicaragua.

In Phase 2 (P2; late 2017-2019), we worked with 50 households (in each site) who represented different livelihood diversification strategies. We carried out farm mapping (46 in Mexico; 50 in Nicaragua), interviews (46 in Mexico; 50 in Nicaragua) about farmers' motivations and background in diversification activities, and household surveys. The surveys were conducted monthly for over a year, focusing on the division of labor in diversified farms, food production and consumption, as well as seasonal sections related to diversification activities, and climate change. We also conducted several focus group discussions (18 in Mexico; 26 in Nicaragua) with the Phase 2 participating households (adult men, women and teenagers). These covered various topics (e.g., beekeeping, milpa systems, food security and sovereignty, agricultural calendars, gender equity), and used participant observation as a method for deepening our understanding of the project themes (on-farm diversification, food security, climate change resilience and gender equity). The focus group discussions also included a farmer-to-farmer component as they were led by the local facilitators/promoters, and typically involved an action element, such as diversification activities training or sharing experiences. All the data was collected by the project team (facilitators/promoters, ALC-UVM, USC, UNA students, and CAN staff).

In parallel, a capacity-building and mutual learning process among researchers, cooperative staff, and facilitators/promoters continued. This included frequent meetings that addressed a variety of topics, such as aspects of PAR and human development. We also carried out two cross-site learning exchanges (in Nicaragua, 2018 and in Mexico, 2019) with farmers, scholars, cooperative leaderships, and the participating NGOs. Those exchanges provided concentrated opportunities for sharing that highlighted the richness of comparing experiences and exploring new ideas. In addition to following community-based and participatory principles (Méndez et al., 2017), all research was conducted after receiving approval from the relevant University Institutional Review Boards.

Data Analysis

During this 4-year project we collected a substantial amount of quantitative and qualitative data. However, in this paper we focus primarily on those findings relevant to answer our research questions (see Section Introduction). In that regard we use descriptive statistics and qualitative data from transcribed interviews and focus group discussions to complement a more interpretive argument about the role of farm diversification, cooperatives, and PAR in transformative agroecology.

The quantitative survey data was exported, cleaned, and preliminary results were shared and discussed with respondents during the focus group discussions, as well as with cooperative staff/promoters. Descriptive statistics and *T*-tests are calculated in Excel spreadsheets. To define the role of on-farm diversification in the process of achieving food sovereignty, we follow the ranked indicators presented in **Table 1** (Section Conceptual Approach).

RESULTS

Several key findings responded to the overarching objective of how current diversification activities contribute to transformative agroecology for advancing food sovereignty, and the role of PAR in the process. Section Food Sovereignty and Transformative Agroecology Elements presents some comparative findings between the two cases, and Section Cooperative-Specific Observations delves more into some context-specific highlights.

Food Sovereignty and Transformative Agroecology Elements

Our study has confirmed that member farmers of both cooperatives manage diversified farms, consisting of farm animals and various crops, in addition to coffee (**Table 2**). Our initial survey (Phase 1) showed that fruit trees were the most common diversification strategy in both study sites, followed by poultry and vegetables. Another important strategy was milpa/basic grains (either in diversified milpa plots or in small scale monocultures of corn or beans), which was present in more than half of the households (Mx∼63%; Ni∼55%). Although the percentage was higher in the Mexican case, we saw a trend of simplifying the milpa system to corn/bean monocrops in both sites. Livestock as an important income source was much more prevalent in Nicaragua.

In terms of food security, 72% of CESMACH respondents in Mexico reported experiencing at least 1 month of seasonal food insecurity (or lean months)[6] in the year prior to the survey (**Table 2**). The average number of lean months reported across the 159 surveyed households (including those reporting zero months), was 2.5 months. The average number of lean months for those households that reported experiencing at least 1 lean month was 3.5 months per year (SD = 1.6). Approximately 50% of the 171 survey respondents from PRODECOOP (Nicaragua) reported at least one lean month in the year before the survey. The mean number of lean months reported across all households was 1.6 months per year (SD = 2.1), which is significantly lower than the mean in Mexico. The smallholders reporting at least one lean month share one important similarity between study sites, in that their average amount of lean months is 3.2 months per year at the Nicaragua site (SD = 1.9) and 3.5 months per year (SD = 1.6) at the Mexico site (**Table 2**). In both study sites, the rainy season coincides with the most severe experiences of lean months (**Figure 2**), exacerbated by delays in receiving the second payment of the coffee harvest. For Fairtrade coffee, a portion of the payment for the crop is paid upfront, with the balance, including the price premiums, paid later in the year. However, **Figure 2** shows that this income does not imply an instant relief from the lean months. In contrast, relief from the lean months coincides with 1) a peak in local fruit consumption in the Mexican site, 2) honey harvest in the Nicaraguan site, and 3) the beginning of the staple crop harvest (i.e., corn and bean) in both countries.

In particular, the cultivation of milpa plots is a significant expression of seed sovereignty in Mexico. In our interviews

TABLE 2 | Engagement in diversification, farm characteristics and prevalence of food insecurity for study cooperatives.

Engagement in diversification activities in the P1 survey (% of households)		
	CESMACH, Mexico ($n = 167$)	PRODECOOP, Nicaragua ($n = 171$)
Fruit trees	98	99
Milpa/basic grains	∼63	∼55
Poultry	88	78
Vegetables	65	74
Livestock	15	38
Farm animals (pigs, rabbits)	30	∼34
Beekeeping	22	19
Farm characteristics		
	CESMACH, Mexico ($n = 159$)	PRODECOOP, Nicaragua ($n = 171$)
Mean farm size (ha)	8.7 (5.7)	5.7 (6.8)**
Farm area under coffee (%)	74% (22)	52% (36)**
Experience of food insecurity		
	CESMACH, Mexico ($n = 167$)	PRODECOOP, Nicaragua ($n = 171$)
Experience of at least one lean month (% of households)	72%	50%
Mean number of lean months for all households (months)	2.5 (2.1)	1.6 (2.1)**
Mean number of lean months for households with >0 lean months (months)	3.5 (1.6)	3.2 (1.9)

***$p < 0.05$ or lower, ***$p < 0.01$; Parentheses denote standard deviation.*

[6]The experience of lean months is an indicator of seasonal hunger. It indicates the number of those months during which the food produced on-farm has run out, and households face difficulty purchasing additional food. Common coping mechanisms include the consumption of less preferred food, borrowing money to buy food, and sometimes skipping meals or going to bed hungry (Bacon et al., 2014).

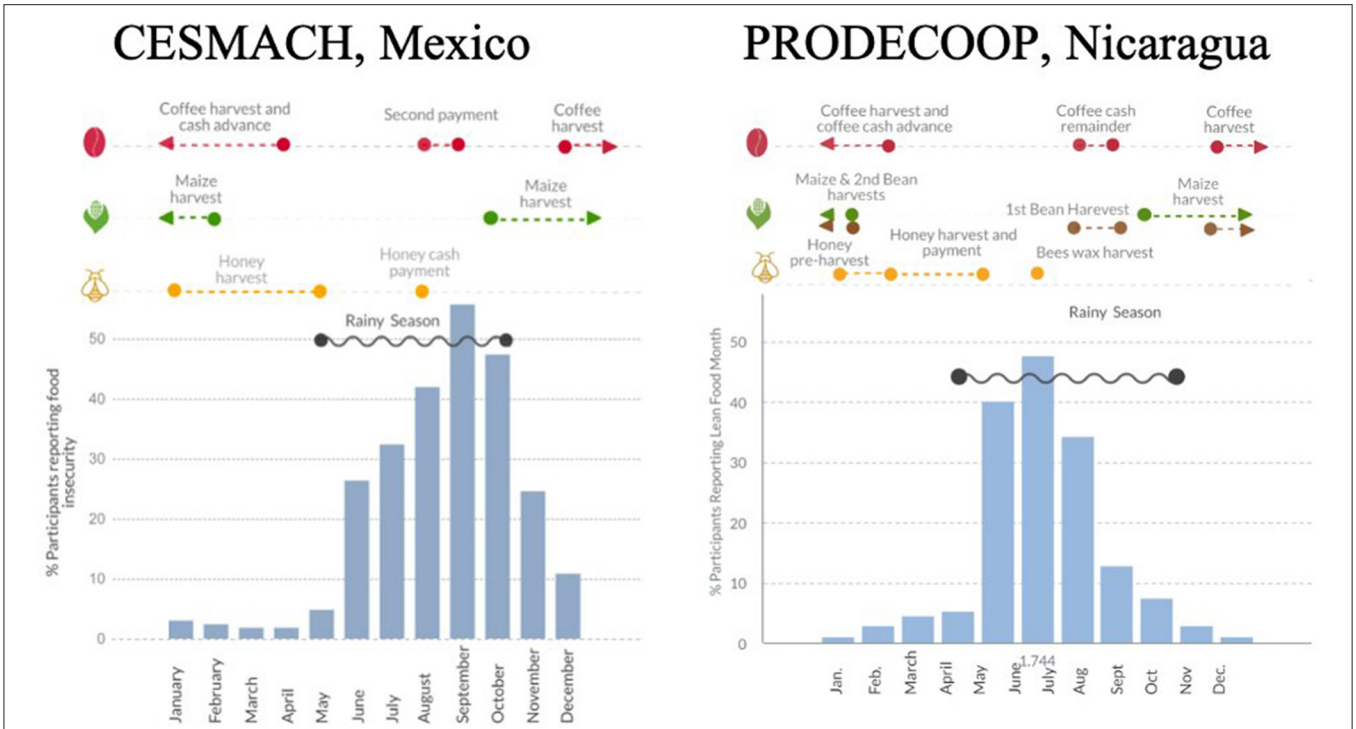

FIGURE 2 | Key moments in the agriculture and cooperatives cycles, as well as lean months. Left graph was published in Anderzén et al., 2020, p. 42. Right graph data came from 171 Household Surveys Northern Nicaragua, 2017 and Focus Groups (Bacon et al., 2021).

and participant observation, many of the coffee smallholders cultivating milpa plots reported using one or several native and creole varieties[7] of corn and beans, either in a traditional milpa system or a simplified system. Through interviews, focus group discussions and Phase 1 surveys, we identified thirteen corn and seven bean varieties that farmers associated with specific features, such as increased yield, adaptation to local climatic conditions, preferred altitude, and specific food uses. In contrast, some farmers mentioned that native and creole varieties do not grow well without agrochemical input or that they produce lower or even no yield. These varieties are also considered as a cultural inheritance with important cultural meaning. Moreover, our data suggest that these landraces may increase the adaptive capacity of the household to climate variability, as one Mexican farmer pointed out during a focus group discussion:

> *There are seeds that are specialized to withstand cold, heat, weather, and so on. Yes, to dedicate myself to planting corn seeds appropriate to face climate change* (*Male farmer*).

Participant observations and collective reflection showed that key seed sovereignty activities in the Nicaragua study location included households with an active participation in seed saving, as well as the maintenance and exchange of vegetative plant material, such as tree cuttings. These tree cuttings can be used in live fences, yuca or cassava root trellises (*Manihot esculenta*), starts for bananas and plantains *(Musa spp.),* and others. After learning from the *Campesino-a-Campesino* Program's innovative community-based seed banks during several farmer exchanges (for more details see Bacon et al., 2014), the smallholders affiliated with PRODECOOP and the rural assistance staff started promoting the establishment of seed and vegetative material "banks" (or "Bancos Vivos") for *in-situ* agrodiversity conservation. By the time of writing this article the cooperatives have undertaken this activity for over 10 years. In addition, there is farmer-led experimentation for the identification of seeds that are resistant to the impacts of climate change.

Diversification activities (and their implementation) are highly dynamic in relation to the landscape and seasons. In the Mexico site, and based on the farm maps drawn by 46 households, we found that most plots, including coffee agroforestry systems, were home to various edible species and/or farm animals. These species provided a wide variety of nutrients to household members, and contributed to the diet of seasonal workers during the harvesting season. In addition, home gardens typically contained a mix of vegetables and fruit trees along with poultry or pigs. Most coffee plots, as agroforestry systems, contained fruit trees and various types of wild food, such as mushrooms and vegetables, which are collectively important food sources during the lean months.

In the Nicaragua site, the maps drawn by cooperative members revealed significant spatial dispersion between households and farm plots, with many farmers managing coffee

[7]We refer as native to seeds from the Americas, and creole as seeds that although not native to the Americas, have undergone adaptation (García López et al., 2019).

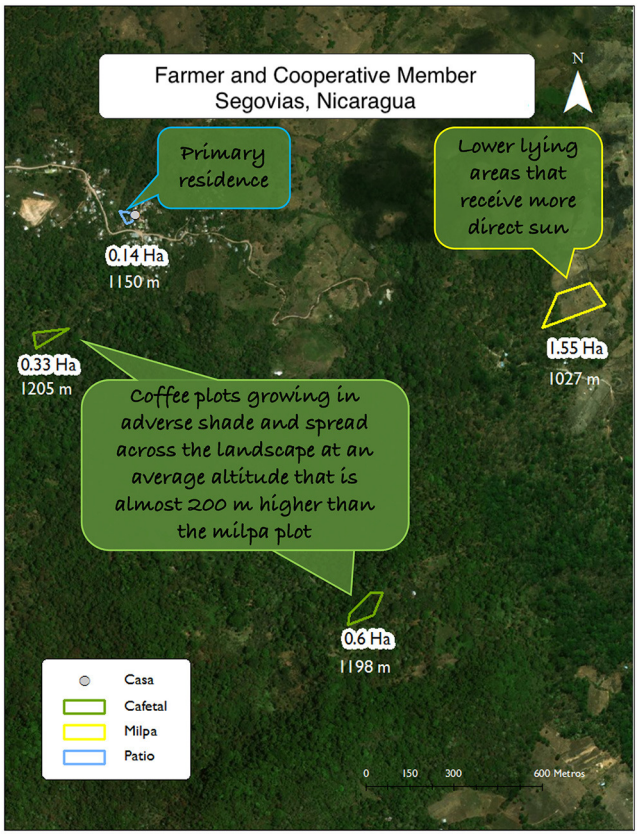

FIGURE 3 | Spatial distribution of productive plots of one farmer in PRODECOOP, Nicaragua.

plots at higher altitudes. These plots can be located >5 km from the household and the lower altitudes of the milpa plots. Although there are no frost zones, the low-lying mountains of the study areas exhibit significant microclimatic variability, and farmers can use different locations to accommodate this high diversity of crops (see **Figure 3**). For instance, beekeepers in the study sites described how they move hives during the year, according to flowering plant availability at different altitudes.

Regarding agrobiodiversity, in the Mexican site, monthly household surveys reported a wide range of edible species. Domesticated species included multiple species of roots (5), vegetables (16), flowers (5), aromatic plants (13), fruits (31), and animals (7). In addition, for wild edible species, households also reported multiple species of vegetables (24), fungi (16), and animals (16, including insects, birds, and mammals). In the Nicaraguan site, households reported several maize (31) and bean (37) varieties. Ten of the varieties of basic grains are handled exclusively by "milpera" women. Families integrated these crops in their plots either for home consumption or for sale. Home gardens are one of the most important agricultural activities, where all family members participate, and with 5–15 crops grown per household. Although progress has been made in the preservation of fruit seeds, spices, tubers, and vegetables for home garden cultivation, there is still an external dependence on vegetable seeds. It is important to point that many families have a strong interest in learning more about vegetable seed preservation.

There were many similarities between the smallholders surveyed at both study sites, as well as considerable variation within each site. The farms surveyed in Mexico averaged 8.7 ha in size, which was significantly larger than the 5.7 ha of average total farm area in the Nicaraguan site (**Table 2**). It is also important to note that the average total farm area dedicated to coffee production was higher for the farms surveyed in Mexico compared to those in Nicaragua (74% average coffee cover in Mexico vs. 52% in Nicaragua). This suggests that although the surveyed farms in both locations may contain a similar number of crop species, when comparing plant diversity per unit area, Nicaraguan farms contain more species.

Finally, coffee remains a key source of agricultural income in both sites. In Nicaragua, most farms <10 ha reported coffee as their primary income source (82%), while in Mexico 35% of all producers reported coffee as the only source of agricultural income. This shows a relatively high specialization focus by these farmers on coffee production for income generation. Furthermore, in both study sites, coffee production is largely dependent on family labor.

Cooperative-Specific Observations

In Sections CESMACH, Mexico—PRODECOOP, Nicaragua, we discuss some of the specific features of each cooperative, according to their importance for achieving food sovereignty. In this sense the sections below reflect the needs and interests of the cooperative partners, and the intrinsic PAR characteristics that are site- and context-specific. This makes it impossible to completely replicate the methodologies, or fully compare findings and PAR impacts between the two cooperatives.

CESMACH, Mexico

Smallholders' Motivations for Diversifying

When asked how diversification activities started within the cooperative, most smallholders mentioned that they started growing certain crops or raising animals through their own initiative. Conversely, the adoption of diversification approaches driven by external support (i.e., NGOs or government funding) was less prevalent. Our Phase 1 survey showed that the production of fruit (from trees), poultry, vegetables, and milpa plots are the four most common on-farm diversification activities, and typically started by farmers themselves (> 87%) rather than through external projects or government programs (<18%). Furthermore, smallholders reported that personal enjoyment was one of the reasons for engaging in these diversification activities. Another motivation for these activities was consuming organically or naturally produced food because they are healthier for people and nature. As one farmer said in an interview: *"That's why we think of health, not of business"* (*Male farmer*).

We argue that these farmer-initiated, on-farm diversification activities for diet improvement and personal enjoyment can be interpreted as food sovereignty-oriented motivations. This

is because they are rooted in households' cultural and environmental conditions, traditional production systems and agrobiodiversity, as well asself-sufficiency. However, other households reported discontinuing the production of poultry, vegetable, and milpa plots in the last 10 years. Among the main reasons for abandoning these activities (either temporarily or permanently) were their high labor requirements, lack of access to sufficient land, or a desire to focus more on coffee production (i.e., increase specialization). Our observations, focus group discussions, and interviews pointed to multiple feedbacks among diversification and production activities. Among others things, they enhanced dietary diversity, which also strengthened food sovereignty.

Origin of Locally Consumed Food

Our monthly surveys identified the high dependency of the surveyed households on purchased food. In particular, rice, cookies, and pasta were among the most commonly purchased types of food reported for all months. This is often low-quality and highly processed food, with high sugar or sodium content. However, following purchased food, self-produced food was most commonly consumed between September and March. This aligns with harvest season for staple crops. Wild edible species (e.g., plants, fungi, insects, other animals) were the second most commonly consumed type of food between April to August, which aligns with a decline in access to purchased food during the rainy season.

This high consumption of self-produced food or food harvested from the wild highlights their potential to help households achieve food sovereignty, while also exposing the vulnerability that high dependence on purchased food can bring. For example, this vulnerability can be particularly significant in a context where roads usually close and communities become easily isolated during the rainy and hurricane season.

Cultural Attachment to Milpa Systems

The cultivation of milpa plots can have a synergistic or antagonistic effect on food sovereignty, depending on the context. For instance, although there is a tendency to simplify the traditional milpa systems to include fewer crops, smallholders acknowledge the many advantages that continuing farming milpa plots can have. These included finding edible wild species in their milpa plots or including other edible crops such as chayote (*Sechium edule*) or camote (*Ipomea spp.*) to "*help the corn grow better*", as a farmer noted in an interview. Some of the interview respondents also suggested that the bean leaves in milpa plots can protect the soil and provide livestock feed after the harvest.

We also observed a strong cultural attachment to milpa systems. Some smallholders explained during the interviews that they grow corn "*only for the fresh corn cob*". In this sense, farmers continue growing corn so their families may enjoy eating it as a snack for some days during the year. It is interesting to note that for some of those smallholders, producing this delicacy implies walking as much as 6 h round-trip once a week, to cultivate small milpa plots (usually <0.5 ha), since the best land closer to home is usually reserved for coffee production.

Only a quarter of the surveyed households were producing enough maize to meet their needs for the whole year. However in some interviews it was suggested that other agricultural activities beyond coffee were important for food consumed within households, including the output of milpa plots that can act as a buffer to annual changes in the diet, and thus represent an important element for achieving food sovereignty. For example, as expressed by a farmer during focus group discussion with farmers that had milpa plots:

> *"Now, gentlemen coffee growers, (...) the detail is, you cook your money and see if that's going to fill you up- (...) it's the truth, we have land to plant, and we buy, and a farmer can not only live from a product, but the farmer lives from different types, not just coffee.* (*Male farmer)"*

PAR Contributions to Food Sovereignty

PAR principles were followed in every activity carried out by CESMACH members. However, the outcomes of the implementations of those principles are hard to measure, especially in the short-term. We identified the capacity-building of community facilitators and the development of popular education tools as the strongest PAR contributions to a transformative agroecology process.

The community facilitators' training focused on three different themes that were treated during three-day monthly sessions: 1) Coffee value chains, which traces the process of the coffee crop from the farm to the cup (e.g., agricultural practices, cupping/coffee appreciation, processing); 2) PAR and research approaches (e.g., livelihood diversification, coffee agroecosystems, food security and sovereignty, climate change, gender equity); and 3) human development (e.g., personal experience with gender dynamics, self-esteem, skill-building). Facilitators had the opportunity to attend national and international conferences and courses about agroecology, food sovereignty, and gender equity. Overall, during the 4-year PAR process, we witnessed personal and professional growth in each of the facilitators, who have also become leaders and advocates for participatory processes, agroecology, and diversification.

In regard to popular education, we (researchers, community facilitators, and a visual designer) created three tools to guide collective reflections to achieve transformative agroecology and food sovereignty (see below for description). The first draft of each tool was created through focus group discussions replicated in three communities. These activities were led by the facilitators, with the support of researchers or CAN staff, and were undertaken as workshops using craft materials (e.g., color papers or drawings) with all the participants. The researchers integrated the three tool drafts for a follow-up validation process with CESMACH's leadership, facilitator team, and (at least) two other communities. Finally, the designer put together the validated tools drafts, which were reviewed one more time with the cooperative's leadership, facilitator team, and researchers, until a consensus was reached.

The first tool was the Nourishment Plate (**Figure 4**), which was developed to outline the most frequently mentioned cultivated or wild local food consumed among CESMACH

FIGURE 4 | The Chiapas Highlands Nourishment Plate education tool that highlights the most common local food resources reported by CESMACH households. Created by Daniela Gallardo Olimón.

member households. Another tool was an agricultural seasonal circular calendar that included all activities that families carry out for coffee production, milpa plot cultivation, and beekeeping, separated by productive activity. Through these tools, we initiated rich and useful discussions to assist decision-making on production issues at the household, community, and cooperative levels.

PRODECOOP, Nicaragua

Smallholders' Perspectives on Diversification and Food Sovereignty

In a series of interviews, PRODECOOP smallholders expressed why diversification is important to them. Most respondents (70%) mentioned that diversification practices help them increase agricultural output from their land. All of the certified organic farmers also reported that diversification practices have environmental benefits. Approximately 72% of these diversification activities began through farmers' own initiative, whereas 15% were linked to a project and 5% to cooperative membership.

Farmers also suggested that diversification activities can help improve their households' food security, save money on food purchases, improve soil fertility by using green manure, and reduce the risk of crop loss after environmental and economic livelihood shocks. Many of these elements also contribute to their sense of autonomy and food sovereignty. For example, as one farmer expressed:

> *"We faced the 2014 drought, which was tremendous, but we, the family farmers, managed it. We preserved soils and had diversified our crops.… [Although] the corn yields were very little, we could rely on the Musaceae [bananas and plantains], the root crops, we thus did not hinder the food part... On the farm, you are going to see the live barriers, and up to 3 or 4 crops, because [we] know how to associate well, in ways that do not compete for light (...). This Canavalia is sown as a cover crop for the summer period, then when the new sowing season starts, you cut it and leave it on the fields*" (Male Farmer).

This quote from a coffee producer, who also maintains a milpa plot, reveals their use of agroecological knowledge to establish and maintain intercropping systems, live fences, and cover crops.

The coffee smallholders of PRODECOOP also demonstrated a strong cultural and material attachment to milpa systems, perhaps with greater importance given to bean production. About half (56%) of the smallholders maintained milpa plots, and farmers prioritized self-consumption of both corn and beans. Corn was primarily consumed within the household, as only 11% of the surveyed smallholders reported selling it in 2017. Conversely 30% reported selling either the culturally preferred Nicaraguan red chili beans or the black beans, usually to external markets.

As illustrated in **Figure 3**, farmers also diversified the location of their plots, since many of these plots are spread across the landscape. One farmer explained the importance of arranging crops in ways that reduces the distance from their homes, allowing thus to invest more care and labor for agricultural activities.

> *"In the* first *place, [I decided to diversify in order] to have more crops closer to home. In the second place for taking more care of them - what we have nearby is easier to care for, because every day we are seeing them, and if they are far away, we cannot go visit the crops every day"* (Female farmer).

Linking Agrobiodiversity to Food Security, Dietary Diversity, and Land Access

The survey analysis found that across all PRODECOOP respondents some variables are correlated with household dietary diversity. Specifically, we found that on-farm crop diversity correlates with measures of household dietary diversity as measured by the weekly consumption of major food groups (coefficient $= 0.09$, $p < 0.001$). These findings suggest the importance of producing multiple crops for household consumption, although it is also likely that some of the crop diversity (e.g., citrus for sale) also contribute to income generation, which is in turn used to purchase more diverse foods. Furthermore, we have documented a strong relationship linking farm size (even slightly larger farms among these smallholders) and higher incomes to fewer lean months per household.

Positive Effects of Affiliation to PRODECOOP

Affiliation to PRODECOOP, as a cooperative union, generated benefits to member households such as technical assistance for organic coffee production and better coffee prices from sales to specialty, Fairtrade, and organic markets. PRODECOOP also used Fairtrade coffee roasters and development assistance organizations to channel aid to the smaller farmer cooperatives, helping them secure buildings, gain knowledge on agroecology, and establish community-based grain and seed banks. In the past 25 years, PRODECOOP has offered legal, technical, and political agency to help secure individual and collective land titles for affiliated cooperatives and smallholders. This was done within a challenging national neoliberal context and local preferences that often favored privately held property rights. PRODECOOP also has a history of female leadership in key staff positions (e.g., general manager, head of exports) and an innovative gender promotion program. This program prioritizes women's empowerment through training and support for human rights, women's economic development, reproductive health, youth leadership, and reducing violence against women.

DISCUSSION

Contribution of Diversification to Food Sovereignty

Below we offer an overview highlighting some key elements of the diversification practices adopted by households in each cooperative. In particular, **Table 3** summarizes the contributions and challenges that diversification offers for food sovereignty in each of the study sites.

In the Mexico case study, our monthly survey, observations, and collective reflections suggest that the lean months reported by households affiliated with CESMACH do not always reflect a scarcity of food, but rather a change in diet. In other words, there is a reduction of regular availability of purchased food coming

TABLE 3 | Contributions and challenges to food sovereignty due to diversification practices.

CESMACH, Mexico	PRODECOOP, Nicaragua	Common elements
- Experience of lean months may reflect a change in diet	- Diversification practices are integral to agroecological farm management	- Farmers own relatively large parcels of land
- Cultural attachment and long-term engagement to a diversified farming system	- Diversification increases local resilience and reduces water stress	- Strong potential to achieve seed sovereignty
- Wild food perceived to be "food of the poor", rather than nutritious or healthy food	- Long-term engagement with diversification efforts, and women and youth capacity building	- Corn cultivation and beekeeping are two important income sources with cultural meaning
- Families struggle between engagement in the global coffee value chain and the achievement of food sovereignty	- Current PAR processes started in 2009	

from outside the communities. Yet, this does not necessarily imply that the quantity of food is lower than normal. In fact, the availability of wild and cultivated food during those lean months increases (see Section Smallholders' Motivations for Diversifying). As the facilitators' coordinator noted: "It is possible that during lean months, families are having even a healthier diet because they are consuming natural food that grows on their plots". In contrast, the use of these seasonal wild food resources is not common in Nicaragua.

There are complex complementarities between on-farm diversification and transformative agroecology for food sovereignty. On the one hand, previous analysis revealed that farmers combining coffee with milpa (traditional or simplified) reported fewer lean months than farmers without these two key activities, especially if they also practiced beekeeping (Anderzén et al., 2020). Farmer motivations appear as cultural values attached to the farming systems (e.g., for milpa), and in the prevalence and diversity of fruit trees in almost all of the households. In that regard, milpa is a traditional system that, beyond the ecological and nutritional complementarity between the species, is the foundation of the Mesoamerican diet and an expression of a historical process of biocultural co-evolution (Toledo and Barrera-Bassols, 2020). Motivations are rooted in the long-term linkages between farmers' livelihoods and the cultivation of milpa plots, as well as vegetables and poultry for self-consumption, healthier food, or enjoyment (see Section Smallholders' Motivations for Diversifying). This reflects the cultural attachments to certain diets that appear as resistance toward industrial food, However, it should be noted that one of the disputed areas in this regard is the perception of wild foods as "food of the poor" (as some participants described them during focus group discussions), rather than nutritious or healthy. Similar perceptions have been documented in other case studies showing that, although local food sources may be undervalued, it is not enough to replace traditional diets completely (Jenatton and Morales, 2020). All of these elements suggest that CESMACH member families cannot be reduced to agricultural micro-entrepreneurs, but rather have various other concerns that enrich how they are attaining their food sovereignty and reproducing their livelihoods.

In sum, on-farm diversification responds to a historical process for CESMACH member families. As Phase 1 surveys showed some diversification activities were the outcome of projects implemented from external institutions, while others were the continuation of traditional practices. This includes a relationship with coffee as a commodity[8] and engagement with external projects, which can sometimes be in tension with the strengthening of CESMACH governance. It is in this context that CESMACH member families play a political role moving between participation in the global coffee value chain and achieving food sovereignty.

In the Nicaraguan case study, although the process of achieving food sovereignty for PRODECOOP members still has some way to go, it has advanced significantly and benefited greatly from a long organizational process that goes beyond coffee production and commercialization (e.g., incorporation to the *Campesino-a-Campesino* program, and establishment of community based seed banks). In productive terms, rather than reducing diversification to "increasing the number of activities", it is closer to integral agroecological farm management (soil, agrobiodiversity, intercrops, live fences, cover crops), mimicking ecological processes inside the plot, and (potentially) at the landscape scale (see Section Food Sovereignty and Transformative Agroecology Elements). This is a major element that has increased the resilience of local households to severe water stress during seasons also characterized by high food insecurity (Bacon et al., 2021), which compromised local food sovereignty. According to the surveyed households some specific outcomes of this agroecological diversification are the increase of food security, diet diversity, and environmental benefits. This may be reflected on the fact that, overall, the respondents in the Nicaraguan site reported on average 1.6 lean months per year, which is lower than what has been reported in previous studies in the Mesoamerican region, including PRODECOOP (Caswell et al., 2012; Bacon et al., 2017). On the other hand, 2017 was considered a "good year" in terms of rainfall and harvests. Furthermore many of the households that were in the initial population identified for sampling have engaged in diversification activities, while their average total farm area is also slightly larger than those included in similar samples (Bacon et al., 2021). Additional potential explanations for the differences

[8]CESMACH's position within a global value chain makes it possible for farmers to contact international organizations that usually promote diversification activities.

seen here, include the longer term engagement of PRODECOOP with diversification efforts, when compared to the relatively recent efforts within CESMACH.

The food sovereignty achievements of PRODECOOP members reported in this work have been the outcome of a historical process that we can start to describe in 2009, with the beginning of the current PAR process, and in collaboration with key stakeholders such as the Asociación de Desarrollo Social de Nicaragua (ASDENIC) and the *Campesino-a-Campesino* program (Holt-Giménez, 2002). In terms of transformative agroecology, this process and collaboration have contributed to the political dimension, bringing awareness of structural and historical context, specifically documenting challenges and capacities in the cooperative (and its farmers), as well as collective decision making. Related to the environmental and productive dimensions, the process and collaborations yielded specific outcomes, such as seed banks and farmer experimentation approaches. Finally, regarding the food sovereignty dimension, PRODECOOP's strategy also included capacity-building and empowerment of women and youth, as well as the integration of investments into both larger regional cooperative-led grain (corn and bean) storage and re-distribution centers with connections to local centers.

There are complementarities and dynamic tensions in efforts to use PAR and agroecology to support on-farm diversification and advance a transformative agroecology that moves toward food sovereignty. This is especially the case with PRODECOOP, which is essentially a multi-service cooperative union that receives its primary revenue and global recognition through the production and export of Fairtrade coffee. PRODECOOP has not only helped affiliated farmers to produce and sell more coffee but also leveraged millions of US dollars in training and direct investment for diversification, promotion of gender equity, and more. In some cases, this work was also informed by PAR processes, which sought to advance diversification to improve farmer food sovereignty, but there are also dynamic tensions. For example, coffee funds pay cooperative staff salaries, maintain the functioning of the business, and provide access to credit. This could reduce the cooperative's interest to invest significant funds away from coffee.

As common elements for food sovereignty, previous research that focused on measuring food sovereignty in different geographical contexts and scales (Binimelis et al., 2014; Jones et al., 2015; Ruiz-Almeida and Rivera-Ferre, 2019; Hernández et al., 2020), agrees that indicators must be context-dependent and multidimensional. In this sense, our work, as developed through our PAR process, coincides with other food sovereignty assessments in terms of the general dimensions (e.g., traditional knowledge, local production and consumption, degree of famer autonomy *vs.* dependence), as well as specific indicators (e.g., food access, seed sovereignty, and the diversity and use of crops grown on the farms).

Land access is a key factor in attaining food sovereignty (La Vía Campesina, 1996; Sauer, 2020). In that regard, and as an outcome of historical processes in both countries, farmers at both sites own relatively large parcels of land (on average 8.7 ha and 5.7 ha per family in Mexico and Nicaragua, respectively) compared with other coffee areas in Mesoamerica. For instance, in the Los Altos region of Chiapas, Mexico the reported total amount of land per family was 1.0–3.2 ha (Pérez Pérez and Villafuerte Solís, 2019), while in western El Salvador it was between 0.7 and 3.7 ha per family (Méndez et al., 2010a). Thus, in terms of access to land, we consider that CESMACH and PRODECOOP member families have considerable potential to achieve food sovereignty.

Another common element is the potential to achieve seed sovereignty. In CESMACH, according to our observations, seed care has been carried through informal and small-scale processes, something that is reflected by several varieties at this site. Seed conservation seems to be pursued mainly by the elderly, while the youth are linked with the simplification of milpa systems and increased dependency on purchased food. In PRODECOOP, *in situ* seed conservation can support the achievement of seed sovereignty through training in seed conservation, PAR, and other techniques, as well as some validation of the technology for participatory breeding (Bacon, 2015). All these efforts have been made in collaboration with CAN.

The similarity among the smallholder families that experienced at least one lean month in both location (See **Table 2**), suggest that future work could prioritize the design of integrative food security and sovereignty strategies with those households reporting >3 lean months per year. In contrast, corn harvest implies a local and important food resource for those families that grow it. We also observed that beekeeping has the potential to become an important income source for some households, which may help alleviate seasonal food insecurity. However, the number of coffee smallholders that engage in beekeeping activities is relatively small (**Table 2**), while both the honey harvest and price vary from year to year (see also Anderzén et al., 2020).

Diversification activities in both study sites were mostly self-initiated (87% in Mexico and 72% in Nicaragua). Those activities imply the permanence of traditional activities, such as milpa, poultry, and fruit trees, three of the most relevant food production strategies. In terms of innovative activities at both sites, we found that beekeeping has the highest potential to strengthen food sovereignty. In Mexico, our findings suggest that families carrying out beekeeping and milpa, in addition to coffee, can generate higher income and experience fewer lean months. In Nicaragua, beekeeping was linked to a high dietary diversity score. This provides further evidence of the positive contributions of beekeeping to food security and rural livelihoods in the global south (Potts et al., 2016; Kassa Degu and Regasa Megerssa, 2020).

Contribution of Diversification to Transformative Agroecology and Food Sovereignty

The most important contribution of diversification to transformative agroecology is that it goes beyond the number of productive activities, and rather represents a broader strategy that incorporates and harmonizes ecological conditions, local/fair markets, and reproductive labor to achieve gender

equity and local governance (La Vía Campesina, 2015; Anderson et al., 2019; FAO, 2019; Gliessman, 2019; HLPE, 2019).

Evidence suggests that the combined effect of experiences, research, and dialogue has influenced many cooperatives and smallholder organizations in Mesoamerica to recognize the limits of depending on a single crop, which has in turn influenced them to diversify (Toledo, 1993; Bacon et al., 2005; OSALA (Observatorio de Soberanía Alimentaria y Agroecología), 2011). The processes of CESMACH and PRODECOOP outlined in Section Results represent examples of how the inclusion of diversification strategies has promoted transformative agroecology at the cooperative level. These organizations have chosen to invigorate and promote food sovereignty among its members, in part by having aligned political and social relations among its associates. In addition, the study cooperatives have strengthened their organizations by prioritizing the wellbeing of their members and investing in securing healthy and culturally appropriate food for members' households. Other cooperatives in the region have also used diversification as an approach toward achieving food sovereignty and transformative agroecology. For instance, the Mexican Cooperatives Union Tosepan[9] is currently working toward achieving food and cultural sovereignty, based on diversification activities that include coffee, pepper, and honey, within landscapes that contain more than 200 useful species (Toledo, 2005).

The multiple on-farm activities observed among the member smallholders were found to depart, to some degree, from practices maintained over generations. This suggests transformative and multidimensional potential of these strategies by directly supporting food sovereignty. Such examples include covering basic needs (e.g., overcoming months of food insecurity), building seed sovereignty, questioning the control and governance of the global coffee value chain (or specific dependencies), and caring for local identities. Seen this way, diversification practices can represent a concrete expression of a transformative agroecology, driven mainly by the people themselves, but also facilitated to further its potential by the cooperatives, and supported by the PAR process and associated allies. This has been documented in other similar processes (see Mier y Terán Giménez Cacho et al., 2018; Hernández et al., 2020).

PAR Contributions to Diversification as Part of Transformative Agroecology

Drawing on the strong organizational structure of the study cooperatives, the use of agroecology and PAR helped to involve the cooperative leadership and youth on work related to learning activities, diversification practices, and in some cases, food sovereignty. These concepts also resonated with smallholder households as expressed in workshops and interviews. It is worth noting that the cooperatives we collaborated with during this 4-year project are in different moments in their journey of achieving food sovereignty and engaging in PAR processes. On the one hand, CESMACH is in an early-stage of this journey and our research showed how, as part of the PAR process, investing in facilitators' capacity-building and farmer pedagogies (e.g., popular education tools, facilitator-led focus groups) was the best way to scale transformative agroecology practices and awareness. On the other hand, PRODECOOP, was at an advanced stage of this journey with more than a decade-long engagement. Our research showed in this case how PAR and capacity building following farmer pedagogies, can generate tangible outcomes with direct positive impacts on food sovereignty (e.g., seed banks, reduction of lean months experienced).

Overall, we see the value of PAR in the transformative agroecology process mainly in two aspects. First, it generates inputs and evidence for the collective acknowledgment of vulnerabilities (e.g., lean months, high consumption of industrial food) and leverage points (e.g., traditional knowledge, edible wild food) to move toward food sovereignty. Second, the established collaborations can act to catalyze other important processes (e.g., capacity building, *campesino-a-campesino* networks), as well as to amplify farmer voices (Bacon, 2010).

A pervasive challenge for PAR and agroecology is how to maintain such processes in the long-term, including how (and in what role) do the external actors stay involved (Méndez et al., 2017). This is a key question that the research teams examine as they continues working with the cooperatives beyond the project reported in this paper. From a research perspective, the critiques of PAR point to it as being expensive, taking too much time, and not yielding sufficient academic outcomes (e.g., peer-reviewed publications). Our experience informs us otherwise, suggesting that more effort needs to be invested to attain a more intentional and detailed documentation of finances and outcomes in these long-term processes. Keeping track of ecological and social processes requires time, and we are working on incorporating the use of agroecological principles in forthcoming work exploring the possibility of better integrating them into PAR processes (Caswell et al., 2021), with the objective of generating both scholarly and practical outcomes.

Obstacles and Opportunities of Diversification as Part of Food Sovereignty Efforts

The realities faced by smallholders are deeply complex and dynamic, and the path toward food sovereignty is highly site-specific. This makes it hard to identify obstacles or opportunities that are universally applicable across smallholder contexts. Moreover, historically, farming communities have shown their potential of turning obstacles into opportunities in diverse ways. However, the bigger challenge for food sovereignty, in the context of smallholder coffee cooperatives, is linked to the high profitability of coffee, as most households prioritize coffee production over other agricultural activities (Vera et al., 2021). This specialization toward coffee production implies the diversion of land, labor, and time to generate coffee income. This creates some tensions with the archetypical tendency of smallholders toward self-provisioning (van der Ploeg, 2010), which aligns with food sovereignty. The high rates of purchased

[9]This group was constituted by Nahua and Totonaca Indigenous populations in 1977, has been supported by a group of scholars, and later received help from governmental and non-governmental organizations (Toledo, 2005; Tosepan, 2017).

food among surveyed households showed a dependency on external food suppliers, as a result of reducing the volume of self-produced food.

In addition, some particular aspects of smallholder coffee production, such as the high reliance on family labor and its gender dynamics, are some of the biggest challenges facing diversification in an agroecological transformative context (Machín Sosa et al., 2010; Jaffee, 2014; Bezner Kerr et al., 2019; Anderzén et al., 2020). However, we were not able to address these key issues with the necessary depth and complexity in this study, and this would thus require further attention in future studies.

In contrast, for these households, the biggest opportunity to reach food sovereignty is through the considerable size and quality of their available land. Such resources are "*the main defining elements of the peasant and include water, animals, and timber, among other resources heritable to the next generation*" (van der Ploeg, 2010: 3). Another important component of food sovereignty is the fact that the current diversification activities within "diversified farms" (i.e., traditional and culturally-relevant activities) and diversification (as novel activities) provide an opportunity to incorporate and mix new knowledge and skills with traditional ones. This is a key characteristic of transformative agroecology (Anderson et al., 2019). Farmers have maintained diversified production in both the Mexico and Nicaragua sites for generations, and the expansion of coffee production has been important in the emergence of agroecological diversification processes (Perfecto and Vandermeer, 2015). This accumulated local and indigenous knowledge is one of the reasons why most diversification initiatives arise from within the cooperatives, rather than from other development projects.

Another opportunity for achieving food sovereignty is the local attachment to traditional diets. This dietary preference contributes in multiple ways toward diversification that protects agrobiodiversity and native seeds, agroecological practices, and landscapes (Brush and Perales, 2007; Tamburini et al., 2020). Finally, and probably the most important opportunity to advance food sovereignty is leveraging the social fabric of both cooperatives. The development and joint implementation of collective strategies has been broadly recognized as a requirement for alternative and transformative projects (Mier y Terán Giménez Cacho et al., 2018; Anderson et al., 2019). In this sense the collective strategies coordinated under the two study coffee cooperatives have facilitated access to capacity-building, local empowerment (particularly for youth and women), and long-term alliances.

CONCLUSIONS

In this study, we viewed diversification practices in a transformative agroecology framework that focused on increasing its impact on food sovereignty. Along these lines, maintaining and increasing agrobiodiversity is an important diversification strategy, and a key component of achieving food sovereignty at the household level. This is linked to the high ecological complexity found in coffee plots, milpa plots, home gardens, and the broader landscape.

We observe that both study cooperatives in Mexico and Nicaragua are on a transformative agroecology pathway by using diversification to achieve food sovereignty. However, this represents a long-term process that requires constant adaptation. In our experience, a key element for the development of this process is smallholders' knowledge and learning exchanges between households and cooperatives. Through the 4-year project summarized in this paper we have witnessed various experiences that confirm other findings in the literature, including the relevance of food and seed banks, and the importance of ecological complexity and productivity of other crops within coffee plots. However, in accordance with the idea that there are no universally-applied recipes in agroecology, but rather there are guiding agroecological and PAR principles, our most important lesson for the cooperatives is to invest in the knowledge and capacity-building of their members These are, in a way, seeds within the organizations that support their internal potential to find their own ways toward transformative agroecology. Finally, scholars that embrace a PAR approach, as we do, can contribute as allies toward the generation of relevant knowledge that is useful to support the collective decisions of smallholders.

DATA AVAILABILITY STATEMENT

All relevant data is contained within the article. The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Boards at University of Vermont and Santa Clara University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AG and CB: conceptualization, methodology, investigation, validation, formal analysis, writing—original draft, and writing—review and editing. VM: conceptualization, methodology, investigation, formal analysis, and writing—review and editing. MF: methodology, investigation, validation, formal analysis, and writing—original draft. JA: methodology, investigation, validation, formal analysis, writing—original draft, review. MM: formal analysis, writing—original draft, and review. RH, MR, HD, and ÁB: methodology, investigation, and validation and writing—review. All authors contributed to the article and approved the submitted version.

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Food systems transformations in South America: Insights from a transdisciplinary process rooted in Uruguay

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The wicked nature of sustainability challenges facing food systems demands intentional and synergistic actions at multiple scales and sectors. The Southern Cone of Latin America, with its historical legacy of "feeding the world," presents interesting opportunities for generating insights into potential trajectories and processes for food system transformation. To foster such changes would require the development of collective understanding and agency to effectively realize purposeful and well-informed action toward desirable and sustainable food futures. This in turn demands the transdisciplinary engagement of academia, the private sector, government/policy-makers, community groups, and other institutions, as well as the broader society as food consumers. While the need for contextualized knowledge, priorities and definitions of what sustainable food systems change means is recognized, there is limited literature reporting these differences and critically reflecting on the role of knowledge brokers in knowledge co-production processes. The political nature of these issues requires arenas for dialogue and learning that are cross-sectoral and transcend knowledge generation. This paper presents a case study developed by SARAS Institute, a bridging organization based in Uruguay. This international community of practice co-designed a 3-year multi-stakeholder transdisciplinary process entitled "Knowledges on the Table." We describe how the process was designed, structured, and facilitated around three phases, two analytical levels and through principles of knowledge co-production. The case study and its insights offer a model that could be useful to

inform similar processes led by transdisciplinary communities of practice or bridging institutions in the early stages of transformative work. In itself, it also represents a unique approach to generate a language of collaboration, dialogue, and imagination informed by design skills and methods. While this is part of a longer-term process toward capitalizing on still-unfolding insights and coalitions, we hope that this example helps inspire similar initiatives to imagine, support, and realize contextualized sustainable food system transformations.

KEYWORDS

transdisciplinary research, Latin America, bridging organization, sustainability transitions, knowledge co-production, community of practice

Introduction

Scholarly literature has firmly established the urgent need to transform our globalized food systems if society is to secure a sustainable future (Gordon et al., 2017; Pereira et al., 2020; Dengerink et al., 2021; Hebinck et al., 2021). The dynamics and practices that compound food systems are at the core of many crucial issues, including justice, health, poverty, climate change, land use change, loss of biological and cultural diversity, development and human wellbeing (Foley et al., 2005; Whitmee et al., 2015; Lartey et al., 2018; Leach et al., 2018; Rockström et al., 2020). However, while these dynamics significantly connect the local to the global in multiple and intricate ways, transitional processes will likely adopt different orientations and strategies depending on the context-specific needs and priorities, or the network of actors that define them (Dengerink et al., 2021).

For the purpose of this paper we understand transformations as ethico-political (Scoones et al., 2020; Merçon, 2021) and social-learning processes that transcend scientific domains, disciplines, or siloed sectors (e.g., government). This requires understanding, mobilization of collective imagination and purposeful action in processes that need to be transdisciplinary (Pohl and Hadorn, 2007; Fazey et al., 2020; Norström et al., 2020). Many definitions and terms are used to refer to this type of problem-driven, action- and often solution-oriented research. Some examples include post-normal science, type-2, participatory action-research, co-design, knowledge co-production, and transdisciplinarity (Pohl and Hadorn, 2007; Lang et al., 2012; OECD, 2020; Chambers et al., 2021).

An emergent transformational approach (Anderson and McLachlan, 2016) in sustainability science (Miller et al., 2011) has surpassed the so-called knowledge deficit assumption (Howarth et al., 2022; Matsumoto et al., 2022). It posits the need for moving from knowledge to action in ways that engage the different voices and needs at stake (Grunwald, 2004; Tengö et al., 2014; Pereira et al., 2019). While different understandings of transdisciplinarity exist (Cundill et al., 2015), they most generally imply an improved agency and capacities for action in two ways. First, through the collaboration of participants from different sectors and levels of society (e.g., community organizations, government, industry), aimed at integrating diverse knowledge systems (e.g., modern science, traditional/indigenous knowledge) and generate mutual learning to address locally relevant problems. Secondly, *via* the role that knowledge brokers (often researchers) play in starting or supporting such change processes, known as doing boundary crossing work (Hefetz and Ben-Zvi, 2020). Research institutions labeled as "bridging organizations" play a key role (Hahn et al., 2006) expanding the science-policy interface to allow for improved cross-sector, multi-level collaboration (Folke et al., 2005; Kowalski and Jenkins, 2015). These "arenas" for dialogue can be initiated bottom-up, top-down or from research institutes or other non-governmental organizations, and imply a concerted and directed effort at enabling learning and collaboration for solving socio-ecological problems (Hahn et al., 2006). Similarly, groups not necessarily anchored in a single institution form communities of practice (CoPs; Wenger, 1999) to advance knowledge, methods, tools, and practices in relation to a common interest or need. Such initiatives can create "social learning" platforms (Bergmann et al., 2021) that engage a multiplicity of participants concerned with particular issues to exchange and experiment in advancing solutions. Examples of CoPs abound in educational settings (Tseng and Kuo, 2014; Hernández-Soto et al., 2020; Merçon, 2021) where background areas (disciplines) and perspectives share affinities. However, there is an emerging interest in the role that such CoPs play in transdisciplinary processes addressing socio-ecological issues, especially in confronting the challenge of engaging very different domains (e.g., academic disciplines or sectors) and those "less interested" actors (Cundill et al., 2015; Bergmann et al., 2021; Matsumoto et al., 2022). CoPs tend to be cross-scalar and be structured broadly in three main levels (Wenger et al., 2002; Mavri et al., 2021) that range from a core group with active layers of different engagement and a periphery which may involve outside actors that are less interested or willing

to engage (e.g., industry, political actors; Cundill et al., 2015). Transdisciplinary projects (Walter et al., 2007) are successful in fostering positive social and ecological change when they can connect knowledge and understanding (system knowledge) to desired goals (target knowledge) and also advance the practical ways to realize them (transformative knowledge; Pohl and Hadorn, 2007).

The types of sustainability transformations that food systems need would require systemic and integrative perspectives (van Bers et al., 2019) that transcend traditional disciplinary and sectoral compartmentalization. This work is resource intensive and demands specific leadership and mediation skills (Hahn et al., 2006; Howarth et al., 2022). Beyond the ecological/environmental aspects, food systems' social dimensions include cultural and political characteristics that further complicate their sustainable transformation. Actors in food systems have different values, interests, and needs (often felt or expressed at a visceral and affective level), making the mere identification of problems, actions and outcomes impossible to objectively pin down. In a recent review of the literature, Weber et al. (2020) highlight the value-laden motivation of any type of proposal for change for sustainable food systems (e.g., a focus on sustainable diets/health or on alternative food movements). This confirms how little agreement exists around *how* to define and achieve sustainable food system outcomes (Stefanovic et al., 2020) especially since context becomes a key dependent variable. For example, van Bers et al. (2019) argues that the historical and current governance arrangements of a particular place determines its possibilities for food system governance change. Dengerink et al. (2021) further confirm that strategies and priorities for policy change vary by region and require understanding the local needs and perspectives, and what this means within a landscape of complex local and global dynamics (Caron et al., 2018).

Living Labs (Bergmann et al., 2021), for example, have offered evidence that place-based platforms for joint dialogue, experimentation, and learning offer more meaningful, appropriate and locally relevant outcomes. There are some similar, albeit limited, experiences for food system-focused experiences of situated co-production processes. For example, a recent study by Adelle et al. (2021) rooted in South Africa adopted a collaborative research effort by conforming a transdisciplinary community of practice (TDCoP). This case confirms there is no one-size-fits-all in food system transformations and that this type of transformative social learning environment offers potential to facilitate sustainability transformations. Thus, attention needs to be paid to how they are created and nurtured, and particularly on how to keep these processes open to newcomers, integrate creativity and insights from academic fields such as the arts, as well as to manage power differences. Few empirical studies of co-production exist in the literature that particularly reflect on the process and their outcomes (Oliver et al., 2019) pointing to a need for a larger pool of cases.

This article aims to fill this gap by reporting and analyzing the process and outcomes of a transdisciplinary project led by the South American Institute for Resilience and Sustainability Studies (SARAS) Institute. We start by introducing and contextualizing our case study, presenting the methodology and process design and development as well as its results. We then discuss the main outcomes and insights drawn, focusing especially on the type of transdisciplinary model and outputs produced while reflecting on the limitations and challenges encountered.

Methodology

Research approach

The research presented here constitutes a descriptive case study (Yin, 2003) of a transdisciplinary process developed by a CoP hosted by SARAS, an interdisciplinary research institute. The transdisciplinary process was rooted in Latin America's Southern Cone region, with Uruguay as the main context (Section Case study: Food system transformation in Uruguay). The research focuses on highlighting the nature of the process (the how) and the types of outcomes and insights produced spanning for over 3 years between preparation, development and outcomes (see Juri, 2021; see Section Design and implementation of the transdisciplinary process for more details). Two of the 3 years coincided with the COVID-19 pandemic which meant that most of the work was constrained to online virtual environments and interactions.

Central to the transdisciplinary process outlined in this paper is SARAS, an interdisciplinary research institute which, for nearly 15 years, has focused on the production of knowledge and insights to help enable sustainable futures in the broader region (Scheffer and Mazzeo, 2019; Calderón-Contreras et al., 2022). Understood as a bridging organization (Folke et al., 2005; Kowalski and Jenkins, 2015), SARAS has essentially been a platform that integrates diverse approaches to enhance resilience and facilitate transformation, especially attempting to expand the science-policy interface in the Uruguayan context (where its headquarters are located). SARAS also constitutes an international CoP that emerged of the conviction that achieving sustainable futures would require new and innovative ways of thinking and acting. To that end it has built a collaborative network that currently includes academics, civil servants at the National Institute of Agricultural Research (INIA, a public institution informing national policies), several ministries and municipal governments, various local commissions, media (e.g., radio, local press), agricultural producers' organizations, and civil society groups, to name a few. Over the years, SARAS

emerged as a trustworthy and legitimate stakeholder, and a well-known reference for dialogue on sustainability and transdisciplinarity in Uruguay. Without this long trust-building effort, it would have been very difficult, if not impossible, to identify and connect with all the actors that later became involved in this transdisciplinary process.

The main activities and outputs reported in this paper took place from 2019 to 2021. These include a collective participatory process known as the "Thematic Cycle on Food and Sustainability" which was part of the SARAS Public Conferences Series[1] This process essentially started in 2018, when a small group of researchers and artists prepared a proposal on how to approach the broad theme of "Food and Sustainability" and leverage the expertize within the network. The proposal outlined an initial 2-year and two-stage participatory process. First, an important feature of the configuration and the process was the fact that participation was based on interest or experience in the topic, which created a CoP within this existing wider network. Second, only limited funding was available, which meant that financial compensation was not a motive for engaging in this transdisciplinary process (i.e., the work was mostly voluntary). The core group members were either already working in similar areas or found ways to connect this work to their funded roles in other institutions (e.g., two PhD students connected this process to their research). The first Cycle activity in 2019 consolidated an Organizing Group that included 11 senior and early career researchers from the fields of: Economic History, Visual Arts, Literature, Ecology, Natural Resources and Environmental Management, Sustainability Science, Biology, Design, Agronomy, and Biophysics. This group later received technical support through three funded roles in communication, graphic design, and project management. The final team converged the necessary knowledge and skills to catalyze and steer an emergent transdisciplinary process by bridging multiple boundaries (Corkal and Sauchyn, 2018; Gustafsson and Lidskog, 2018), organizing and facilitating actual and online events, and communicating and disseminating its products.

As a whole, this cycle at SARAS sought to foster the participation and dialogue of diverse actors and knowledge systems through collective generative modes (co-production). It also sought to achieve a multidirectional/cross-scalar mobilization of knowledge (Anderson and McLachlan, 2016) rather than expert-led unidirectional knowledge transfer. Theoretically and methodologically, the process was informed by multiple system-based approaches thus adopting methods, theories, and concepts from Resilience Thinking (Biggs et al., 2015), Sustainability Transitions (Loorbach et al., 2017), and Sustainability transformations (Pathways Network, 2021).

Our approach is essentially the result of the hybridization of the knowledge and practices of the members of SARAS CoP (Hefetz and Ben-Zvi, 2020), which involved researchers and artists. The design and facilitation of most of the transdisciplinary process followed the concept of Transition Design (Irwin, 2015; Zurbriggen and Juri, 2021), which leverages capacities and methods spanning design thinking and doing (Dorst and Cross, 2001; Sydelko et al., 2021).By adopting this design-informed approach (Irwin, 2015), our transdisciplinary process aimed at enhancing knowledge integration and mobilization, collaboration, collective learning, experimentation, and creativity while building capacities for action. Transition Design adopts a plurality of analytic, synthetic, and generative/creative methods to serve different purposes along the transdisciplinary process (from problem scoping to dissemination or creating actionable knowledge). For example, this process included co-creation and problem-scoping workshops that sought to outline the problem space and identify local needs and opportunities for action. Arts-based methods such as collage were used to spark collective imagination, creativity, and sense-making, while challenging the status-quo. Visioning and future-search activities including backcasting (Dreborg, 1996) were used to explore change trajectories and the actions and sectors (i.e., types of change) that needed to be activated. Finally, we generated a Theory of Change (van Es et al., 2015) in the early stages to help define a collective vision for the transdisciplinary process itself, discuss participants' assumptions and reach consensus on the types of outcomes and impacts sought by the Cycle. The main participatory activities fall under the broad category of facilitated dialogues (Drimie et al., 2021), a range of flexible methods that can be applicable to different contexts for creating "safe enough" spaces for learning and experimentation.

Finally, we adopted a Multiple Evidence-based Methods approach (Tengö et al., 2014). This was essential for creating an enriched picture of the problem and solution space, while engaging not just academics but also actors from community and local initiatives. This way, local and scientific knowledge systems could be equally valued and leveraged to contribute to knowledge, while allowing their own modes and different expressive media. Pluralistic approaches like these also aim to uphold different knowledge types (explicit, tacit) and transcend the art-science divide (Halpern, 2012; Scheffer et al., 2015). The complementarity and richness resulting from this type of assemblage can thus enable the generation of new insights and more creative innovations.

The projects that were developed within the Cycle further adopted various quantitative and qualitative methods including interviews, expert consultation/Delphi methodology, audiovisuals, and mappings/systematizations (see Section Design and implementation of the transdisciplinary process for

1 SARAS Public Conferences are a series of open events attempting to bridge knowledge and practice, while integrating voices from academia, decision-makers, and the general public, among others. Refer to: http://saras-institute.org/thematic-cicle-food-and-sistainability/.

more details). Two evaluation and assessment strategies were adopted at the end of the process: a reflexive core-team meeting and an online survey distributed among the Cycle's participants.

Case study: Food system transformation in Uruguay

This work is focused on the context of Latin America, a region with outstanding natural diversity, as well as major significance for global food systems both historically and currently[2] (Baraibar Norberg, 2020). The export bonanza of the first globalization wave (1860–1914) caused unprecedented land conversion and natural resource exploitation, while at the same time exacerbated inequalities in access to natural resources (Baraibar Norberg, 2020). In the last three decades, Latin America has become the largest net food exporting region in the world (Zeigler and Nakata, 2014). Importantly, food production (especially for exports) has been identified as the cause of the largest environmental impacts in the region[3]. Notwithstanding some country-specific variation, the agricultural production structures across the continent remain largely specialized on a few commodities such as beef, sugarcane, or soy. Such simplified agricultural systems often expand in carbon and biodiversity hotspots at a dramatic pace (Graesser et al., 2015) leading to one of the highest rates of biodiversity loss and ecosystem services degradation worldwide (Laterra et al., 2019).

Importantly, despite its wealth of natural resources, there is a critical lack of production models that are sustainable and equitably distribute its benefits. Currently, Latin America is the region of the world characterized by the highest inequalities (CEPAL and NU, 2021). At the same time, the quality of prevailing diets is quite low and there have been concerns about their broader effects to human wellbeing (FAO et al., 2021; IFPRI, 2021). For example, food security has been declining in parts of Latin America since 2014, with these patterns intensifying ever since (Rezende Machado de Sousa et al., 2019), especially on the aftermath of the COVID-19 pandemic (FAO et al., 2021)[4] Unequal access to food explains to some degree this prevalence of food insecurity (FAO et al., 2021). While the region is often referred to as the world's future breadbasket (Zeigler and Nakata, 2014) given the abundance of natural resources necessary for food production (OECD-FAO, 2021), food security improvements in the next 20–30 years would depend on crop expansion (Delzeit et al., 2017; Zabel et al., 2019). This would most likely create further conflicts of interest (OECD-FAO, 2021) and clearly shows the highly complex and multifaceted sustainability issues that underlie food systems in the region (Wigboldus, 2020). Tackling this complexity requires systems-based approaches that can consider and integrate marginal actors and embrace both local and global dynamics, while at the same time having the ability to focus on concrete and contextual circumstances (Eakin et al., 2017; Caron et al., 2018; Anderson et al., 2019; Dengerink et al., 2021; Hebinck et al., 2021).

Uruguay offers an interesting case study in this context, as it shares many of the social and environmental challenges and risks outlined above. Today, Uruguay has some of the largest tracts of native grasslands and grass-fed beef production systems (Table 1), which is seen as a competitive advantage for reducing greenhouse gas emissions from beef production, a food item that is increasingly identified as highly unsustainable at the global level (MVOTMA, 2019). The rapid expansion of crop cultivation (Baraibar Norberg, 2020) over the last 20 years involved a re-primarization of Uruguay's economy, which focused on a few agricultural commodities that presently comprise 82% of export goods in terms of economic value (UruguayXXI, 2020)[5]. While Uruguay's productive capacity could feed an estimated 30–60 million people (Gómez Perazzoli, 2019; i.e., 10–20 times the local population) there is still prevalence of malnutrition and food insecurity[6]. This is aligned with regional trends (FAO et al., 2021; Arrieta et al., 2022) and represents a significant contradiction for a net-food exporting region.

Uruguay has shown a commitment toward improving environmental management in its National Environmental Plan (MVOTMA, 2019) and the latest dietary guidelines (Moratorio and Bove, 2016). However, progress is slow and there is a lack of transversal and participatory processes in the thematic area of food, compared to other thematic areas such as climate

2 Latin America contains 60% of the world's biodiversity (UNEP-WCMC, 2016) and houses very diverse cultures. Importantly, it also inherits wounds caused by colonization that have both shaped and have been shaped by global change linked to food (e.g., slavery for sugar plantations).

3 For example, according to FAOSTAT (2022), in 2020 >50% of the entire soybean production was exported.

4 The number of people experiencing hunger in South America increased by 36% between 2019 and 2020 alone (FAO et al., 2021).

5 At least three quarters of the area under agricultural and livestock production caters for exports and the rest the domestic market (see Table 1). Commodities such as frozen bovine meat, soybeans, concentrated milk, and rice comprise 82% of Uruguay's export goods mainly for markets such as China, Brazil, Netherlands, United States, and Argentina.

6 The prevalence of overweight and obesity are particularly high, above global averages and increasing. Overweight and obesity prevalence in 2013 was 65% for adults 25+ and 10.5% for children under 5; "Diagnóstico de la Situación alimentaria y nutricional," (2016). Diet-related diseases and other lifestyle habits contributing to NCDs are the major national public health issue, accounting for about 85% of deaths ("Mortalidad Por Enfermedades No Transmisibles, Uruguay" 2019, Medina et al., 2020).

TABLE 1 Main features of Uruguay's past and present in relation to food systems/agriculture (a), including details on main commodity chains (b).

(A) Uruguay's characterization—main features

Population and area	3,387,605 people (92.5% in urban areas)–176,215 km^2 (second-smallest South American country).
Location	Southern South America (Southern Cone), bordering the South Atlantic Ocean, between Argentina and Brazil.
History and migration	Colonized by Europeans (seventeenth century). Independence reached in early nineteenth century. Livestock production and concentration existent since colonial times. No settler-type development path during European migration wave-early twentieth century. Soil considered not prime for agriculture, land already in the hands of big ranchers (little use of labor, capital, technology).
Economy	Free market economy characterized by an export-oriented agricultural sector (member of Mercosur). Re-primarization of the economy in the last 20 years (agricultural commodities).
Natural resources (production)	Arable land, followed by hydropower, minor minerals, fisheries. Territory covered by native humid temperate grasslands. Majority of farmlands dedicated to beef production. Rapid expansion of cultivation in the last few decades.
Commodities	Agricultural commodities comprise 82% of export goods (UruguayXXI, 2020).
Exports	Top commodity exports: Sulfate Chemical Woodpulp ($1.57 B), Frozen Bovine Meat ($1.51 B), Soybeans ($675 M), Concentrated Milk ($457 M), and Rice ($380 M) (see below). Export destinations: China, Brazil, Netherlands, United States, and Argentina. At least three quarters of the land is destined for export, the rest for the domestic market.

(B) Main productive chains detail*

Supply chain	Area (thousands of Ha)	Exports (approx. %)	Level of concentration of production	Level of concentration of commercialization	Last decade trend
Fruits and horticulture	61	9	Low	Low	Area retraction, slight production rise
Meat (mainly beef)	12,000	85	Low	Intermediate	Area retraction, slight production rise
Dairy	602	70	Low	High	Stable area, Intermediate production rise
Grains	1,156	85	Intermediate	High	Great area and production expansion
Forestry (mainly pulp)	1,140	80	High	High	Great area and production expansion
Beekeeping	N/C	35	Low	Low	Great area and production expansion
Rice	145	75	Low	High	Stable area and production

*This table indicates the total area occupied in 2019, the estimated fraction exported, the level of concentration of production and marketing/industrialization, as well as the trend in area and volume produced observed in the last decade. Data were obtained from the FAOSTAT platform (crop area) and from INALE (milk production). The livestock area was obtained by difference with respect to the total area of the country. Trends were obtained from FAOSTAT production data. Export fractions were obtained by comparing the volume produced according to FAOSTAT and exports according to ResourceTrade.Earth of Chatham House (United Kingdom). Concentration levels reflect a qualitative scale obtained from the literature describing production systems and the Uruguay XXI index of exporting companies.

change or water management. In addition, consumers do not understand well some of the dimensions of sustainability in relation to food (see Ferro et al., 2022 for an example on food waste). For example, the positive and negative sustainability impacts of beef production and consumption are ambiguous given the contrasting narratives that co-exist and interact with long-held preferences and cultural traditions (Laborde, 2017; Arrieta et al., 2022). Until SARAS Cycle, and before the visibility of activities such as the UN Food Systems Summit Dialogues[7], Uruguay presented a lack of arenas for debate and dialogue in the topic and complexities of food system sustainability. In particular, and as reported by other scholars,

7 As part of the global agenda of activities belonging to the UN Food Systems Summit, Uruguay organized an official country dialogue which was convened by the nation's vice-president during June 2021 (see more at https://summitdialogues.org/country/uruguay/).

the compartmentalized nature of public institutions as well as knowledge generation platforms (University's disciplinary silos) continuously limits the systemic and integrative engagement that food systems require. In this context, the collective behind this work saw an opportunity to develop a platform for enhancing understanding and motivating action, while exploring the trade-offs, nuances, challenges, and opportunities that currently exist in the region, and how these could shape local and global food system transformations.

Design and implementation of the transdisciplinary process

General overview of the transdisciplinary process

SARAS' IX Public Conference process particularly aimed at facilitating cross-sectoral dialogues among local actors and sectors not well-connected on the topic of food and sustainability. This included academics from different domains, government, civil society organizations, and the agriculture, industry and service sectors. Such dialogues can become a precursor of institutional and social change for systemic transformation (Drimie et al., 2021). To achieve this, the Organizing Group adopted a transdisciplinary approach stressing the engagement of diverse actors with the aim of approaching commonly defined problems (OECD, 2020) and addressing local needs or gaps in knowledge.

Being particularly interested in sharing and advancing knowledge and skills, the group chose to adopt the encompassing term of knowledge co-production and four of its main principles as defined and characterized by Norström et al. (2020)[8]. In this sense the SARAS Cycle was designed to be: (a) context-based (anchored in Uruguay's reality); (b) pluralistic (multiple knowledge systems and perspectives); (c) goal-oriented (purposefully and collectively planned toward impact); and (d) interactive (*via* frequent iterations of engagement and dialogue). The goals set by the organizing group ranged from identifying contrasting local wants, needs, and barriers to the generation of new dialogues and alliances while, at the same time, developing novel knowledge, and creative practices to address complex problems.

Therefore, a multi-stakeholder process (Brouwer et al., 2015) was outlined to begin with a problem-scoping/co-design in-person workshop that would determine how the process should unfold during its second phase. The goal was to

8 The term co-production loosely encapsulates a series of participatory and transdisciplinary research approaches that have emerged in the past four decades. These include mode 2 science, interactive research, civic science, post-normal science, transdisciplinary and joint knowledge production, action research, among others (see Section Introduction).

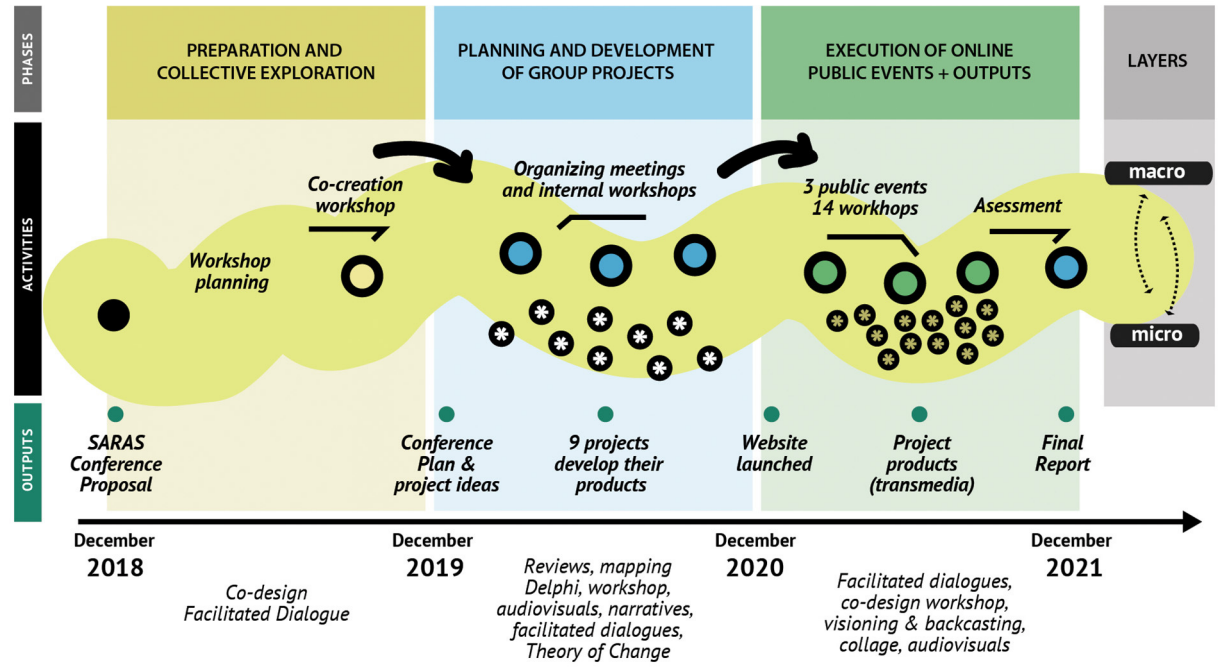

FIGURE 1
Visual outline of the evolution of the process and its phases between 2018 and 2021. This graphic shows the activities, outputs, and methods (below) adopted. It also highlights the two analytical layers used (macro and micro).

TABLE 2 Breakdown of SARAS cycle phases: We display the processes, activities, type of participants engaged, and main outcomes produced.

Processes	Activities	Participants	Outcomes
Phase 1: March 2018–December 2019			
Preparation	Group meetings to develop a preliminary proposal to approach Food and Sustainability as a Theme for the following SARAS Public Conference.	SARAS members, core team of organizers.	Cycle preliminary proposal presented to SARAS Advisory Board and approved.
Initial planning (internal)	Initial Organizing Group proposes and design workshop plan and contents.	SARAS members, core team of organizers.	Workshop Plan, structure, and materials.
Collective understanding /Exploration	Participatory workshop to explore understanding, challenges, and opportunities.	SARAS members, RESACA Network, guests by invitation (NGOs, producers, chefs...).	Dialogue and synthesis of main insights. Ideation of a main open event and potential activities. Networking.
Phase 2: February 2020–December 2020			
Planning of public cycle	Reconfiguration of Organizing Group. Project/cycle definition and goal setting.	SARAS Organizing Group.	Project outline document and plan.
Generation and development of cycle projects	Definition of series of projects and funding for those.	SARAS Organizing Group. Project leaders.	Project proposals & funding. New alliances formed within projects (transdisciplinary work).
Synergizing of projects and learning	Regular Organizing Group meetings. 3 Internal workshops: 2 to share progress and enhance collaboration, 1 to define ToC.	SARAS Organizing Group. Project participants (transdisciplinary).	Meeting notes (internal communication). Workshop synthesis, videos and Theory of Change document.
Phase 3: January 2021–December 2021			
Anchoring/dialogical platform	Developing of website for the project.	SARAS Organizing Group.	Website development. Text, graphic and video contents.
Knowledge co-production and debate	Planning and development of 3 virtual events (March, June, October) Webinars and workshops. Dialogue, synthesis, and integration of new perspectives: website contents, videos.	SARAS Organizing Group. Project participants. Open events (general public, free registration, diverse audience).	Virtual events. Video recordings. Workshop video and written summaries. Video interviews.
Closure of the cycle and outcomes	Organizing Group closing meetings and assessment (including survey). Collective reflection—writing of academic paper. Systematization and synthesis. Dissemination of project results and products. Development of Report.	SARAS Organizing Group.	Survey results analysis. Cycle Report. Website updates. Project products or outcomes dissemination. Promotional video. Academic paper.

engage Uruguayan stakeholders such as policymakers, civil society organizations, food producers, the service sector (chefs), together with scientists, artists and the general public (often in their roles as consumers). This transdisciplinary process eventually evolved over time and unfolded in different layers and phases, which meant that a diversity of modes of knowledge co-production co-existed (Chambers et al., 2021). Retrospectively, however, the process can be analyzed over three main phases: (a) preparation and collective exploration; (b) planning and project development; and (c) public events, dissemination, and outputs. We describe these phases in detail below. Figure 1 provides an overview and timeline of this process, and Table 2 an overview of its main stages.

While the process was envisioned and designed as a whole, it included several activities, smaller projects and perspectives which constituted a rich and adaptive constellation. For the purpose of analysis, it can be conceptualized as comprising two interactive layers. First, the macro layer consisted of the Organizing Group, the main public events and workshops, and the overarching outcomes and products (see Figure 1). Secondly, the micro layer consists of a series of projects which included a series of sub-groups of participants and the products developed by them. The two layers continually interacted and informed each other to offer insights, align goals, and co-define the overall process' outcomes. Projects were given freedom to develop and explore different facets or topics within the entanglement of identified issues related to food systems. This led to further integration of new and diverse actors and the adoption of different methodologies and epistemologies to suit their needs. Overall, nine projects were carried out, representing a significant part of how knowledge co-production evolved. All projects sought to enhance understanding and mobilize knowledge[9] and actors in multiple ways while focused on developing concrete products. These often resulted in tools to aid dialogue, learning, dissemination, and communication. Table 3 provides a more detailed overview of each project, including their processes, approaches, and outcomes.

The flexibility of an emergent process responsive to needs (instead of outlined from the onset or driven by strict project-based timelines) enabled adaptability when faced with disruptions, such as the COVID-19 pandemic. The two-layered nature, with various single projects and events, enabled approaching a series of complex food system issues from different angles by assembling necessary resources (e.g., funds, knowledge, actors) and skills anchored on the delivery of tangible outputs. This helped overcome the challenges of fund-scarcity and bridging knowledge domains. The individual projects were built around areas of interest and expertize and leveraged social bonds that existed within SARAS' network and with different local stakeholders (more details about individual topics are included in Table 3).

The Organizing Group was fundamental to the design and implementation of this transdisciplinary process. An early-career researcher (the first author) pursuing her PhD within the Transition Design approach played a leading role. This had implications on how the process and outputs were conceived, facilitated, and implemented. Firstly, by helping to coordinate efforts toward commonly defined goals, ensured the adoption and creation of tools and methods to integrate knowledge domains, while engaging non-academic actors, transcending expert-only-dialogues and fostering creative interactive formats. Secondly, to secure the development of communication/dissemination products, the synthesis of information and the materialization of the co-created knowledge into shareable outputs. Importantly, given that the process was steered mostly by researchers, epistemic hierarchies were undoubtedly at play. However, this was pivotal to sustain this type of collective endeavor, as well as to create a safe space for dialogue while connecting perspectives otherwise positioned as opponents or not valued as valid knowledge. This inherent difficulty in evaluating transdisciplinary processes has been pointed in the literature (Walter et al., 2007). While processes need to be open and flexible to allow for co-leadership of various actors (beyond academics), they also need a starting point from which meaningful collaboration can be enabled. This often requires the initial steering and supporting role of researchers. In transdisciplinary communities of practice, researchers play an important role during the early stages (Matsumoto et al., 2022). Researchers and leaders often provide information, approaches or tools in their boundary crossing and interactive roles (between a diverse assemblage of stakeholders) that help build more autonomous capacities. Later they may shift to a position of support. Careful consideration of the different perspectives, knowledge systems and the types of evidence that count as legitimate or valuable is fundamental for any transdisciplinary coalition (Tengö et al., 2014; Norström et al., 2020). Here, design played this integrative and mediating role, helping cope with the layers of complexity that are added as different actors reconcile, integrate or open new epistemologies (Belcher et al., 2016).

First phase: Preparation and collective exploration (2018–2019)

The SARAS IX Public Conference proposal (2018) planned to develop a two-year cycle that would include a scoping workshop in 2019 and a public event in 2020. An initial participatory workshop aimed to enable a dialogue and generate an "enriched picture" of the problem (Tengö et al., 2014) to

9 By knowledge mobilization we mean a process that is not unidirectional but rather allows for knowledge to be created and bridged across knowledge hierarchies' dynamics (i.e., cognitive justice) with a particular attention to valorizing plural, non-academic knowledge in the process of allowing intentional social change (Anderson and McLachlan, 2016).

TABLE 3 Description of the 9 projects developed including members, topics and outcomes.

Project name	Topics covered	Co-production process	Actors engaged	Outcomes and products
Ambiente y Desarrollo hacia 100 relatos y 100 datos [Environment and Development: toward 100 stories + 100 facts]	Ideas of development, productive models, science and technology, innovation, national strategy, policy.	Mainly interdisciplinary, science-policy interface. Focus on exploring narratives and pathways, brokering power and navigating differences.	SARAS researchers + members from academia and other institutions (The Food and Agriculture Organization of the United Nations, National Council for Science and Technology Innovation-Uruguay).	Series of online seminars, discussion roundtables, and synthesis videos.
Cocinería Colectiva [Collective Cookery]	Sustainable food habits, emergent initiatives, bottom-up processes, innovation, transitions, action-research, systemic change, collective and reflexive learning.	Transdisciplinary Focus on empowering voices, navigating differences and reframing agency.	SARAS researchers and practitioners/students + representatives of emergent social-innovation initiatives.	Website mapping initiatives, online workshops/conversations, capacity building course. https://cocineriacolectiva.net/
COVID Foodways	Food practices (production and consumption), resistance, persistence and resilience, COVID-19 impacts, agroecology, collective bottom-up action, lived experiences.	Transdisciplinary Focus on navigating differences.	SARAS researchers and artists + participating individuals from around the world (multiple universities, social organizations and networks).	Videos, online workshops/conversations. https://saboreandosostenibilidad.net/2021/09/05/taller-impact-of-covid-19-on-food-systems-international-experiences-of-vulnerability-and-resilience/
Fluruguay Globalimentario	Trade flows, economic flows, material flows, global trade, agri-exports, value chains, commodities (beef, rice, soybean, forestry, fish), land-use change.	Interdisciplinary. Focus on synthesizing and visualizing information, navigating differences.	SARAS researchers, Ph.D. students connected to SARAS network.	Website (online tool with tables and visualizations), online workshop. https://saboreandosostenibilidad.net/proyectos/fluruguay-1/
Huella de un Plato [Footprint of a Dish]	Economic, ecological, and social footprints, sustainable diets, comparative of production models, traditional dish.	Inter and transdisciplinary. Focus on science communication, educational tool, locally-relevant indicators and framework. Researching solutions and brokering power.	SARAS researchers + academic institutions, local and regional networks and organizations.	Website and online tool (interactive video), online workshops. https://saboreandosostenibilidad.net/proyectos/huella-plato/
Book: "Identidad uruguaya en la cocina" ["Uruguayan identity in the kitchen"]	Local food culture and national identity, imaginaries and narratives, recipe books historiography.	Interdisciplinary Focus on science communication.	SARAS researchers.	Book. Edition and publication of PhD thesis in general audience book format.

(Continued)

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TABLE 3 (Continued)

Project name	Topics covered	Co-production process	Actors engaged	Outcomes and products
Saboreando cambios en la pesca artesanal: innovación, adaptación y transformación en la pesca artesanal en Uruguay [Savoring changes in artisanal fishing in Uruguay: innovation, adaptation and transformation].	Fisheries, artisanal (small-scale) fishing, circular economy, emergent initiatives, local development, resilience, lived experiences and stories, futures.	Transdisciplinary Focus on mapping of emergent initiatives (futures seeds), empowering voices, reframing agency.	SARAS researchers, external academic international collaborators + representatives of initiatives.	Website (online catalog), catalog of initiatives (publication), workshop, scientific paper and newspaper article. https://saboreandosostenibilidad.net/pesca/
Sobremesa podcast	Consumption practices, lived experiences, everyday dilemmas, humor, fictitious character.	Interdisciplinary Focus on relatable experiences, provocation, awareness, general-public engagement, arts integration.	SARAS network members.	Podcast series (audio shows) https://saboreandosostenibilidad.net/proyectos/sobremesa/
Sensibilización y experimentación en capacidades y competencias anticipatorias para expandir el diálogo sobre los futuros de la alimentación [Sensitization and experimentation in anticipatory skills and competencies to expand the dialogue on the futures of food]	Food futures, anticipatory capacities, imagination, collective creativity, food cultures, innovation, food waste, circular economy.	Inter and transdisciplinary. Focus on capacity development, collective dialogue and imagination. Navigating differences and reframing agency.	SARAS network members + local and international guests from academia, institutions, entrepreneurs, etc.	Online workshops and roundtables on different topics. https://saboreandosostenibilidad.net/2021/10/08/taller-alimentos-y-futurosque-cambiamos-exploramos-mundos-posibles/

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set priorities for investigation and action rooted in Uruguay. The workshop took place over 3 days in the coastal region of Bella Vista (Uruguay) in December 2019. This "dialogical event"[10] sought to facilitate learning and knowledge transfer in all directions and allow equity, inclusion, respect for differences and the examination of assumptions to take place.

The group of more than 50 participants comprised of stakeholders from civil society (e.g., individual and organized food producers, chefs, artists, activists), the local public sector (e.g., governmental institutions, decision-makers), international and regional non-governmental organizations and institutions (including FAO), the private sector (e.g., gastronomic sector, small businesses) and academia (e.g., local, regional and international artists and researchers; see SARAS Institute, 2019). The selection of participants was carried out purposely (Moser and Korstjens, 2018) by the Organizing Group who identified individuals with whom the CoP members already had connections or ease of access (based on previous collaborations). We sought to achieve a wide diversity of perspectives and interests in terms of knowledge domain and sectors, without however aiming to represent all of them. A guiding principle for selecting actors was to ensure a productive collaborative environment (Howarth et al., 2022). Workshop sessions were structured around group work and plenaries. Groups were organized to represent prominent tensions in the region, namely related to (a) fisheries (small- vs. large-scale sectors), (b) agri-export (large-scale vs. traditional agri-food system, global vs. local dynamics), and (c) agroecology (micro-local production/consumption circuits). Groups were determined by the Organizing Group in a way that could leverage participant's expertize while ensuring diversity. This allowed, for example, the otherwise unlikely encounter of an early-career humanities researcher, a performative artist and the now ex-head of the Uruguayan Ministry of Livestock, Agriculture, and Fisheries (also director of the Rural Association of Uruguay) to debate the role of meat in the productive and cultural landscape. The workshop concluded with a plenary synthesis discussion to explore ideas for future projects addressing the identified needs or gaps, and to co-design the plan for the 2020 Public Conference. The consensus was that this should adopt a festival format with engaging activities that would move away from the typical academic conference format of knowledge dissemination alone, and thus be able to engage a wide range of stakeholders and audiences (SARAS Institute 2019; Juri, 2019).

Second phase: Planning and project development (2020)

The start of this phase coincided with the early stages of the COVID-19 pandemic in March 2020 which meant several disruptions to the institutions and peoples involved. The Organizing Group was forced to propose changes to the timeline and the nature of the activities such as (a) extending the Conference an additional year, and (b) focusing on online activities until conditions were favorable for an in-person event. Most of the work was thus internal as opposed to public and was centered on the development of small-projects based on the results from the 2019 workshop. Out of 14 initial project ideas, nine were fully implemented. Each project was steered by at least one member of the Organizing Group and most often included scholars, artists, practitioners and members from multiple organizations and institutions (see Table 3).

Projects adopted different methodological approaches, from arts-led to inter- and transdisciplinary. Frequent cross-group interactions (e.g., monthly meetings, workshops for cross-fertilization, and the design of the Theory of Change[11]) aimed at ensuring cohesion and goal alignment. An agreed plan for action (vision) emerged and projects advanced their work with products, insights and by synergizing efforts (see Figure 3 for project synergies). For example, the members of a project related to fisheries provided systematized data about this productive chain to another project generating infographics to visualize local/global trade dynamics. Project sub-groups grew in size through exchanges between members of the Organizing Group that contributed to different projects and the recruitment of external actors (from students to civil society organizations).

The pandemic significantly disrupted the arts and humanities-based initiatives envisioned in December 2019, which were mostly designed for in-person events. Although some projects were discontinued, the role of artists and humanists was important in this phase. Their practice and project-based creative explorations were determinant in shaping outputs such as a podcast and multiple audiovisuals (which represent knowledge artifacts in themselves) and helped create a more engaging language. They also ensured a critical engagement with historical and cultural issues.

Third phase: Public events, outputs, and dissemination (2021)

As the pandemic continued into 2021, the team decided to transform the Public Conference into a series of three online

10 By dialogical, we mean a process of encounter and exchange of diverse and often contradictory ideas or opinions (including the researchers'), allowing the expression of subjectivities without erasuring differences that could trump the possibility for mutual learning and transformation (Meban, 2009; Cipolla and Bartholo, 2014).

11 A Theory of Change is an approach and a product that helps to guide complex collaborative processes directed toward action and intentional social change (van Es et al., 2015). This process results in a visualization that encapsulates a definition of a desired change, the actions to be taken, an examination of the assumptions behind these and the strategies to measure its evolution and degree of success (Retolaza Eguren, 2010).

events. Although this meant that the aspiration for an in-person playful participatory experience in the form of a festival had to be reconsidered, the team explored different means of online communication and engagement by using or generating online tools, interfaces and activities. Clear and appealing communication was thus needed to: engage multiple audiences, integrate new voices across the system equitably (systems of knowledge), provoke dialogue and collective creativity, and enable to compete with the large number of online events available at that time. A specific branding for the three online events was developed[12] which was accompanied by the development of a dedicated website. Events were structured to advance three consecutive aims: (a) an introduction to the Cycle, the problem space, and ongoing projects; (b) nurturing conversations through learning from new perspectives and types of practices/knowledge paradigms; and (c) leverage the insights developed to define future visions and outline potential transformative pathways (Table 4). The design and format of each event varied to align to these aims and ranged from presentations and roundtable debates to generative and co-creation workshops.

A program of 14 online workshops was added to ensure meaningful interactions in smaller dialogues. Workshops were proposed and led by members of the Organizing Group, the on-going projects and other SARAS network affiliates. All information and documentation of these activities was communicated *via* a website, and included project results, video recordings, interviews, graphics and textual synthesis of events, among others. The last online event proposed a generative workshop to identify collective visions and "ecologies of interventions" as priorities for action and change. This phase concluded in December 2021 with an assessment and a digital synthesis report.

Results and observations

Over the course of more than 3 years, the group of researchers and artists from SARAS' CoP facilitated a transdisciplinary process anchored on dialogue, knowledge co-creation, coalition, and capacity building around the main themes of "what," "how," and "why" food system transformations is needed in Uruguay. The planning and development of an initial scoping and co-creation workshop [first phase, Section Third phase: Public events, outputs, and dissemination (2021)] helped outline the main priorities, needs, and knowledge gaps. Furthermore, it established critical social connections between diverse stakeholders (i.e., academia, public and private sectors, civil society organizations) and allowed the collective proposition of ideas (i.e., projects) to address the complexity of food system issues in the region. Through the development of nine projects and their outcomes (second phase, See Second Phase above) and the series of 14 online open events and workshops (third phase, See Third Phase above) the process moved past identifying system knowledge to exploring "target" and "transformational knowledge"[13], collectively outlining priorities, visions and potential change trajectories and actions. Projects involved more than 40 members, including SARAS affiliates and external actors. Collectively these participants converged to approach the complexity around sustainable food system transformations in Uruguay from different angles and strategies.

Some projects resulted in interdisciplinary collaborations while others expanded beyond academia and created alliances or bonds with organizations like the FAO, the National Agroecology and Seed Saving networks, small-scale fishers and entrepreneurs from the gastronomy sector, among others. This in turn resulted in a multiplicity of actions and outputs well-beyond academic papers (see Table 3). Projects aimed to produce socially relevant, effective, and legitimate knowledge[14] that could be translated into products with pedagogical usage potential. For example, in the project "*Fluruguay*" researchers from different disciplines gathered, synthesized, and graphically visualized local and global material flows and resource exchanges of five key contrasting export commodities: rice, soy, fish, beef, and wood pulp. The outcomes were offered as an open learning resource through the project's web page. Another project, "*COVID Foodways*," included an exploratory phase that sought to understand aspects of resilience in how consumption and production practices changed due to social-distancing measures caused by the pandemic. This was captured through a series of interviews and surveys, both locally and internationally, and shared *via* videos and online seminars.

The whole transdisciplinary process achieved the materialization of multiple transmedia outputs such as a podcast, a book, videos, a website, online visualizations, an interactive educational video, an online and physical catalog as well as opinion pieces published in a national newspaper. The

12 The series of online events that were part of the Food and Sustainability Cycle was publicly branded as "Knowledges on the table: Toward sustainable food systems and practices." See more details at: https://saboreandosostenibilidad.net/.

13 Following Pohl and Hadorn (2007) these concepts reflect an analysis or understanding of the problem space (systems knowledge), the deliberation upon a normative goal or stance that guides action (target knowledge) and the understanding and implementation of courses of action through which to achieve a transformation (transformation knowledge).

14 Belcher et al. (2016) define research quality in transdisciplinary work and outcomes across the following principles: relevance (i.e., significant and useful), credibility (i.e., trustworthy and robust), legitimacy (i.e., fair, ethical, inclusive), and effectiveness (i.e., contribute knowledge or innovations).

TABLE 4 Overview of virtual events during the third public phase: "Knowledges on the table: toward sustainable food systems and practices."

Event and topic	(1) "Food and crises: resiliences"	(2) "Food, society and nature: synergies"	(3) "Food and just futures: transitions"
Date	March 2021	June 2021	October 2021
Format	Presentations, roundtable debates, six workshops, conversation, participatory activities, and prompts	Presentations and discussion	Summary and generative workshop
Participation	Researchers and students from SARAS networks, partner institutions, public policy actors, civil society organizations, artists	Members of SARAS network, organizations, general public	Members of the Organizing Group and SARAS networks. Representatives from local and international organizations (e.g., FAO)
Goals	Introduce the Cycle, projects and preliminary results. Explore the territory from global to local scales and from different perspectives	Expand understanding by including new regional, local and new disciplinary perspectives (e.g., design, anthropology). Increase engagement of new areas and knowledge systems Introduction of a program of 8 workshops and webinars (developed between July and October)	Review main insights of the process and co-creation of visions and transition pathways. Identification of future questions and actions

dedicated website helped share information, outputs, and act as a roadmap that helped navigate an extensive and multifaceted process for those engaged internally and externally. Outputs sought to layer[15] and translate complex information by avoiding academic jargon and facilitating interpretation. For example, the project *"Huella de un Plato"* attempted to synthesize and educate the public on the concept of the social and environmental footprints of food. This was done by analyzing a traditional local dish and creating an interactive/gamified video tool. The podcast *"Sobremesa"* was conceived as an artistic endeavor which used a fictional character and humor as empathetic and relatable strategies in highlighting the multiple dilemmas food consumers face daily.

Activities such as roundtable debates and workshops, and some projects, explicitly leveraged and integrated small-scale collectives as examples of social-innovation or bottom-up initiatives (e.g., food-service entrepreneurs, restaurants, small-scale fishers) that could represent "seeds" of the future[16]. They served to value and integrate local and traditional knowledge and foster sharing. For example, two projects developed online and offline repositories and organized activities where the actors involved in the initiatives synergized and exchanged insights. Multiple new relations resulted from these spaces, including between participants themselves (e.g., through networking) and by forming alliances with new institutions or networks especially focused on education and community outreach. Overall, the workshops were particularly helpful in fostering more intimate exchanges and developing generative/creative outputs. The three main online events organized in 2021 helped keep this process open to the general public. This scaffolded structure (see Table 3) helped: (a) maintain, anchor, and motivate the core community through a calendar of virtual gatherings, (b) reach new individuals with different degrees of interest in the topics, at times, by sparking curiosity, (c) continually integrate new facets or excluded perspectives, and (d) move the process from exploration to propositions.

The last virtual event represented the consolidation of the process from a transformative potential angle. The event was designed to create future visions and pathways through a collective backcasting exercise. Participants were prompted to outline a desirable future vision by considering what is good to preserve and what needs to change, and to suggest the types of actions that would enable us to move toward that vision. Visions imagined food system futures that would: (a) accept the co-existence of contrasting productive models responsive to *glocal* dynamics in a context of strong regulations; (b) focus on stronger/empowered small-scale circuits with a "One Health" overarching goal; and (c) transcend dichotomies

15 Layering (Anderson and McLachlan, 2016) means recognizing the different layers of complexity and detail that are needed in the process of communicating ideas with different actors. People will gain a different understanding depending on their knowledge and abilities and this requires careful consideration, for example, in how and when to use technical or academic language.

16 Following Pereira (2021) a seeds approach attempts to collectively identify emergent initiatives of any type (e.g., technological, social) that do not constitute part of the status quo and thus are not consolidated or dominant in the present, while having the potentiality to do so in the longer term.

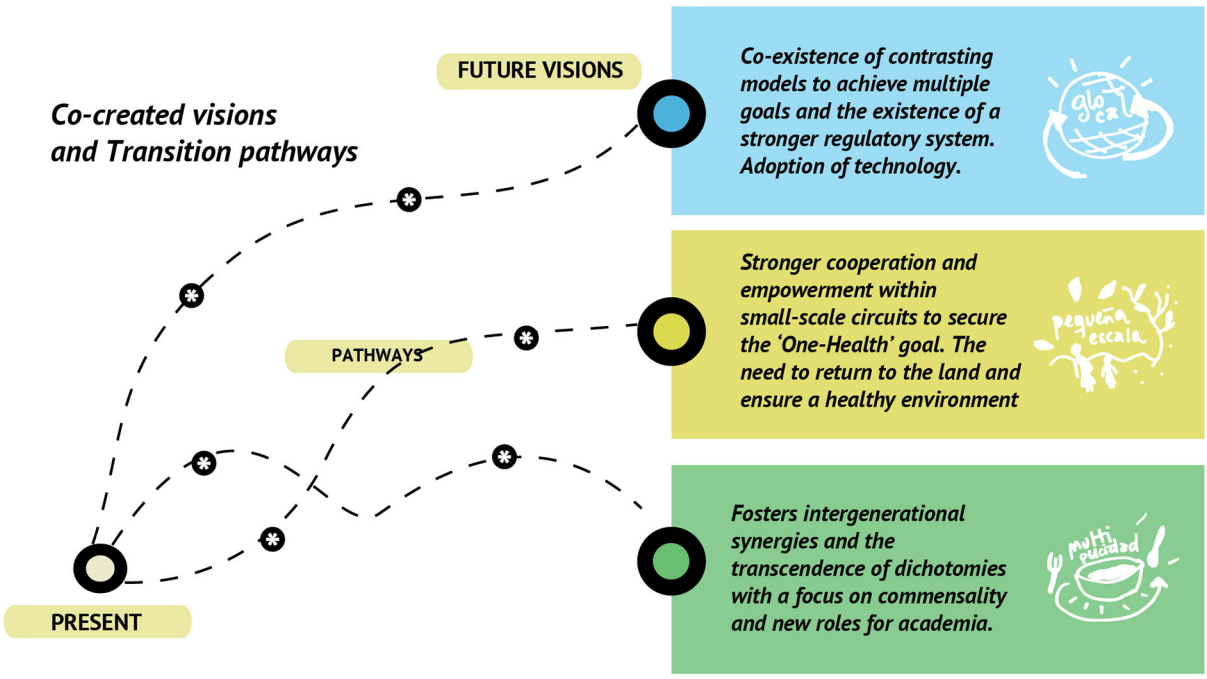

FIGURE 2
Visions and transition pathways: synthesis of the three co-created visions and action-pathways developed in the last virtual event held in October 2021.

via a multiplicity of perspectives enabled by academia, and the re-centering of commensality and intergenerational justice (see Figure 2 and more detailed description in the Supplementary Table 1).

This outcome proves that different values, interests, and perspectives determine what is of most local relevance. This was based on the type of interventions and topics that emerged, ranging from national and global regulatory measures to local and experiential food-literacy practices. While the three resulting visions seem to portray different types of food system futures, four elements emerge as a common thread for the type of change that is deemed important for this region: (a) revising consumption patterns overly reliant on meat products (especially limiting meat production that drives deforestation and land use change); (b) regulating better market flows and exchanges between the local, regional, and global markets while engaging better local and national governments; (c) enabling a wider social dialogue that engages all relevant stakeholders, transcends ideological dichotomies, and considers what positive role contrasting models could achieve if synergized; and (d) leveraging local and even traditional practices (e.g., production or consumption) and knowledges to enable and secure change in desirable, appropriate, and just ways.

The transdisciplinary process concluded with a synthesis report documenting the Cycle and its outcomes (see Juri, 2021 for more details). This offered an overview of all project outputs and an assessment of the impacts, including statistics and survey results. This report synthesizes part of the co-produced knowledge and was therefore designed to be useful for multiple audiences by being descriptive and analytical, while also visually engaging (see Figure 3).

Our assessment strategy comprised a reflective meeting and an online survey. The evaluation criteria revisited the goals, outcomes, and type of impacts that were collectively defined at different stages of the process (see Table 5). Some of the most significant relevant insights highlight that there was a shared perception that this process enabled participants to expand their understanding of the complexity of the issues around food and sustainability in Uruguay. This often provided new knowledge without drastically changing previously held perceptions. Respondents confirmed acquiring new information and tools, and leaving the transdisciplinary process with an optimistic feeling about the future of food systems in the region even though a lot of work needs to be done to achieve this transformation. The general perception of agency was high. On average, individuals felt they have a role to play in this transformation and were willing to engage in more actions or were already engaged through their daily practices or work contexts. There was a recognition that conditions more conducive to change were sorely needed, including those that transcend the spheres of the personal and daily life.

Respondents highly valued the open, diverse and participatory nature of the activities of the conference.

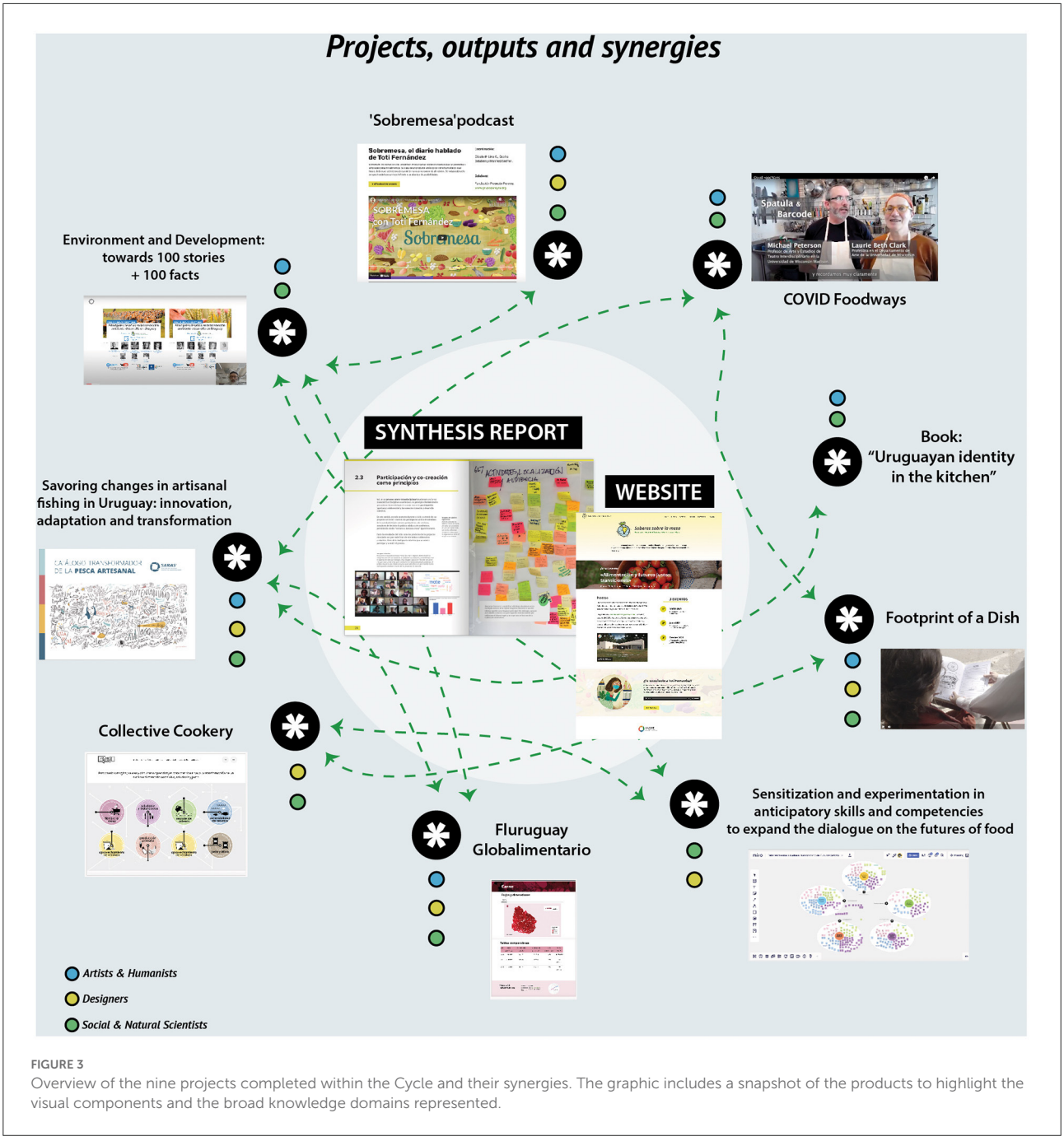

FIGURE 3
Overview of the nine projects completed within the Cycle and their synergies. The graphic includes a snapshot of the products to highlight the visual components and the broad knowledge domains represented.

Some of the most highly appreciated aspects included the online format that was free of charge, the innovative format and engagement approaches, the developed products, the valorization of local *knowledges*[17] and the opening of spaces for exchange of knowledge, collective reflection and networking. Half of the respondents mentioned that the tools and information available on the conference website were useful, clear, and accessible. These results are meaningful takeaway messages even when engagement with the survey was low. Students, researchers, participants connected to SARAS networks and representatives of relevant institutions (e.g., FAO) were particularly committed and motivated to sustain participation through the very long process.

17 To speak of plural types of knowledge, we adopted the Spanish the term "saberes." Therefore, here we choose to use a plural version of the term "knowledge" as the closest term to capture this wide concept.

TABLE 5 Breakdown of goals, types of outcomes, and impact sought and our evaluation criteria.

General goals (initial proposal)	Impact sought and outcomes	Evaluation criteria (theory of change)
a) Understanding the needs and desires across different local stakeholders, and the knowledge gaps preventing more sustainable food systems.	a) Degree of enhanced understanding of problems and identification of new alternatives.	a) Be continuous during the process (focused on learning).
b) Developing spaces for dialogue and the creation of new alliances that could inform decision-making across different scales and actors.	b) Creation of new spaces for dialogue.	b) Attend to knowledge co-production.
c) Exploring similarities and differences of what "sustainable food" means for Uruguay in contrast to other parts of the world.	c) Integration of perspectives able to transcend ideological fragmentation.	c) Transcend quantitative statistics based on audience and participation alone.
d) Developing integrative and innovative strategies to approach complex problems and synthesize results.	d) Generation of communication/dissemination products that translate and transcend scientific knowledge.	d) Focus on analyzing the types of collaborations achieved, especially between projects and the Cycle as a whole. e) Enable a process of collective meaning-making.

In relation to our goals, this transdisciplinary process was successful in creating new spaces and platforms for facilitating dialogue through the adoption of innovative methods and tools. This meant embarking on a collective process of both learning and imagination. Furthermore, it enabled participants to expand their understanding grasp the breath and complexity of food system transformation, consider alternatives, and access relevant information and tools. While not all stakeholders were engaged and/or represented in the process (e.g., global export/trade companies, large agribusinesses, advocates of technological innovation in agriculture, the forestry sector, indigenous communities), the process still enabled the integration of multiple perspectives and valued plural knowledges and experiences as valid sources of evidence. The frequent interaction and exchange between all components of the transdisciplinary process allowed for an ongoing assessment of the progress, adaptation to changing circumstances, and the emergence of new needs. We believe that simple quantitative statistics such as audience numbers proved misleading and less relevant. For example, the rates of interest during registration to open online activities (>1,000 registered participants across all activities) differed vastly from actual attendance (<50% of registered participants attended), which may be due to a myriad of factors. The continuous online engagement of participants (especially beyond the core group) was difficult to maintain and significantly decreased toward the end of the process. However, beyond these shortcomings, we assert that the goals of achieving a participatory process of knowledge co-production and mobilization were achieved.

Two additional key outcomes were trust-building and creation of new alliances with community organizations, educational institutions, and entrepreneurs. For example, the FAO entrusted SARAS to lead a research project on the theme of "Agroecological Transitions." Also, three of the Cycle's projects secured external funding which helped to externally validate them as locally relevant, as well as ensure the materialization of their proposed products and create opportunities for previously non-existent institutional alliances. The action-research spaces developed within many projects enabled networking and mutual learning in the process of developing purposeful products or informational tools. Some survey respondents confirmed having adopted these products and tools in educational settings mainly. Projects or workshops that converged multiple knowledge systems and diverse stakeholders also contributed by building social capacity (through competences for systems or anticipatory thinking or collaboration)[18], inspiring action, and potentially contributing to future innovations or behavioral changes. Results also highlight that the process represents a concerted effort that was built on the previous capacity and social capital found within SARAS CoP. This created preconditions for new opportunities for learning and action, which are still unfolding and will take years to fully assess.

Discussion

SARAS' Food and Sustainability Cycle outlined in the previous sections represents the first ambitious transdisciplinary process with a food systems focus in Uruguay. As such, it is

18 Some of the key competences in sustainability include systems thinking (i.e., grasp of the complexity of a problem constellation across time) and anticipatory competence (i.e., ability for developing future visions and scenarios; Wiek et al., 2011).

only a snapshot of a longer-term process, which is nurtured by SARAS' past and is extending into the future. Our action and participatory-oriented research (Miller et al., 2011) entailed a process of knowledge co-production with outcomes that needed to be contextually relevant and effective in stimulating further innovations, solutions, and actions (Belcher et al., 2016; Norström et al., 2020). This meant transcending epistemic problems alone (Maxwell, 2007; Pohl and Hadorn, 2007) and moving toward intentional (teleological) action, which is a paradigm shift in how scientific research is advanced and positioned within society (Fazey et al., 2020).

Transdisciplinarity and knowledge co-production

Our transdisciplinary process produced different types of knowledge. A prominent goal in some projects (Table 3) and a necessary general starting point was to produce "system knowledge" that sought to enhance understanding and identify causalities and research gaps related to local food systems. To inform and enable change, we produced "target" knowledge (i.e., purpose and goals in the form of normative visions) and "transformational knowledge" (i.e., concrete practices and courses of action; Pohl and Hadorn, 2007). This was achieved through a scaffolded process that advanced in phases, and layers in which different types of co-production took place.

Out of the six ideal-type modes of transdisciplinary co-production proposed by Chambers et al. (2021), four were present in our process as explained below, namely researching solutions, reframing power, navigating differences, and reframing agency. Firstly, although the transdisciplinary process did not aim to actually develop solutions, it created a multifaceted dialogical platform to explore potential avenues and motivate further action toward them. It started from the perception that a lack of integrated knowledge was one barrier for change, and in this sense, offering evidence could help bridge gaps across sectors and inform policy and decision-making. Second, attempts were made at "reframing power" especially during the first scoping workshop in 2019. The different tensions that arose[19] were managed by facilitators that focused on opportunities and completed concrete tasks such as the co-creation of a conference plan where all ideas were valued and considered regardless of who had proposed them. Third, the Cycle and many of its projects aimed to "navigate differences" by empowering diverse voices and promoting collaboration. Events, workshops and project activities created a "safe-enough-space" (Pereira et al., 2019) to enable actors engage in a dialogue and transform their perspectives thereby "reframing agency." This created a social learning environment where people were comfortable to share views, which is a requisite for social learning in any CoP context (Tseng and Kuo, 2014; Hernández-Soto et al., 2020). These insights were confirmed in our closing survey both by researchers belonging to the core group and participants of the transdisciplinary process. Importantly, the multifaceted nature of our transdisciplinary process meant that multiple modes of knowledge co-production co-existed but no single project (or the process as a whole) would fall strictly under the ideal types defined by Chambers et al. (2021). The diffuse and emergent nature of our process (without strict pre-defined timelines, project goals, or funding) resulted in an adaptive model particularly useful in supporting (Matsumoto et al., 2022) the initial phases of long-term collective transformational processes. SARAS role was that of "infrastructuring" (Hillgren et al., 2011; Karasti, 2014), which meant creating and facilitating a series of relationships and tools for advancing capacities and agency across scales and sectors with the particular input of participatory design creative approaches (see Björgvinsson et al., 2010).

Allowing a genuine *diálogo de saberes* (i.e., a dialogue of knowledges or wisdom) was key for achieving novel ways for doing action-research and promoting transformative practices (Delgado, 2016; Moreno-Cely et al., 2021). However, the configuration of the Organizing Group and its modes of working still meant that there was a bias toward academic knowledge (with low representation of other knowledge systems) mainly from the natural and social sciences with lower integration of the arts and humanities. Despite their underrepresentation in terms of number of participants/initiatives in the projects and the cycle as a whole, we recognize the value of these domains in their critical reflection, historical reconstruction and speculation on the values and beliefs that underpin societal dilemmas. The study of the media and other cultural artifacts allows us to grasp and open debates around the communicated or reproduced values that shape the task of imagining and realizing changes in new forms of food production and consumption. Indeed, systemic transformations demand cultural change (*via* values, beliefs, narratives, and artifacts), which acts as a strong and necessary lever of change (Meadows, 1997). In our case, a workshop that reunited a panel of literary scholars, a performance artist and a chef-poet was particularly revealing. By aiming to criticize current patterns of food consumption (particularly the loss of food identities/traditions) the underlying "wicked problem" addressed by the panel revolved around their perception of

19 For example, during the 2019 workshop different tensions arose with representatives from the Rural Association (ranchers and advocates for production and export of beef) and on the other hand, with Slow Food activists, both of which raised concerns that the discussions were biased to support either of those ends of the spectrum (dichotomies) in terms of models of production and consumption at local and global levels. Facilitators brought conversations to less divergent understandings and an opportunity to learn from the different views without assuming either as preferred or true.

a loss, if not the waste, of the humanities in public and private cultures, which has been relegated to a vocabulary of sybaritism (wellbeing by means of luxurious representations). A valuable lesson for future processes aiming to transcend the arts-science divide is that not every person engaged in the arts and the humanities is ready-made for a co-production for sustainability (in this occasion, reshaping narratives of food consumption differently to the traditional food narratives in the humanities). Food systems sustainability is not necessarily on their disciplinary agendas, nor is transdisciplinarity and solution-oriented work an established trend (maybe with the exception of film and public performative art). As a result, these constructs and approaches need to be introduced from the onset of the transdisciplinary process.

Finally, while many activities flourished in the online environments[20] (with participants collaborating across multiple countries and regions), this mode is conducive to only certain types of interaction. This essentially limits embodied/multi-sensory experiences and learning. The number of projects in the arts and the humanities dropped when in-person events were restricted. Some projects were able to adapt (e.g., a collage-based workshop was translated to an online format), while others simply lost motivation or their whole purpose (e.g., ideas for food-tasting or cooking experiences). In this respect, it is important to be aware of the pros, cons, and limitations of online experiences. Furthermore, it is necessary to account for the important non-cognitive dimensions of learning and anticipate ways in which to support the adaptability of goals and means across very different knowledge domains and their practices.

Design, facilitation, and the role of dialogical artifacts

SARAS' Cycle was highly facilitated and informed by design-based approaches and methods (Section Research approach). This aligns well with recent postulates of the potential role that the field of Design has in fostering transitions to sustainability (Escobar, 2015; Irwin, 2015; Gaziulusoy and Ryan, 2017; Fry and Tlostanova, 2020). Developing communicational and dialogical spaces and artifacts was a key part of enabling very different "voices" to converge into a space and enrich it by contributing from their lived experiences through their multiple roles in society. Enhancing communication and understanding required the adoption of a "language" that could appeal to (and at the same time engage) multiple audiences. It further meant the need to mobilize skills and methods to build capacities for openness and dialogue so that learning and transformation could occur (Ryan et al., 2016). The range of transmedia products (e.g., websites, publications, interactive videos) constitute "dialogical artifacts," which we conceptualize as material or virtual objects used in the process of (or as the result of) knowledge co-production and mobilization. Similarly to concepts such as boundary objects (Star and Griesemer, 1989), knowledge artifacts or intermediary objects (Cabitza, 2015), these artifacts afforded the possibility to transcend epistemic boundaries by bridging "social worlds." They acted as carriers-of-knowledge (as sharing vehicles) and objects-for-knowing (Cabitza, 2015), enabling the convergence of multiple views into processes of meaning creation and learning. They also helped develop joint work for a common goal and act as inspiration or motivation for further action, as is the case of "transformative boundary objects"—see Tsurusaki et al. (2013) and Sakakibara et al. (2019) as cited by Matsumoto et al. (2022).

As important outputs, these artifacts also acted as prompts for discussion and speculation. In this process they enabled us to contemplate, imagine and materialize visions of the future and offer avenues to understand how to get there (Fazey et al., 2020). Some of these artifacts demanded design skills and creativity (Runco, 2007; Klein, 2017; Montuori and Donnelly, 2020) to innovate and develop them as tools (e.g., graphics, worksheets, presentations). They helped facilitate generative dialogues in virtual events and workshops (Manzini, 2016) and enabled people to express different facets of their own creativity (Sanders and Stappers, 2008). This is key to fostering the political and transformative imagination (Galafassi, 2018; Fry and Tlostanova, 2020) necessary to generate inspiration or develop new alternatives that may transcend the status quo (Gaziulusoy and Ryan, 2017).

The integration and hybridization of plural *knowledges* is visible in the main conference website and report, which share results in text and graphic form (Figure 3). A design researcher assumed a leading and facilitation role from 2020 onwards. This meant that design essentially acted as a "third culture" (Cross, 1982) between the great divide of science and art (Snow, 1959; Halpern, 2012), and academic and non-academic knowledge to foster a type of "consilience" of knowledge (Wilson, 1998).

Moving toward transdisciplinary communities of practice

As a bridging organization, SARAS offered the possibility to foster interactions across sectors, motivate learning and sense-making beyond hierarchical levels and disciplinary boundaries, and enable trust-building and coalition-forming processes, while identifying common and conflicting interests (Hahn et al., 2006). This network leveraged existing relationships

20 New conditions enabled by the pandemic became opportunities for two editorial projects: (a) a compilation of narratives by non-academic actors involved in the fisheries sub-group, and (b) the publication of a monograph on the history of Uruguayan identities through its cuisine.

with multiple stakeholders and enabled the creation of new ones. As the members of the Organizing Group converged to collaborate on different goals and products, eventually more peripheral individuals were also integrated. This led to re-invent collaboration and knowledge co-production practices as members were found in new social learning environments, adopting and transforming new/unfamiliar methods or concepts. This is a common outcome of any transdisciplinary CoP. Myriad online gatherings and workshops enabled teams to experiment in ways that enabled them advance and "reify" their goals in tools that go beyond abstract concepts (e.g., a group of natural and social scientists engaged in the design of an interactive gamified video). This led them to hybridize their own expertize and broker knowledge (Hefetz and Ben-Zvi, 2020) from external communities, while simultaneously nurturing and learning from a new practice. Importantly, social connections were enabled through an already existing network of trust, which rests on sensitivities, attitudes, and values guiding the practices and interpersonal relationships within SARAS CoP. This is an important feature which Merçon (2021) conceptualizes as the "ethico-affective dimension" that is fundamental for a transdisciplinary community of practice (TDCoP).

Our case aligns with the experiences reported by Matsumoto et al. (2022), whereby researchers (and in our case artists) played a fundamental role in generating information, tools and the platform needed to cross boundaries, increase interactions, and foster capacity building at the start of a transformational process. SARAS' transdisciplinary process followed similar stages (i.e., understanding potential, coalescing as a community, maturing through learning to outlining future transformative activities) but differed on two main aspects. First, we did not aim to develop solutions or achieve complete consensus within the CoP, while the layered and multifaceted nature of our design (a constellation of projects and workshops) allowed for flexibility giving individual projects or groups enough autonomy to keep opening paths far into the future. Second, our case clearly shows the explicit and prominent role that humanists, artists, and a design-informed facilitation can play, which aligns with recent reports on the emergent potential for design and creativity to contribute to transdisciplinary projects related to food systems (Massari, 2017, 2021). Also, our process was not facilitated by outside researchers and was reliant on the long track of relations and trust that already existed. The engagement of the TDCoP is long-term and is not necessarily characterized by research and traditional academic schemes, especially since most active participants did not receive any funds for engaging in these activities. Indeed, there is no formal ending point for this rather non-traditional "transdisciplinary project," where many projects and cycle participants are still engaged in projects or continue to collaborate in new endeavors.

Significance for food system transformations

The questions around what types of transformations are needed (goals) and how such processes should unfold are ambiguous. This due to the co-existence of often vague ideas of what sustainable food systems means and various competing food production and consumption models and visions. The literature on food system transformation has highlighted that these processes of change need to be understood contextually because: (a) the priorities, goals and the necessary actions vary by region (Stefanovic et al., 2020; Dengerink et al., 2021), (b) the need to carefully account for local and global expectations (Caron et al., 2018), and (c) the contextual governance arrangements (social, ecological, cultural, and political) determine what type of transformation is possible. The complex multi-scalar, socio-political challenges that these processes of change present, demand systemic approaches (Hebinck et al., 2021). These need to consider the multiple types of negotiation and reconfigurations that need to take place (Leeuwis et al., 2021) when new practices, models or actors try to assert change and transform or dismantle the status quo. Engineering-type or sector-specific approaches are often unsuccessful. Deep levers of change need to include system goals, intents and paradigm or cultural shifts (Dorninger et al., 2020). This means shifts in power and agency with a clear future orientation (Anderson et al., 2019; Mangnus et al., 2019; Pereira et al., 2020), which also inevitably includes a change in knowledge systems (Anderson, 2015).

There is a need to create the conditions and build the necessary capacities for this. Collective examples from local multi-stakeholder processes (Herens et al., 2022) or living labs (Gamache et al., 2020) are promising. However, while they can span boundaries and enhance learning and adaptability, they may be less effective for larger food systems change. This highlights the need for work that is cross-scalar and both globally and locally aware. Den Boer et al. (2021) stress that effective approaches to accelerate change require reflexive, integrative and participatory research and innovation processes. However, at present, we lack examples of how these processes are designed and conducted, and what types of methodological and contextual mixes work in each region.

SARAS Cycle aimed to fill this gap and leverage the trajectory already present in its international CoP. Our process aimed not at proposing optimal solutions, but rather a systemic exploration of the solution space (Rosenhead, 1996). This was done through knowledge mobilization (Anderson and McLachlan, 2016) that was heavily reliant on facilitated dialogues (Drimie et al., 2021). Transformations toward sustainability are by default complex and long-term endeavors that cannot be fully controlled, planned or defined by "experts" alone (Miller et al., 2011). They also require adaptability and

creativity to deal with its emergent features (Pereira et al., 2019) and to manage multiple knowledge systems. Our Cycle was creative in that it unfolded and materialized the creation of new connections, boundary crossing and the generation of useful outcomes (Klein, 2017). Balancing flexibility and openness throughout the process design and development, while still adhering to a purpose of enhancing dialogue and communication was important to ensure engagement, translation, and the achievement of goals. Our case confirms insights from elsewhere in the literature, whereby the co-produced outputs of a transdisciplinary process are only one part of the legacy of a TDCoP like the one reported in this paper (Adelle et al., 2021). Arguably, one of the most important achievements has been the generation of a cohesive group that attains a new shared way of knowing, redefining previous practices, and outlining a potential identity that unfolds from dialogue and negotiation.

The transdisciplinary process was also useful in collectively moving from problem-structuring to solution-finding through brokering knowledge, reframing problems and solutions, and reframing agency (Chambers et al., 2021). However, at the same time, the outcomes, especially the visions and potential trajectories of change, represent alternatives that should be used mostly as stimulation for a wider and more engaged political dialogue (Gaziulusoy and Ryan, 2017).This work also shows that leveraging opportunities to collaborate amicably beyond conferences or other established academic formats (e.g., through food-sharing acts, performativity, arts-based, or co-creative experiences) can motivate, inspire and celebrate the transdisciplinary process as transformative in itself. The alliances and newly forged connections can offer promising prospects to develop and take these outcomes forward. Here, the identification of new questions, challenges and insights on what types of future engagements are necessary are of fundamental importance, as is having a set of tangible products that can further inform the dialogue and debate that needs to continue.

The developed visions and pathways suggest that while different interests and values prevail, alternative pathways, narratives and actions (i.e., outcomes) could likely co-exist (Stefanovic et al., 2020). It should be important to avoid narratives and processes that promote or determine singular pathways without accounting for synergies and trade-offs, or are adopted from a naive view that optimal solutions are possible. Therefore, a deeper reflection on narratives and embedded values is still necessary if we aim to enable reflexive and transformative (i.e., double to triple loop) learning (Argyris and Schön, 1997; Peschl, 2007) whether at the level of the transdisciplinary process and institution, or at the level of society. Based on the lessons learned from our transdisciplinary process we argue that artists and humanists should play a key role in this.

We were able to identify a few key messages that are particularly relevant when considering the characteristics and trajectories of sustainable food transformations in Uruguay (see Table 6). Priority concerns relate to enhancing the resilience of local food systems under the increased influence of global markets, as well as in the context of growing food/nutritional insecurity and diet-related diseases in the country (Section Case study: Food system transformation in Uruguay). For a major food-producing nation, this represents one of the most salient paradoxes and demands further debate.

New research questions or insights for further exploration in the Uruguay context include: (a) identify which aspects of the current food systems should be preserved and which should be transformed while recognizing multiple trade-offs; (b) transcend dichotomous thinking to achieve multiple goals and outcomes for food system transformation; (c) rationalize the role of technological innovations in steering desirable change in food systems (especially in the case of commercialization and access); and (d) understand how to limit the expansion of transnational ownership of land and resources. Some questions and insights from a more socio-cultural lens include: (a) maintain biocultural diversity and avoid the colonization of native ecosystems from exotic species; (b) learn from (and strengthen) synergies between bottom-up or emergent initiatives to enhance a critical mass and a social debate for food system transformation; and (c) consider carefully the rhetoric of discourses that highlight social and cultural dimensions of food and the stories behind them (i.e., the underlying values and types of food system futures that they prefigure). The latter is quite important as it could lead to a market-led "aesthetic" and even "fetichization" of food identities/cultures without a genuine and critical exploration of the role of cultural identity and tradition as leverage points for deeper systemic transformation in food systems.

Challenges, limitations, and next steps

Below we offer a critical reflection about the limitations of the transdisciplinary process and the challenges encountered during its design and implementation. These should inform future activities or represent a transferable model for planning similar transdisciplinary processes, particularly in the context of food system transformation and sustainability.

The Cycle engaged multiple stakeholders across different sectors involved or interested in food systems. However, stakeholders from some sectors were particularly underrepresented or even not represented at al. This led to the lack of some distinctly divergent voices even when those that did participate held different perspectives and values themselves. The most well-represented groups were academia and non-governmental organizations. This forces us to consider whether the process expands a dialogue within a vaguely defined echo-chamber, and points to the need to find strategies to engage excluded actors, or actors holding opposing views. Further efforts should be made to ensure to not just appreciate

TABLE 6 Key points for sustainable food system transformations identified for the Uruguayan context.

Key points for sustainable food system transformations for Uruguay
a) Multiple transition processes are underway in relation to production and consumption practices, the role of technology and the interactions of food systems with other sectors (e.g., energy, forestry, tourism).
b) Uruguay has already implemented mechanisms and practices that ensure quality, transparency, efficient resource use and low-environmental impacts and there is an interest to preserve this trajectory.
c) Food cultures and the identities and narratives attached to them play a critical role in promoting and validating the country's production matrix (livestock, soy) and demand critical reflection as new counter-narratives gain prominence (e.g., plant-based diets).
d) Global/local dynamics have always played a decisive role and presently directly impact the nation's economy, the distribution of capital and its benefits to society and the use, ownership and exploitation of natural resources which are undergoing increased pressure (especially land-use change, biodiversity loss and pollution and degradation of water resources) with additional impact on livelihoods and health.

but actively engage far more plural voices. For example, in our experience, attempts were made to engage representatives from indigenous communities who expressed interest in this process but did not participate in the end. While we cannot speculate the reasons for this, indigenous and other ethnic minorities did not have a collaborating history with SARAS, which maybe reflects how overarching epistemic and systemic inequalities (Laborde, 2017; Rodríguez and Díaz, 2018; Sans et al., 2021) are hard and slow to subvert.

We acknowledge that the transdisciplinary process presented here is only part of a longer-term process of transformation. In this sense the insights and trajectories outlined serve as starting points to continue a larger dialogue promoting deliberation and further re-framing of the sustainability challenges and solutions in food systems in order to secure and problem-ownership and jointly develop policy and other interventions. We also point out that while social and cultural changes take time, it is still possible to identify seeds of potential futures (in multiple practices and emergent initiatives) that rely on or acknowledge norms and values that prioritize human-nature connections and planetary health and wellbeing.

We cannot claim that this process effectively transformed the food system in Uruguay, but the actions and knowledge informed, inspired, and activated a multiplicity of spaces in which transformations are being actualized or nurtured. As stated elsewhere (Levin, 2008; Belcher et al., 2016; Phipps et al., 2019; Drimie et al., 2021), it is difficult to evaluate a long dialogical transdisciplinary process that consists of multiple elements acting at different spatial and temporal scales. This would require a significant amount of time and resources (e.g., skills, infrastructure, funds), and will likely take years (Walter et al., 2007).

As this transdisciplinary process was mostly steered by academics and considering the low participation of powerful actors with different vested interests and needs entrenched in the food system (particularly agribusinesses or lobbyists that benefit from preserving the status quo), the process has arguably limited potential to affect large-scale systemic transformation. While not all outcomes of the current globalized industrial food system are negative, some powerful actors may oppose fundamental food system transformations by preserving or accelerating certain dynamics that they find desirable (Anderson and Leach, 2019). Some such examples can include market-driven maximization of production, discounting of externalities, pressure on global geo-politics that determine or preclude land ownership and ecosystem stewardship, or measuring success and development with metrics that exclude certain dimensions such as wellbeing, health, justice, cultural value, or social-ecological resilience (Caron et al., 2018; Stefanovic et al., 2020). Multistakeholder platforms can have transformational potential by raising awareness, aiding to shift narratives and problem framings, and generally supporting processes that may impact policy-making and overall food system governance change (Leeuwis et al., 2021). However, their impact is limited (Herens et al., 2022) if mentioned lock-ins are not subverted and without powerful actors aligning toward significant paradigm changes (Bui, 2021; Ruben et al., 2021).

Beyond the shortcomings outlined above, we particularly highlight: (a) the usefulness of approaching a complex process and topic such as food system transformation in two interacting and mutually reinforcing levels (macro and micro) and (b) the multiple opportunities that are opened and explored by developing a series of diverse projects where actors and knowledge are mobilized, and new alliances can be created. For transformative learning to take place, a TDCoP needs to be open to the public and new perspectives instead of becoming a closed community (Matsumoto et al., 2022). However, at the same time there is a need to keep within a TDCoP the deep and specialist reflections and discussion that are needed for co-production (Adelle et al., 2021). We also stress the positive role that integrative facilitation and leadership combined with Design-skills and methods played in producing artifacts and outputs that capture, create and share knowledge. Finally, here the TDCoP helps guide the development of not just a project geared toward food system transformation, but also

the creation of an experimental and flexible social learning community. This requires not just attending to knowledge but also to values, beliefs, affective bonds/needs. Furthermore, it also stresses "second order" transformative change, not just in daily life and practices, but also in terms of knowledge creation and reflexivity, while developing critical and creative capacities (Grunwald, 2004; Fazey et al., 2018; Den Boer et al., 2021).

Conclusions

Tackling the many interlinked and complex issues preventing food systems from moving toward more sustainable pathways is a serious challenge. It calls for novel approaches that speak to the different priorities and features found in each particular context. Latin America, as a major food-producing region, is at a crossroads with multiple challenges and opportunities for food system transformation. Transformation pathways will likely impact both regional and global food system dynamics in multiple ways. The case study presented here focuses on food system transformation in Uruguay given its contrasting trends of development (e.g., trade-offs related to food production and consumption of beef) and its historical role within the globalized food system.

SARAS Institute, positioned as a bridging institution, developed and steered a 3-year transdisciplinary process that explored how to nurture food system transformations in practice. This collaborative endeavor represents an example of a transdisciplinary community of practice that particularly aimed at bridging the arts/science and science/society divides. In our case, the goal of creating a new dialogical arena was supported and achieved through a series of knowledge and communication products (i.e., material and digital artifacts), which constituted key dialogical objects working internally and externally. In a sense, this represented the generation of a language of collaboration and knowledge mobilization, which was purposefully facilitated and informed by design creativity and integration. Our insights offer a model that could be useful to inform similar processes led by Transdisciplinary Communities of Practice (TDCoP) or bridging institutions in the early stages of transformative work, specifically in relation to food systems and their governance. It also represents an example of change within an institution following the precepts of serving society to achieve sustainability goals, while undergoing adaptation through reflexivity and creativity itself.

Our work confirms that institutions for collective action can initiate food system transformation through transdisciplinary processes. However, knowledge alone is not enough, and multi-stakeholder platforms also have limitations. We also need to keep in mind that the magnitude of food system unsustainability is huge. While many small-scale initiatives to achieve positive change are underway, many aspects of the food system (in Uruguay and Latin America more broadly) have been driven by short-term profit considerations, with little attention to long-term sustainability or social inclusion. It is a big and difficult task to transform the historically rooted injustice and unsustainability in the Uruguayan food system, not the least because there are strong interests seeking to keep the status quo. It is thus clear that our case is only the start of a longer-term process toward capitalizing on insights and coalitions, increasing engagement and ownership, and operationalizing and expanding avenues for change across system levels and sectors. We hope that our dialogue can enhance understanding and create constructive pressure on decision-makers. We also hope that this example helps inspire similar initiatives to imagine and realize not just smart, but also wise sustainable food-system transformations.

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

SJ conceived the article conceptually and structured the draft, presented and analyzed the case study, and developed the graphics and tables. LD, MB, MM, MT, NM, JM, and CZ contributed conceptually and with revisions. MB and EJ analyzed and reported data to characterize the case study context. LD, MT, MB, JM, and NM contributed with significant revisions and reviewing. All authors contributed to the design and evaluation of the process reported in this article.

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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

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.887034/full#supplementary-material

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Learning, playing, and experimenting with critical food futures

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Imagining sustainable food futures is key to effectively transforming food systems. Yet even transdisciplinary approaches struggle to open up complex and highly segregated food policy governance for co-production and can fail to critically interrogate assumptions, worldviews, and values. In this Perspective we argue that transdisciplinary processes concerned with sustainable food system transformation need to meaningfully engage with critical food futures, and can do so through the use of soft scenario methods to learn about, play with, and experiment in futures. Specifically, soft scenarios contribute in four ways: 1) questioning widely held assumptions about the future; 2) being inclusive to multiple perspectives and worldviews; 3) fostering receptiveness to unimaginable futures; 4) developing futures literacy. Based on insights from a 5-year transdisciplinary action research project on sustainable food transformation across Asia, we demonstrate how these processes play out in narratives, serious games and interactive art featuring soft scenarios. We conclude by discussing the potential for collaboration between transdisciplinary and futures researchers, especially for transforming food systems.

KEYWORDS

food systems, transformation, scenarios, futures literacy, transdisciplinary

Introduction: Re-imagining future food systems and transdisciplinarity

Imagining sustainable food futures is essential to effectively transforming failing food systems. How food systems are failing their stakeholders, including producers, consumers and the living beings produced and consumed, is well understood (FAO, 2021; IPCC, 2022; McGreevy et al., 2022). Realizing sustainable food systems will not come through incremental adjustments that replicate the status quo and underlying values and logics, but by critically interrogating the foundations of the current food

system and catalyzing comprehensive transformation (McGreevy et al., 2022). As the editorial to this collection lays out, transdisciplinary approaches seek to foster food system transformation through new knowledge co-creation processes that in turn lead to action on the ground. Yet even transdisciplinary work struggles to open up complex and highly segregated food policy governance for co-production (Barling et al., 2002; Anderson et al., 2019).

The process of transdisciplinary research can be exceedingly challenging and fraught with obstacles. Ensuring cooperation and motivation among participants, the inclusion of diverse perspectives and needs in the process, arriving at joint problem and system definitions, and integrating knowledge in a meaningful way are just some of the issues that can derail transdisciplinary research (Scholz and Steiner, 2015). Transdisciplinary research for food policy development, for example, needs to build consensus between multiple, highly-segregated sectors of the food economy and work at the intersection of competing interests and demands. In addition, the need to address the challenges of transdisciplinarity while at the same time thinking about and planning for sustainable food futures is an essential yet understudied perspective in the transdisciplinary literature.

"Another world is possible", the slogan of the World Social Forum and rallying phrase of activists engaged in transformative struggles in the early 2000s (Fischer and Ponniah, 2015), highlights another related issue transdisciplinary research has yet to fully address—the inertia of the status quo. John Robinson's suggestion that environmental issues are not a failure of information but of the imagination, and the philosophical work of Cornelius Castoriadis on the necessity of the radical imaginary ("seeing something as it is not") for questioning the status quo of society (Castoriadis, 1987) are highly relevant in this regard. Counterintuitively, this seems to apply even more to questions about what futures radical transformation toward sustainability ought to strive for.

To explain, we turn to research on futures, futuring methods and futures literacy, defined simply as the ability to "use the future" (Miller, 2018) or to "use an appreciation of projectivity to act upon the future" (Mangnus et al., 2021). Assuming what the future may look like, or in contrast, assuming nothing at all immediately limits what outcomes a process to envision sustainable futures as part of transformative transdisciplinary research might produce: "people's fictions about the later-than-now and the frames they use to invent these imaginary futures are so important for everyday life, so ingrained and so often unremarked, that it is hard to gain the distance needed to observe and analyze what is going on" (Miller, 2018, p. 2). Whether a result of past experiences, failing to include diverse stakeholders, or not providing sufficiently safe spaces for expression, participants engaged in futuring may limit the perspectives and viewpoints they consider for discussion (Pereira et al., 2015; Hebinck et al., 2018). Radical futures that critically examine what is taken for granted might seem so alien and implausible that they are discarded. Critical food futures, then, actively interrogate the underlying assumptions, values, and worldviews that reinforce how the current food system operates. In the context of food practices, its embodied and habitual nature further complicates extracting oneself from the trajectory of past experience and commonly-held assumptions to "see the food system as it is not", thereby gaining the capacity to examine food through a critical futures lens. Different approaches to futures and thus to futures literacy have been used to engage with these challenges, tackling issues from future-inherent deep uncertainty to the role of the imagination to the lack of reflection about future-oriented work (Mangnus et al., 2021). Ahlqvist and Rhisiart (2015, p. 92) point out how futures methods becoming mainstream has not alleviated a lack of criticality in how empirically driven methodological choices "construct future-oriented knowledge" and how implicit assumptions, worldviews, and values go unquestioned in such processes. In our opinion, the simultaneous rise of transdisciplinary research and futures methodologies creates an opportunity to address the issue of criticality by exploring how both might be combined. This could help avoid reducing transformative efforts to reformist, incremental tinkering by procedurally impoverished imaginations or by shrinking away from the overwhelmingly vast possibilities of future worlds.

In more than 5 years of working on food system transformation as part of the FEAST Project [Lifeworlds of Sustainable Food Consumption and Production: Agrifood Systems in Transition, 2016–2021; continued as an NPO from April 2021 (FEAST, 2022)] at the Research Institute for Humanity and Nature in Kyoto, Japan, we witnessed stakeholders grapple with the ways local food futures simultaneously seem to hold endless possibilities (after all the future hasn't happened!) yet hope for real change then suffers death by a thousand cuts (capacity of individuals to engage despite time poverty, a corset of multi-level governance permitting only the faintest of movements, a dominant global economic order dictating the need to (out)compete and profit for survival). Some days, another world and brighter futures seemed impossible to us, not just as researchers but as members of our local communities.

Building on these experiences, in this Perspective we argue that transdisciplinary processes concerned with sustainable food system transformation need to meaningfully engage with critical food futures and can do so through the use of soft scenario methods to learn about, play with, and experiment in futures. Among the many different forms of workshops and stakeholder engagements employed as part of the FEAST Project, soft scenarios (Garb et al., 2008) stood out as a way to critically approach food futures with stakeholders that allowed 1) questioning of widely held assumptions about the future, 2) being inclusive to multiple perspectives and worldviews, 3) fostering receptiveness to unimaginable futures, and 4)

developing futures literacy. "Hard" scenarios or simulation-based approaches often focus on making processes, drivers, trends, and impacts explicit and thereby risk reinforcing widely held understandings of future trajectories (Stirling, 2008).

In contrast, "soft" scenario approaches (Table 1) aim to critically interrogate the unquestioned values and assumptions that frame thinking about future trajectories by creating a safe and malleable, thus "soft" space for participants to consider critical futures. Narrative and story, interactive art, serious games, virtual reality, performance, and experimental workshop formats are just some of the ways in which scenarios of the future are being conceived. These soft scenario methods allow participants in transdisciplinary engagement processes to learn, play, and experiment with possible critical futures, making them more tangible, relatable, and plausible (McGreevy et al., 2021).

Using soft scenarios for learning involved getting to know—often through stories—the topic at hand, including relevant issues and points of contestation, and gaining an understanding of actors involved as well as their backgrounds and motivations. The mode of learning is immersive, experiential, and encourages reflexivity rather than being limited to exploring abstract representations of data. Learning through soft scenarios foster critical analysis by engaging with multiple learning styles, double-loop learning (Argyris, 2002), multi-modal embodied learning (Kuzmanovic and Gaffney, 2017), non-linear-thinking (van der Heijden, 2011), and the making explicit of mental maps (Berkhout et al., 2002).

Playing with futures as scenarios allowed participants to discover and be exposed to imagined worlds and feel something about them, getting familiar with the context and exploring choices play-fully without the burden of doing it "right". In the words of Kuzmanovic and Gaffney (2017, p. 109–110), playing enables us to "inhabit uncertainty" and "can open up a range of possible futures that may not be so readily accessible through the usual channels of consensus reality". Through play we can also inhabit other roles or personas or identities to create feelings of belonging and empathy that can lead to collective action (Chabay et al., 2019).

Finally, experimenting with futures provided the experience of seeing options appear, change and vanish, as "detailed interventions [are] experimented with by participants embodying the future" (Mangnus et al., 2019). These reciprocal processes of experimenting in the future to enact and change the present are often facilitated through data-driven models or scenarios, interactive scenario creation, or serious gaming. Through this style of experimentation, policy ideas and action plans can be improved and reflected upon to ensure a reflextive co-construction of possible and desirable futures.

With these three aspects in mind, soft scenarios are a hybrid approach to future literacy building that draws upon deep, experimental and critical futures approaches. In turn this hybrid approach does "not presuppose an active, formative engagement with the future as such, but rather bring(s) people together around a reflexive deconstruction of images and imaginaries of the future" (Mangnus et al., 2021).

Insights from FEAST: Learning, playing and experimenting in action

To demonstrate how soft scenarios contribute to learning, playing and experimenting with critical futures, we highlight case study analyses (McGreevy et al., 2021) conducted between 2017 and 2020 in Japan and Thailand as part of the FEAST Project (Table 2). The FEAST Project utilized a multi-method participatory action research approach to explore the realities and potential for bottom-up sustainable agrifood transition at sites in Asia. Over the course of the project, FEAST created partnerships with food system stakeholders to envision desirable and plausible futures and to initiate local food policy and food citizenship-oriented experiments and actions. Specific soft scenario methods deployed during FEAST and included in the cases described below are interactive art exhibitions, digital and tabletop-based serious games, and food practice-focused visioning and backcasting workshops to allow for critical perspectives to emerge. The focus in the following sections lies on the role of learning, playing and experimenting during the collaboration of food system actors and researchers in a transdisiciplinary process. The learning and playing sections center on work conducted in partnership with stakeholders in Kyoto City to co-initiate local food policy institutions (Food Policy Council) and discussions on desirable local food systems. The experimentation section details a multi-phase process of visioning, scenario-building, role-playing, and backcasting future food practices and policy for Bangkok.

Learning: School lunch 2050 exhibit

Assumptions about the future are necessarily based on what we know. However, food systems and food policy are complex and researchers and non-academic stakeholders alike are often only aware of some aspects while remaining ignorant of others. One prominent example is the implication of climate change on food futures, an issue now requiring dedicated evaluation by large expert teams to even outline how far-reaching consequences of (for example) limiting temperature increase to 1.5°C might be. Learning in ways that situate knowledge in everyday experiences and practices rather than simply presenting abstract numbers can thus help question the very assumptions the futures hitherto taken for granted or presumed plausible were based on. In a Kyoto exhibition of possible future school lunch scenarios [now also available online (School Lunch, 2021)], participants, including but not limited to students and their parents, interfaced with four future scenarios (Gardens, Illusion, Desperation, and Gamble). These scenarios

TABLE 1 Examples of soft scenario methodologies and how they encourage learning, play, and experimentation with futures (adapted from McGreevy et al., 2021).

Studies covering methods and providing evidence for…	…*learning* about futures	…*playing* with futures	…*experimenting* in futures
Interactive art installation (Bendor et al., 2017)		x	x
Storytelling scenario workshops (Bowman et al., 2013)	x	x	
Narrative expression case studies (Chabay et al., 2019)	x	x	
Design fiction (Antonsen and McGowan, 2021; Hebrok and Mainsah, 2022)	x	x	
Performative theater (Heras and Tàbara, 2014)	x	x	x
Prehearsals and pre-enactments everyday experiential labs (Kuzmanovic and Gaffney, 2017)	x	x	x
Digital and table-top role-playing games (Dolejšová, 2019; Mangnus et al., 2019)	x	x	x
Serious games (Ritterfeld et al., 2009)	x	x	x
Futures forum emphasizing art and design (Selin, 2006)	x	x	x
Mixed interactive media (games, video, animation, workshops) (Vervoort et al., 2010)	x	x	x
Worldmaking (Vervoort et al., 2015)		x	x

represented success and failure in limiting global warming as well as reliance on or independence from the global capitalist-industrial food complex through plates of food: Satoyama[1] soup and edible school garden grown vegetables, Filipino purple yam flavored New-Zealand cow-free powder milk, bananas grown locally in Kyoto alongside cricket tofu steak, or a medical cube to dissolve microplastics alongside microbiome-building supplements and CRISPR[2]-bug bits instant soup. Far from science fiction gone off the rails, all components were based on research and extrapolated trends, issues and debates already happening around climate impacts on future diets, giving parents and students (and thus potential future grandparents and parents) much to digest.

Since it is considered a school subject like any other, lunch time is actually treated as a learning experience in Japan. School lunches are provided by nearly every elementary and middle school and have widespread cultural significance. Through eating school lunches, Japanese are introduced to national and local food culture, nutrition issues, and respect for natural cycles. Encountering such a ubiquitous meal reinterpreted in very different ways and in presented as a tangible display created an opportunity for questioning assumptions about how food might change in the future. Taken-for-granted staples, such as rice, miso soup, or iconic fruits or vegetables may not be available depending on the severity of climate change or attention paid to local food security and this was a shock for many participants.

Playing: Food policy council simulator serious game

Perspectives and worldviews are strongly dependent on our daily-life roles in the food system. Are we consumers seeking to save by shopping around and keeping an eye on sales? Parents concerned about pesticide residues and ultra-processed food marketed to children? Small-scale producers struggling with increasing competition by cheap imports and vertical market integration? Or are we policy makers trying to enact change on a shoe-string budget while working around the issue that no section of the local government sees itself in charge of food? Even without expanding the circle to non-human stakeholders (Rupprecht et al., 2020), transdisciplinary food projects often struggle to include multiple perspectives and worldviews, an issue that is increasingly tackled by setting up municipal food policy councils (Baldy and Kruse, 2019; Van de Griend et al., 2019; Rivera-Ferre et al., 2021). In addition, institution-building takes time and trust. In the serious game "Food Policy Council Simulator", community members with different roles in the food system participated in a role-play exercise that allowed them to swap roles (Mangnus et al., 2019). They worked together to address real-world local food issues by taking on new perspectives ("roles"), explored and negotiated while building empathy for different views on future worlds and organizational capacity for developing policy proposals

1 A term commonly referring to traditional mosaic landscapes in Japan that incorporate agricultural fields and rice paddies, forests, grasslands, and waterways.

2 Standing for "clustered regularly interspaced short palindromic repeats" and referring to DNA sequences utilized in gene editing.

TABLE 2 Soft scenarios in action and their effects (adapted from McGreevy et al., 2021).

Effects / Soft scenarios	Assists participants in questioning widely held assumptions about the future	Enables the inclusion of multiple perspectives and worldviews	Expands receptiveness to unimaginable futures	Develops futures literacy
School Lunch 2050 exihibition (see http://kyushoku2050.org)	Questions implicit assumptions of food security and continuity by showing how climate change and biodiversity loss may impact the menu; Demonstrates rarely considered tension between heavily imported vs. locally sourced food system	School lunch is a common experience for everyone, enabling a vicarious experience beyond individual perspectives	Engages the senses through art, tangible menus ("seeing is believing"); affective response to "Would I eat this?" and "How did we/our society get to this point?"	Show four possible future trajectories in an easy-to-understand format, modeling a way to "use the future"; Reveals the relationship between climate change and food economy through diverging outcomes
Food policy council simulator serious game (see Mangnus et al., 2019)	Demonstrates the complex nature of food policy in contrast to common simplistic media portrayal; Introduces the interaction of various actors involved in the food system and case studies of good practice in multiple countries, thereby questioning the assumption that "it can't be done"	Role-playing style accommodates anything players can imagine, including fictitious roles able to intentionally introduce diverse worldviews; Role-playing characters promotes empathizing with others	In-game negotiation with other players facilitates discussion of collectively desired future and offers place for social learning; Role-playing elicits affective responses to possible futures/policies	Build organizational capacity to use the future amongst players; Introduces random disruptive elements that impinge upon the effectiveness of planning, thereby fostering capacity to anticipate and deal with uncertainty
Participatory practice-oriented food policy process (see Kantamaturapoj et al., 2022)	Scenarios explored the interplay between technology (A.I., V.R.) and socio-cultural values, highlighting disruptive potential of socio-technical and socio-cultural changes	Scenarios derived from multi-stakeholder, reflexive process; Role-playing characters promotes empathizing with others and adopting new perspectives	Role-playing future narratives elicited affective response; Narratives assist avoiding reflexive dismissal of too-strange futures; Focus on everyday practices facilitated backcasting process	Policy ideas focused on changing practices in integrated and intentional ways, as opposed to simply aggregate individual behavior and choice

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("rules"), all without recreating the stifling atmosphere pervasive in formal participatory engagement processes. Some of the same game participants later established a Food Policy Council in Kyoto, Japan.

Through the role-playing game experience, participants were invited to walk in the shoes of someone else and empathize with their situation and worldview. All participants were interconnected in the local food system in some way, but may be invisible or seemingly irrelevant to one's role or position. For example, a government representative in charge of public health may not have ever taken the time to think about what urban farmers needs are or how there may be hidden synergies that between urban food security and healthy eating that could be supported through unique policies. Playing a role encourages building empathy with other worldviews and human (and non-human) needs. The additional layer of a gamified simulation of a food policy council allowed participants to play with possible food policy ideas, imagine how those policies could address local needs, and how possible futures might unfold based on actions taken now. Participants's sense of agency to impact local food system change was fostered through the safe space of play and gaming.

Experimenting: Participatory practice-oriented food policy process

What if you could eat fresh, healthy meals at home without having to cook? Expanding receptiveness to futures that lie outside the easily imagined can open doors to new potential solutions for problems seemingly wicked within the limits of what looks possible. A multi-phase process of interlinked workshops including visioning, scenario evaluation, and transition pathways brought together consumers, experts and policy makers to tackle sustainable futures of food purchasing, eating out and home cooking in Bangkok using a social practices perspective (Kantamaturapoj et al., 2022). Participants dared each other to leave common sense behind, experimenting with scenario narratives featuring a smart but sharp-tongued personal artificial intelligence shopping assistant steering the protagonist family toward sustainable and healthy food options, an open-air restaurant where dinner can only be paid for with agricultural products pooled and then prepared on-site, and a communal kitchen equipped with a M. O. M (My Optimal Menu) robot tracking and providing meals based on individual members' health needs. This experimentation process enabled policy ideas to realize urban food sustainability in Bangkok to go beyond conventional approaches emphasizing individual behavioral change. Instead, ideas embraced multi-sectoral and systemic strategies that capture how food practices emerge as the result of social, cultural, economic, and technical contexts (Kantamaturapoj et al., 2022).

Within this series of workshops that included envisioning desirable futures, devising scenario narratives of future food practices, role-playing the narratives, and backcasting policy and intervention ideas to reach the ideal futures, participants were able to draw links between the way current practices shape everyday life and how they would like to see them in the future. Using a social practice perspective (Shove et al., 2012; Spurling et al., 2013), the materials, meanings, and competencies needed for a practice to be performed and how these elements interacted with existing policy, markets, technology, and education became the space in which to experiment. For example, ressurecting the practice of home cooking in the future could mean emphasizing food education for a new generation of cooks, creating communal spaces to share cooking and eating, or slowing down the pace of urban life in Bangkok. Each (or all) of these options are theories to elicit societal change and need to be accompanied by different policies or interventions to recraft, substitute, or rebundle existing practices over time. By mixing visioning, immersive futures narratives, and backcasting processes, theories could be tested and receive feedback from participants residing in fictional futures in a reflexive process. This feedback builds futures literacy and was essential in, ultimately, choosing desirable pathways toward future food practices (Kantamaturapoj et al., 2022).

Building receptivity for critical futures and futures literacy for transdisciplinary research to transform food systems

Questioning assumptions, considering multiple worldviews, becoming more receptive to the unimaginable—in all three cases, soft scenarios fostered participants' futures literacy. In this Perspective, we have argued that transdisciplinary research should engage with critical food futures because such futures literacy in turn serves participants to successfully join in and navigate transdisciplinary efforts, where focus often lies on co-production and co-design processes. Mangnus et al. (2021) argue that being futures literate requires reflexivity: "critical awareness of different attitudes toward the future, including what can be known about it, how it affects the present, how to study and measure it, and how to create pathways for action". We suggest this holds true for transdisciplinary research on sustainable food system transitions. For example, bridging gaps in stakeholder inclusion in co-design/co-production processes takes a similar approach to ensuring inclusive engagement with uncertain futures. A lasting lesson we took away from working closely with stakeholders across Asia to reimagine transformative food system futures was how useful and generative soft scenarios

were: while transdisciplinary projects are implicitly future-oriented, soft scenarios encourage consciously "using the future" (Miller, 2018) through learning, playing and experimenting by shifting emphasis from knowledge co-creation to future co-creation.

Scholz and Steiner (2015) identify some 46 various obstacles that transdisciplinary processes encounter in practice and at different stages in the transdisciplinary process. Through our experience, soft-scenario methods serve to address a number of areas that can prove problematic, in particular during the critical initiation, preparation, and core phases of the process. These issues include: "accepting the otherness of the other," "including unconventional thinkers," "joint system/problem discovery," formation of "guiding questions," "faceting the case/problem," building "communication/shared language," "methods of knowledge integration," helping with "stakeholder identification," and "selection of scenarios, evaluation perspectives, and evaluation criteria" (Scholz and Steiner, 2015, p. 657–659). In addition, we find that "limited perception of possible futures" or "futures literacy" are issues not visible present among the 46 transdisciplinary obstacles, which further supports the argument for more cross-fertilization between the futures literature and transdisciplinary studies.

The degree to which dominant food systems need to transform is unprecedented—all sectors of the food economy require "rapid and ambitious" change (Clark et al., 2020, p. 1). This is the driving force behind the need to focus on critical food futures. However, complete food systems transformation can seem like an overwhelming, almost unimaginable task. By assisting in "turning our attention not only to futures as they are presented, but also to "futures-in-the-making" or futures as they are made", soft scenarios are a tool to challenge "predominant ideas about and conceptions of the later-than-now", and "deliberately but sensitively steer images of the future in empowering—and ideally also environmentally-friendly and democratic—ways" (Mangnus et al., 2021).

Looking ahead, we thus propose close theoretical and practical collaboration between transdisciplinary and futures-oriented researchers and practitioners. Experimentation with soft scenarios methods in transdisciplinary settings is expanding into many different fields—comparing the effectiveness of these methods in generating useful and appropriate policy and intervention ideas. In particular, how these methods make assumptions about the future tangible and explicit, enable the recognition and appreciation of diverse perspectives and worldviews, expand receptiveness to unimaginable futures, and develop futures literacy. What are the barriers or enablers to further binding transdisciplinary policy development processes with immersive soft scenario methods and do these experiences yield more robust policy ideas than typical policy development (Kantamaturapoj et al., 2022)? What seemed a particular hurdle in transforming food systems—their embodied and habitual nature—may, instead, pose an advantage. Through learning, playing and experimenting with critical food futures, many of our participants felt empowered to reassess their relationships with food in the present and arrived at a core principle for sustainable food systems that ended up becoming our project catch phrase: enough is as good as a feast.

Conclusion

In this Perspective we have argued that transdisciplinary processes concerned with sustainable food system transformation need to meaningfully engage with critical food futures, an approach to actively interrogate the underlying assumptions, values, and worldviews that reinforce how the current food system operates. Through three examples, we demonstrated how soft scenario methods can empower learn about, play with, and experiment in futures. First, an exhibition of 2050 school lunches explored climate scenarios and their effects on food, communicating future uncertainty and helping students to question assumptions about the future. Second, a serious game allowed participants to play with roles and rules in a local food system setting to appreciate the complexity stakeholder interactions while highlighting intervention potential. Finally, a series of workshops combining visioning, scenario narratives and backcasting fostered experimenting with alternative social practice outcomes and policy implementation pathways. Critical food futures thus foster food literacy, which participants of transdisciplinary co-production and co-design processes can draw upon to "use the future" in transforming food systems toward sustainability.

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.

Author contributions

CR and SM: conceptualized the paper and wrote the first draft of the manuscript. All authors contributed to workshops, data collection, data analysis, manuscript revision, read, 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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Ex-post consequences of participatory foresight processes in agriculture. How to help dairy farmers to face outcomes of collective decisions planning?

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The analysis of the consequences of participatory foresight in agriculture over the long term is little studied in the scientific literature. In particular, it questions how farmers deal with the proposed scenarios afterwards and the modalities of their implementation. This article aims to overcome this by proposing an ex-post analysis of a foresight process with New World Kirkpatrick's Model (NWKM) carried out in mid-2018 in the Fourme de Montbrison cheese Protected Designation of Origin (PDO) area in the Massif Central (France). A set of 24 semi-structured interviews was conducted in spring and summer 2020 with the dairy farmers involved. Moreover, collective organization has been investigated through participatory observation and an analysis of project's progress reports until March 2021. The results show that while the engagement of farmers in the collective dynamic remains, it needs to be continuously rebuilt over time, particularly in order to overcome the effects of social risk-taking and insecurity that farmers must face. In addition, the place of stakeholders needs to be clarified. The article proposes a series of guidelines based on the project's experience and the "Monitor and Adjust" approach of the NWKM. It demonstrates the importance of establishing long-term follow-ups to foresight approaches to encourage farmers into action.

KEYWORDS

prospective, agricultural extension, participation, local governance, PDO

Introduction

Participatory foresight (also called prospective or scenario-guided) consists in an inventory of situation (or diagnosis) carried out jointly with people concerned, with or not experts, followed by the development of scenarios (Vervoort et al., 2015). It is often conducted for a decision-making (shared or by public decision-makers), or even the construction of an agenda of actions. For the past 20 years or so, participatory foresight has been the subject of a real enthusiasm in the fields of agriculture to address environmental or food issues in urban or rural areas (Reilly and Willenbockel, 2010; Vervoort et al., 2014; Hebinck et al., 2018). It is seen in particular as a means of

questioning local strengths and aspirations of different stakeholders (farmers, citizens, consumers, etc.), building resilience in face of crises (global markets, climate change, etc.), establishing new strategies (sectors, new products, etc.) or dealing with territorial recomposition (Duru and Therond, 2015; Barbier et al., 2016). The introduction of a participatory dimension is intended as a means of meeting the needs, expectations and aspirations, but also the limits and constraints of farmers as well as elected officials and citizens… (Abrantes et al., 2016) and gives visibility to local unknown actors (Imache et al., 2009). The methods can then vary (shared diagnosis of territory, decision trees, public meetings, films, creative imagination, serious games, etc.). However, they follow a fairly common operating philosophy (Nikolova, 2014) based on modes of thinking and layers of reality (Voros, 2006). The mobilization of firms specializing in these services is regular and some extension professionals develop competencies in this way (Labarthe and Laurent, 2013; Hauser et al., 2016; Knook et al., 2020).

Many scientific publications highlight the use of participatory foresight approach in the North (among others: Oteros-Rozas et al., 2013; Vervoort et al., 2014; Hautdidier et al., 2016; Mangnus et al., 2019) and in the South (among others: Hertzog et al., 2017; Van Klink et al., 2017; Ajilore and Fatunbi, 2018; Blancas et al., 2018; Schmitt Olabisi et al., 2020). In agriculture, a major orientation since the 90's tends to make participatory foresight, not only a tool for anticipation or prediction, but also a tool for collective construction for action (Ramos, 2006, 2017). Lardon and Noucher (2016), relying on several authors, thus see it as an attitude for action, a way of moving from seeing to doing. Given the fact that actors are involved and that they take ownership of the proposed approaches, and that these approaches make it possible to link political incentives and local initiatives, prospective approaches would gain a certain legitimacy and could be put into action more easily. Participatory foresight would above all be a factory of cognitive arrangements able to promote change and action: questioning preconceived and dominant ideas, building capacity, transforming representations and reconfiguring the interplay of actors to make it easier to take the initiative (Ramos, 2017; Hebinck et al., 2018; Szetey et al., 2021).

However, we often note the absence of a real analysis of the concrete actions carried out following these participatory foresight processes in agriculture, of their scope, of the actors involved, but also of the possible discrepancy existing with participatory discussions and actions taken afterwards. While some studies have addressed the reason of farmers to get involved in participatory research projects, few have attempted comparable studies/researches on the question of real actions *a posteriori* (Vlontzos et al., 2021). It's particularly true with farmers although they play a key role as the primary operator that acts on the territory (Menconi et al., 2017). This may seem understandable because the involvement of researchers in the field rarely takes place over a long period of time. The observations of participatory foresight are thus often short term, whereas the anticipated transformations take place over a longer period of time, especially in farms. Moreover, as highlighted by Barrett et al. (2021), foresight research exhibited considerable naiveté around the potential for scientific knowledge to resolve barriers to the adoption of innovations by producers and, more broadly, to ensure the inclusion of underrepresented groups like farmers. This is reinforced by a large promotion by local extension workers of technical and scientific approaches of knowledge only, who neglect the results of the participatory process (Landini, 2020). Thus, the developed perspectives, changes, innovations, modifications at the agricultural level seem to be difficult to put into action or even to be monitored as illustrated by Rollin et al. (2017) or Antier et al. (2021). These authors show that the approaches are often reduced to the actors likely to participate without friction into it. In this case, actions deeply challenging existing socio-technical practices and productive models of agriculture, are absent from the agendas in the field. Farmers are often disconsidered and require specific power management strategies (López-García et al., 2021). For Serrano et al. (2021), agricultural actors are nevertheless impacted by the orientations chosen collectively, which might come up against their own aspirations, choices and adaptive capacities.

In this perspective, this article addresses the question of the capacity of participatory foresight to generate tangible changes of practices among farmers. It aims at analyzing in a comprehensive way the effects of participatory foresight on the actions of farmers in their activity over several years. The central hypothesis is that the scenarios of participative prospective studies are not adapted directly to farmers. Understanding the kind of subsequent adjustments and negotiations needed for action is essential in terms of support for agricultural extension services.

Materials and methods

Context

This study took place on the PDO area of the Fourme de Montbrison cheese, in the Massif central mountains in France. This blue cheese produced from cow milk is considered a minor appellation among French cheese PDO (46 cheeses), in terms of production levels, geographical area, reputation and the number of farmers and dairies involved. Currently, the geographical area of the Fourme de Montbrison encompasses 33 villages in the Forez mountains, a region where the altitude ranges from 600 to 1,300 m with a predominantly grass-based production (more than 80% of the ration for the farms). In 2020, 64 farms delivered 12.9 million liters of milk, for the production of some 668 tons of cheese proceeded by four dairies companies. Two processors

share more than 80% of the Fourme de Montbrison production. These are large agri-food companies affiliated with two major French groups. A PDO union is composed of all milk producers, processors and related institutions (control for organoleptic quality, respect of the technical specifications, inspections). It is organized in the form of a Board of Directors (BoD) of 10 people (farmers and dairies' representants). A president (always a farmer to date), is chosen and nominated by the directors to represent the union and to apply the policies determined by the BoD. Two salaried facilitators manage the coordination work.

In 2018, a research-action program was carried out at the request of the BoD in response to the low level of farmers participation in decision-making and the PDO's difficulty in projecting itself into the future. This program was based on game-based learning and has been conducted to initiate a collective dynamic and to carry out a participatory foresight. An initial six-stage process that lasted a year, in which serious games played a central role, led to the proposal of 54 actions to develop the PDO by stakeholders: farmers, processors, elected officials, tourism professionals, agricultural advisors, veterinarians, state representatives, teachers of the local agricultural college. This prospective process is detailed by Dernat et al. (2021a) and has resulted in co-constructed guidelines that constitute the backbone of a new common vision for the future for the PDO stakeholders (farmers, processors) with a 10 years horizon.

The guidelines contain four major topics: (i) the internal organization of the PDO and its functioning; (ii) communication focusing on the diversity of the product, reflecting the diversity of production methods and stakeholders, and meeting the different expectations of consumers; (iii) improvement of the product sanitary quality; (vi) an orientation of dairy production toward an agroecological and cultural heritage approach in order to improve economic (higher milk price for farmers) and environmental development of the PDO area (Dernat et al., 2021a).

This last topic involves farmers directly and is at the heart of this article. The new orientation of dairy production toward an agroecological and cultural heritage approach would lead to significant evolutions of current livestock systems. The PDO's BoD major proposition (i.e., not mandatory) was that farmers transition to an all-hay diet for the livestock (with an objective of at least 60% of PDO farms within 10 years). The switch to all-hay (from grass and maize silage, or wraps) is expected to improve both economic performances (through the valorization of milk and cheese), and ecological performances (fewer inputs needed). Particularly, the development of local species-rich permanent pastures would place an emphasis on natural heritage at the heart of dairy production. The link between grassland characteristics and the product's nutritional and sensory qualities is known to appeal to consumers.

After the foresight, in 2019, a process of implementation was initiated within the PDO. A group of farmers, representing 25 farms (of the 69 total farms), voluntarily formed to work on the reorientation of dairy production. The group is facilitated by the PDO board staff, which organize meetings and other events such as training and field trips on a regular basis. In the first post-foresight year, 2019 and until mid-2020, a direction was chosen by the PDO administrators to discuss first and foremost with farmers the all-hay issue collectively in the PDO area through a series of meetings, visits and training (Figure 1). The central idea was to continue the exchange and to highlight the knowledge (local and scientific) necessary to implement changes in practices on the farms.

Farmers received a lot of information about different options to implement an all-hay diet. Quite soon in the process, an emphasis was given to the practice of barn drying. In addition to the flexibility that barn drying confers to the harvest and storage of good quality hay (a crucial point), this practice has other perceived advantages such as a reduction of working time. Moreover, four farmers were already practicing barn drying, providing opportunities for collective learning. About eight events were organized with the farmers and other local stakeholders who had participated in the foresight.

The research team continued to participate in this phase both to support the operationalization of the actions and to analyze them, with the question: How to help farmers to face the outcomes of collective decisions planning?

Data collection and analysis

The data collection is structured as proposed by the fourth level of New World Kirkpatrick's Model (NWKM), as shown in Figure 2 (Kirkpatrick and Kirkpatrick, 2016). Usually used in training and learning programs, Kirkpatrick's model is a recognized conceptual model to evaluate learning processes in agricultural education and extension (Murphrey et al., 2018), and lends itself particularly well to assessing the outcomes of foresight (Gary, 2019).

The first level refers to which participants find the foresight favorable, engaging and relevant to their jobs. It could be assessed by how participants are actively involved in and contributing to the learning experience. The second level refers to which participants acquire the intended knowledge, attitude, confidence and commitment based on their participation. These first and second levels have already been assessed in a short-term assessment (Dernat et al., 2021a): farmers were largely satisfied by the foresight process (level 1: assessed from the debriefing at the end of the collaborative day and at the end-of-year general assembly), and have shared and learned many knowledges and engaged themselves through the project (level 2: assessed through interviews and observations during the whole foresight process).

The third level refers to the new behaviors and attitudes toward action. It is evaluated by processes that reinforce, encourage critical behaviors and foster on-the-job learning.

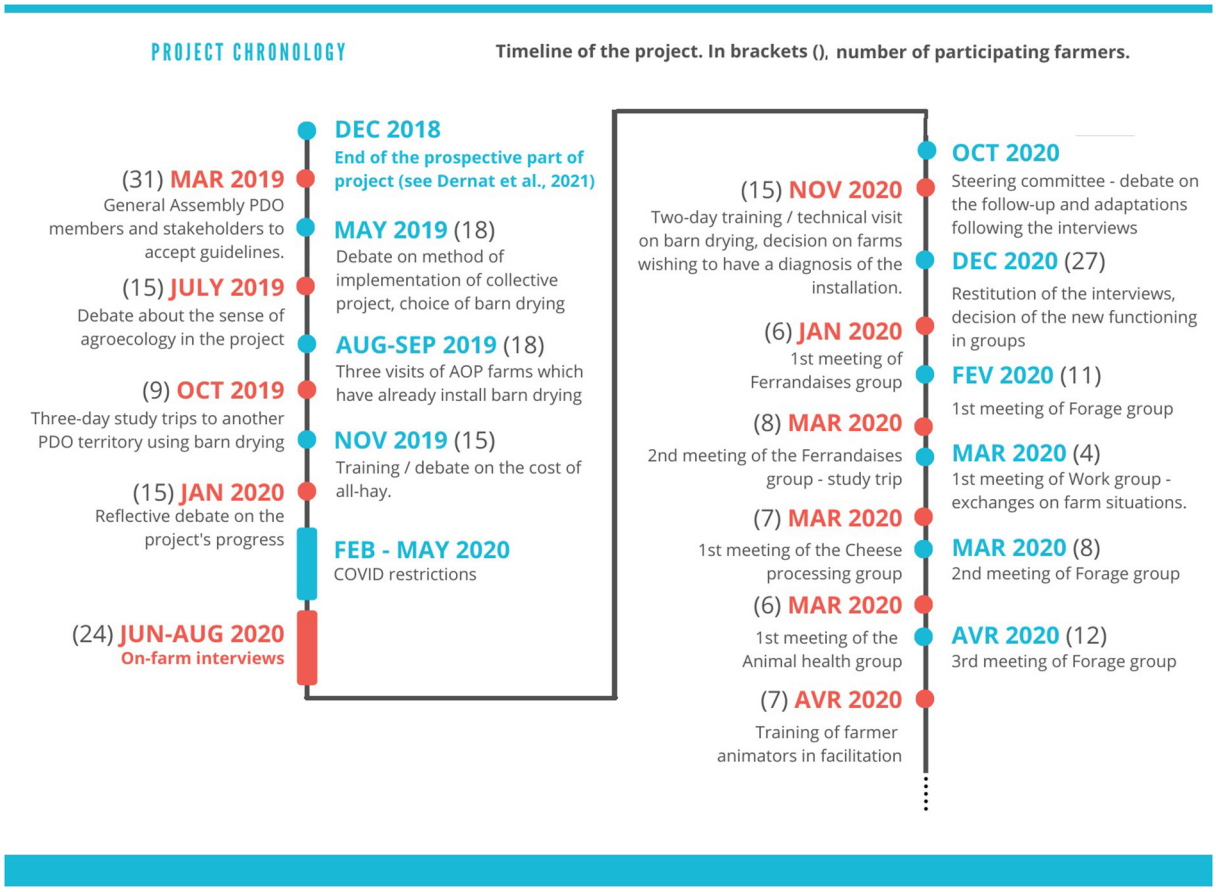

FIGURE 1
Timeline of the project between December 2018 and April 2020.

The fourth level concerns the result of the process, which aims to define what is produced in reality. Here, it is what the participatory foresight has been able to achieve in action: setting up new structures, new practices, new organizations, new activities, etc. It could be assessed by mid-term observations and measurements (leading indicators) suggesting that critical behaviors are on track to create a positive impact on desired results. These two levels are at the core of the present article. According to the NWKM, levels 3 and 4 should be monitored and adjusted over time. The assumption here is that foresight is not an end by itself, but an ongoing process.

Our research team followed all the meetings and events since the collective foresight. We assume a participatory research stance, meaning that we are not passive observers in the process, but also active contributors. For the analysis, we mobilized 26 reports from project meetings, all validated by the farmers/stakeholders participating in the project or by the scientists. They provide information on the evolution of discussions and interactions within the group and with other stakeholders in the area. Reports on trainings, projects and interventions carried out by stakeholders are also aggregated with the data. Moreover, interviews were conducted with 24 farmers of the voluntary group between February and September 2020. The interviews lasted between one and a half and 4 h and were often coupled with a farm tour. They were conducted in a comprehensive approach (Kaufmann, 2011), based on a general structure and open questions. After a brief overview of the farm's history, the farmers were asked about their vision of the collective dynamics, the follow-up of the participatory foresight, the limits or opportunities, and their wishes for the further application in the PDO. The comprehensive approach is not based on similar interviews but on a process of building knowledge as the interviews progress. All interviews were recorded and then transcribed in full. In accordance with French legislation, the agreement of each participant to the collection and use of the data was obtained beforehand. All recommendations relating to the European Data Protection Regulation have been complied with.

The interviews and reports were subjected to a thematic analysis (Terry et al., 2017) with the software QDA Miner Lite

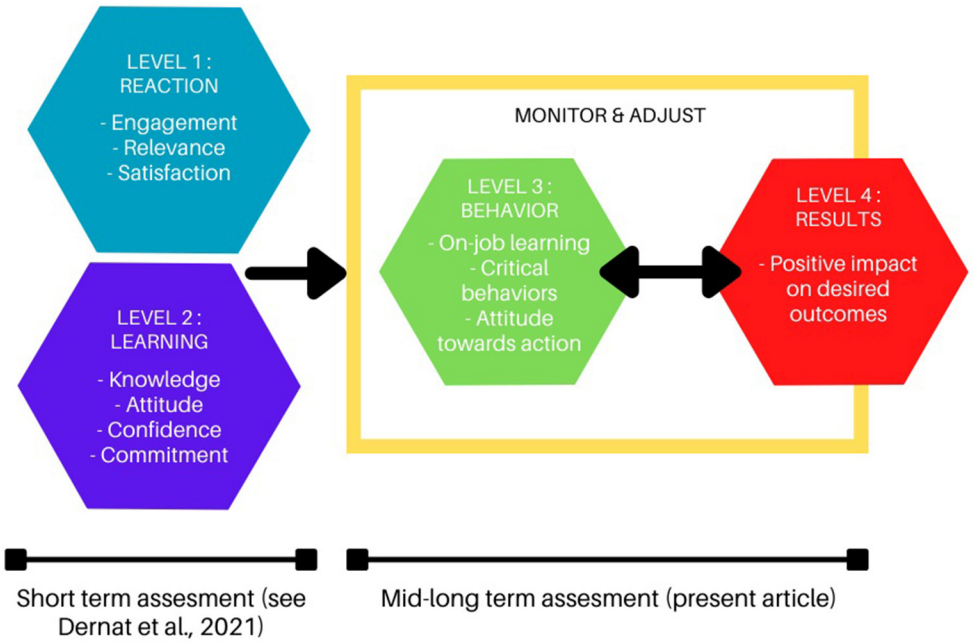

FIGURE 2
New World Kirkpatrick Model (NWKM from Kirkpatrick and Kirkpatrick, 2016).

(v2.0.8, Provalis Research, Montreal, Canada). This analysis allows to identify the salient points in the farmers' discourse. Based on comprehensive interviews (Kaufmann, 2011), this type of analysis does not produce thematic quantitative data. The software is used here to facilitate the identification of salient theme elements based on the model of understanding mobilized in the interviews. A coding of the text is conducted and then refined to produce a thematization (Lejeune, 2019). A first reading is carried out to bring out an initial exploratory of discourses. Each interview is then reread to identify the different themes present, or even to add new emerging themes. This second reading allows the thematization to be refined. A cross-cutting reading of the themes is then carried out and analyzed with the elements of the reports in order to complete it. This method allows the model of understanding to be saturated in order to make the situation under analysis explicit. The data from the project meeting reports provided additional material for building the model.

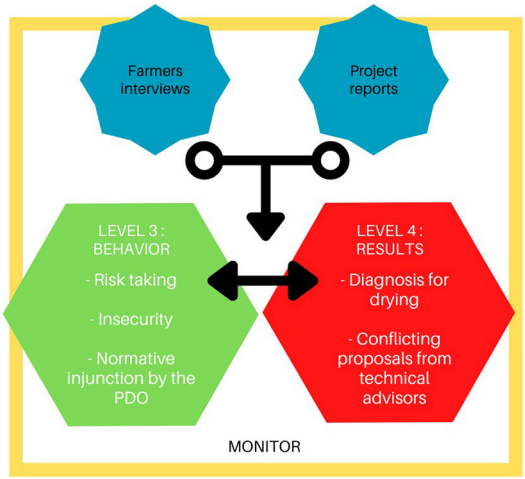

FIGURE 3
Monitoring of behavioral changes (level 3) and practical results (level 4), based on New World Kirkpatrick Model (NWKM).

Results

Project monitoring

Figure 3 summarizes schematically the results obtained from the data collection and analysis, which are then detailed in two parts: the farmers' representations of the post-foresight process and relations between stakeholders.

Farmers' representations of post-prospective process

The analysis shows that the work on barn drying after foresight process gives some results and is translated into actions. Mid-2020, six farms have carried out a diagnosis to install a drying system, in addition to the four farms that already

have one. However, a majority of farmers are still skeptical about the facilitation carried out in relation to this theme of drying system, mostly focused on a technical dimension. For some farmers, the all-hay and barn drying proposals were perceived as a misjudgment on their work, in favor of those who already have a more agroecological approach. Some of them even perceive themselves as being outside of what the PDO wants and this worries them. They think that the PDO standards will evolve without them. For them, there is an overvaluation of farmers who have barn drying. There are also assessments like: *others are looking favorably on the proposed changes whereas I do not feel capable of doing so, or those who will switch to all-hay will have problems, such as keeping the cows in good milk production*. The risk-taking by farmers is at the heart of the debate. In some interviews, "all-grass" appears as a preliminary step toward all-hay. This is easier to initiate but still raises the question of possible shortage of fodder due to drought. All-grass production would be a first argument to the consumer to maintain a favorable economic dynamic before considering all-hay production.

> "In the PDO they talk a lot about hay. I have nothing against hay, but afterwards... all our farms are already limited in terms of food autonomy. Putting everyone on hay... I'm not sure that putting everyone on hay will solve the problem of self-sufficiency. [...] In any case, with the years we've had, we can see that the grass isn't growing... Here, we grow sorghum, we grow corn... but it's not something that's fashionable in the PDO."
>
> *"I have nothing against hay, but afterwards there has to be a price for it. I have calculated that, compared to the price we are paid today, it would cost 100€ more if we set up a barn drying system. Because those who already have barn drying have finished paying for their buildings and everything. As they set up their system, they said: this is great, everyone should do this".*

Farmers have mixed feelings about how the transition to the all-hay orientation has been managed to date, which is illustrated here by a sample of verbatim quotes. Indeed, this orientation raises many questions, particularly in the context of climate change. In the light of the interviews, there is a diversity of fodder conservation methods that are used in different ways (hay dried on the ground, wrapping, silage), with various backgrounds (work comfort with reduced stress, reduction of work time during the mowing season, technical productivity), reflecting a diversity of ways in which farmers consider the risk (putting all their eggs in the same basket or not). Farmers are trying to cope with recent recurrent droughts, and crops appear to be useful buffers compared to hay. For some farmers who are not ready to switch, the all-hay approach rather appears as an injunction to change quickly. Other farmers worry about consequences of all-hay in financial terms (especially farmers at the end of their careers without a successor), but also in their daily work, which can become more stressful. These fears of change reflect the risk-taking nature of the foresight process.

> "Those who don't have barn drying, how do they get it (all-hay) valued? These are real questions"
>
> "On the one hand they say: you have to cut early to make the most of the grass and everything, because in summer it's complicated. Then, if you do all-hay, it means that the cutting is later. Instead of making two cuts, we risk making only one. [...] Before, we used to cut at the end of May or the beginning of June, but in ten years or so, we'll probably cut on the 15th of May. And to make hay on 15 May, if we don't have barn drying, it's complicated, it's even impossible. [...] Barn drying is not possible for me: the building has just been built, that's all. [...] Those who mow early today, or in silage or in wrapping, it doesn't matter, they manage to make two cuts. The parcels that are cut into hay, we only make one."
>
> "It's a whole issue [...] If you go for agroecology, you make all-hay. The parcel where you make hay you don't put ammonitrate. If you use ammonium nitrate, you have everything wrong. But if you don't use ammonium nitrate to make hay, I wish you well..."

The whole situation as perceived by farmers can be summarized as both individual and collective insecurity: as a farmer, it is difficult to know whether one's farm corresponds to expectations of the group and of the PDO and whether the intentions are collectively viable for the future. To overcome these pitfalls identified with the farmers, the new modality of a smaller thematic group on climate change adaptation is perceived as relevant for them. It remains focused on the problem of feeding, but in a broader way than just "all-hay". It brings together a large proportion of the original farmers, but without some of those who already have barn drying or those who find this dimension less central to their thinking. The group's declared ambition is still to be all-hay, but this is done in a less direct way, rather through the redesign of each farmer's systems over time. This new modality has thus brought a renewal to the project, as attested to by a farmer group leader who felt subject to the judgments of others beforehand and rediscovers through the group a renewed modality of sharing his work.

> "Before I didn't want to participate too much (during the first events on barn drying), it wasn't too positive, it was critical. I preferred to go elsewhere. But now we see that there is a new dialogue in the group, that there is sharing, it's good. For me, it's a real rebirth".
>
> "Technically, it's true, to be accompanied, to have training is always enriching. Afterwards, you really have to adapt as you go along, but managing to keep a dynamic is the most important thing. Otherwise everyone works in their own corner. You have to set a common objective, otherwise

> one person will say 'I'm very good', but... there are some who are very good but who don't necessarily go in the direction they should in the long term. We really need to get everyone on the same path, so that in a few years' time, if we need to have a common solution or eventually switch to all-hay or 80% hay, if we're already moving in the same direction in the group, it will be easier to get everyone on the same path. Even if we are not too many in the group, it doesn't matter, everyone has ideas."

Relationships between stakeholders

Two important issues related to the relationships between the different stakeholders: PDO farmers, processors, PDO union, technical advisors, others farmers…

The first issue concerns the role of the PDO union as a support body for farmers and the cheese sector. The farmers were initially very critical of the PDO union's reappropriation of the collective dynamic by encouraging barn drying. In their view, the PDO union had adapted the proposals decided collectively to meet its own needs, in particular with barn drying.

> "That's my opinion, I was still surprised... When we had our meeting in Montbrison (during the 2018 foresight)...then it came out that (he talks about barn drying). I think I'm not the only one to have seen it and say today that it's surprising that it's focused on that. But I was still surprised. The last years there is no problem to dry hay. I would even say that this year we will soon be able to do without barn drying and it will work by itself. No dew, wind... it dries itself. But a few years ago, in 2016, those who had barn dryers were unable to make hay, they made fermented grass wraps".

The second issue concerns the role of some stakeholders involved in agricultural extension (local advisers: Chamber of agriculture, milk control) or education (local agricultural high school). In farmers' discourse, these stakeholders are presented as skeptical about the whole process oriented toward agroecology. Rather, they value a purely technical-economic approach, focused on productivity. During the various events organized in the first year, several interventions in this sense were noted. In particular, a training session was held by PDO board and animated by a private extension firm that openly criticized forage production centered on hay, in disagreement with other interventions proposed elsewhere. The farmers also reveal that these advisors, who are present on the farms on a daily basis, criticize the project and its progress. In this way, they support the farmers in their current practices, which they themselves have facilitated in the past. They even suggest new practices openly in contradiction with the collective "all-hay" orientation, such as the introduction of maize as a strategy to cope with global warming. As a farmer said:

> "I think we were going in the right direction. From a blank sheet of paper, we started with a nice concrete thing. Afterwards, we noticed that it was still a bit slow. What's the reason for this? We weren't helped by... I wasn't there, but on barn drying the intervention of the milk controller was... It's my milk controller though. But it's the typical speech: we don't have to change, we make a lot of milk and that's it. So, when you have interventions like that when there are people who could potentially leave in a system, you destroy everything in a short time."

Project adjustment

After the interviews with farmers, consistently with NWKM model, the project dynamic was adjusted. This was done on the basis of proposals from the researchers and with agreement of the PDO board (Figure 4). Five thematic groups were designed to correspond more closely to the evolving expectations of farmers. The first group (1) deals with the adaptation of feeding to climate change, especially for farmers for whom drying in barns was not suitable (too expensive, operation not suitable in the short term). This group proposes more specifically to exchange collectively, to come to an agreement and to test innovative solutions adapted to the PDO. The other four groups are related to other orientations already present in the foresight. The second group (2) is interested in the integration of the local Ferrandaise breed into the herds (heritage and biodiversity), with the medium-term objective of producing a cheese solely from the milk of this breed. Currently, 90% of the cows on the farms are of the Montbéliarde and Prim'Holstein breeds (with a predominance of Montbéliarde), the remainder being made up of Alpine breeds (Tarine, Abondance), Jersiaise and mixed herds. A group is working on cheese production (3) in order to share techniques between dairies and farm producers to improve quality in the PDO. Animal health and welfare is the focus of a fourth group (4). The aim is to exchange tips and tricks between farmers to reduce the use of medicinal inputs while improving welfare: for example, for drying off without antibiotics. Finally, the last group (5) focuses on the wellbeing and working conditions of farmers at work. This group aims to encourage everyone to express themselves in order to resolve tense situations, and to (re)develop relationships through activities related to work issues (debates, joint events, etc.).

Each group is thus managed by a duo formed by one of the PDO facilitators and a farmer, and supported by a researcher of the project. The presence of the farmer as group leader aims to strengthen shared governance. This rebalances the exchange and promotes mutual trust in the shared project through common governance. The groups are much smaller and operational: farmers could participate to all groups but in fact choose the one or two groups which are the most relevant for them. Figure 2

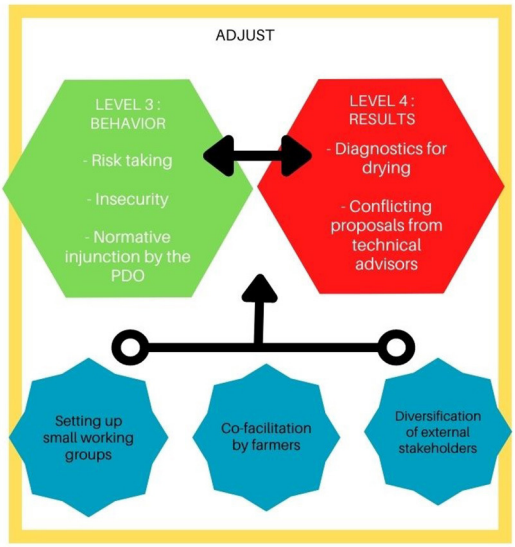

FIGURE 4
Adjustments of behavioral changes (level 3) and practical actions (level 4), based on New World Kirkpatrick Model (NWKM).

presents the timeline of the project, with the number of farmers in each event. The evolution is marked by a switch from events with a unique group of 15–20 farmers at the beginning, to multiple thematic groups with 4–12 farmers per event. The thematic groups are particularly relevant to allow motivated farmers to propose relevant solutions, to be more reflexive collectively and to test them more quickly on the ground.

In order to keep the discussions open, it was decided to involve other stakeholders from the public or non-profit sector. In this way, the diversity of worldviews in the interactions with the farmers is strengthened, bringing a more nuanced approach and balancing the discourse of skeptical advisers. In practice, this adjustment reduces the insecurity felt by some farmers in relation to conflicts between too contrasted discourses. They feel more confident to propose ideas and test them on their farms.

Discussion

Articulating collective and individual support to deal with social risk-taking

As López-García et al. (2021) point out, participatory processes have better chance to work if farmers are specifically managed over the course of participation. Our results illustrate well what Rollin et al. (2017) or Antier et al. (2021) say about the limits of including farmers in participatory perspectives. Implementation on the ground after participatory foresight is not a self-evident fact. An essential element is related to the risk-taking that farmers experience in these processes. This is an important element but is often discussed in a general and economic way (Slijper et al., 2020). We refined it by the example of farmers' view of the all-hay option: farmers worry about the risks related to climate variability and tend to consider more secure buffer adaptations, like the insertion of small areas of crops (Darnhofer, 2014). Our results show that risk-taking is not only perceived by farmers from an economic point of view but also from a social point of view, involving especially changes in their work and their perceptions of it. There is a form of negotiation that takes place between what changes in the collective and what the farmers change at home (on the farms, about themselves, about their work activity). This negotiation is made up of back and forth, involvements and withdrawals. In the interviews, we note many questions anchored in daily life: how to organize myself? Am I doing my activity wrong? Despite it allows critical thinking (level 3 of NWKM), participatory foresight can then appear as an injunction to change and a form of judgment. Risk-taking must therefore also be understood in terms of the perceived norm, i.e., the farmers' perception of how others will judge the planned changes (Khamzina et al., 2021).

This raises questions about the historical shift from agricultural extension to participatory approaches, where the networking of heterogeneous stakeholders has become a major strategy for innovation (Koutsouris and Zarokosta, 2020). Historically, since the end of the 1980s, agricultural extension has been based on individual advice oriented toward technical and economic performance (Labarthe and Laurent, 2013). This can be found in some advisory or education structures of the farmers in our case study (chamber of agriculture, milk control, agricultural high school) which are attached to technical performance with a top-down and question-answer approach to advice as evoked by Coquil et al. (2018a). The metric through which farmers analyze their daily lives and futures is therefore linked to this: it is often technical-economic and short-term. By questioning this metric in the participatory approach (long-term projection, insertion of socio-environmental arguments), the farmers then feel insecure because they find it difficult to hold on to everyday assessment elements. The evaluation of the 3rd level of the NKWM was therefore not a complete success and require adjustments. Support for risk-taking in the transformations induced by participatory foresight must therefore be central and must be achieved by reassuring farmers, redefining metrics and be more open to new criteria (image of the farm, environmental factors, consequences on labor…).

Allowing a continuous (re)building of the foresight

In order to best support farmers in participatory foresight processes, or even participation in general in agricultural extension, it seems necessary to design a continuous articulation

of collective and individual scales. The articulation of the scales of design and the coherence of the project and the scenarios must allow the regulation of collective and individual insecurity: it must encourage the adaptation of farmers to new and more systemic forms of assessment of their work (Coquil et al., 2018a). During the studied period, the structure of the collective project has been modified, from a global approach to smaller and operational farmers' working groups. It corresponds to the fourth level of NWKM by allowing new structures and activities which encourage critical behaviors to impact desired results. These groups make it possible to discuss design solutions directly, while avoiding the pitfalls of a larger number of participants: isolation, asymmetries of roles and knowledge… In this way, they are similar to communities of practice groups (Lave and Wenger, 1991) used in agriculture, focused on the exchange of practices and reflexivity (Morgan, 2011; Dolinska and d'Aquino, 2016; Coquil et al., 2018b), although they do not fully meet all the characteristics of it. This process of operational transition to small groups of farmers on issues that concern them following a broad participatory foresight seems relevant. The participation of all farmers in all actions is therefore not a need, nor a necessity. However, this is sometimes seen as a form of frustration by farmers who would like to participate in everything but cannot due to lack of time and feel that they are not following "what is said" in the groups. This could be improved by better internal communication as proposed by the farmers themselves.

The question of scales seems to be of primary importance for a continuous renegotiation of collective objectives. It is essential to recognize what is reasonably achievable both spatially and temporally for farmers on an ongoing basis. Our study provides a clear illustration with the "all-hay" scenario, which was initially negotiated as a 10-year objective. In practice, it appears that this is not an achievable objective for some farms, for different reasons: financial, technical, no successors, no motivation or unfavorable agroecological conditions. It is necessary to establish intermediate adjustments with each farmer to pay equal attention to how people break with past practices (Vetter, 2020). In the present case, an intermediary objective has been identified as "all-grass", which includes practices such as fermented grass feeds (silage and wraps), reducing crops and concentrated feeds and putting more the grasslands at the center of the feeding system. This allows an intermediate point to be reached which does not remove the initial objective while maintaining the dynamic with the farmers.

It seems important to go beyond the injunction to be participatory in foresight approaches to think of it as a continuum for action. There is a continuous process of (re)building the implementation of scenarios produced with and by the farmers and stakeholders. Allowing continuous adaptive renegotiation of scenarios by groups of farmers, without questioning the initial orientation, thus appears as a relevant guideline.

Adaptive governance with stakeholders

Finally, to achieve the described (re)building, the governance of the partnership over a longer term is a key element: it is necessary to define instances specific to each territory, adapted to local contexts, knowledge and farmers (Nettle et al., 2017). Such adaptive governance has to be aware of power issues between stakeholders' contrasted approaches. In our case study, some extension or education workers (especially private) actively promote technical and modern approaches that neglect the results of the participatory process (Landini, 2020). This is reflected in everyday speech (outside of collective activities) to the farmers. There is a pursuit of legitimacy in the territories by these stakeholders from the agricultural extension, in concurrence with other public or non-profit actors of extension (Prager et al., 2016). These stakeholders are generally companies and associations that depend on support through training, advice, diagnosis, etc. They have an interest in proposing actions quickly that meet both the needs identified, sometimes at the expense of collective orientations as the stakeholders' areas of action are overlapping. This tends to increase the phenomenon of autonomization or individualization of farmers practices (Dernat et al., 2021b). These elements are critical to the fourth NWKM level of evaluation of our support. Even if the project allows the setting up of new structures to think about new behaviors, it remains limited by the typology of actors and their actions. The initial resources put in place to manage the partnership did not allow the construction of a concerted support. It seems that it would have been possible to collectively rethink each other's ways of thinking earlier.

Our findings on farmers' insecurity and partners' relationships confirm propositions of Richter and Christmann (2021): key players are needed for dealing with internal opposition and overcoming external hurdles. These elements argue for the implementation of intermediation between stakeholders in agricultural extension to promote better risk management (Bertolozzi-Caredio et al., 2021) and farmers' role transitions (Hauser et al., 2016). This also means building an approach to advisory work, which must itself be understood more broadly as an intermediation, as Koutsouris (2014) points out. It therefore requires a change in the local level of coordination of actors (Faure et al., 2019). In our case study, returning to the farm with a small group of farmers, accompanied by various advisory actors, has been useful in understanding how the instrumental change could be implemented. Small groups are also useful to deal with the large diversity of worldviews in the present case study. It differs from other situations in literature where collective action is facilitated because farmers and advisors share more similar ideological commitment, as described by Coquil et al. (2018b, 2019). To better understand effective adaptive governance, it seems important to put these new local micro-governments

(small thematic groups of farmers in this case study) on the agenda of research on social innovation in agriculture (Klerkx, 2020).

Study method limits and strengths

Our results must of course be moderated with regard to our sample (which does not represent all the farmers of the PDO) and the specificities of our case study. Moreover, the comments of the farmers interviewed depend fully on the period of data collection. The study time can also be limiting (two years after the foresight) and has been impacted by the COVID-19 crisis. It will be interesting to revisit the farmers after several years of monitoring. It can nevertheless be considered as a long-term analysis in view of the existing literature, which is generally limited to a maximum of 6 months after the foresight. The interest of this study is also in revealing a rapid need for adjustments in facilitation of this type of project with farmers. These results shed important light on the scientific literature on participatory foresight processes including farmers by allowing us to approach longer-term effects. The creativity of participation with a diversity of stakeholders, which is often valued, can thus be faced with a number of long-term pitfalls. Although accepted in foresight processes, proposals may be difficult for many farmers to apprehend over time. However, there is still a black mark: the recurrent non-participation of a small number of farms that categorically refuse any link to the project (or to the PDO collective). Even if reasons can be given (no takers for aging farmers), some remain outside without any obvious reason other than a clearly stated lack of interest.

Conclusion

Participatory foresight does not translate automatically and straightforwardly into tangible actions on the field afterwards: it needs to be monitored in the mid and long term. The farmer, actor of change, cannot be left alone on his farm to adapt practices that have been decided collectively at a different scale, far from his daily life. Particularly, our study suggests that risk-taking must be at the heart of the transition process, and managed through a governance design that allows continuous monitoring between the collective process and the individual situation on the farm.

In the context of the Fourme de Montbrison area, the creation of small thematic operational groups working in a similar way as communities of practice seems to be a promising innovation. These thematic groups encourage the exchange of knowledge and reflexivity in order to adapt the guidelines of the foresight to the farm context. In the process, it is necessary to move away from a traditional technical-economic vision, and to move toward a systemic vision of the adaptations that can deal with huge uncertainties and local specificities.

As a perspective, this research demonstrates the value of an analysis in the longer-term analysis (in terms of analysis of the 4th and 5th levels of the NWKM) to provide new solutions to agricultural extension. This is fully consistent with Williams et al. (2020) on the role of collaborative action research to coordinate challenging imagined scenarios and actors' routines, joint development of concepts, collection and sharing of new information, tensions, generation of ideas, and new tools or frameworks. Whereas, the duration of research projects is generally very short-term, our study shows the interest of an analysis in the longer-term analysis and follow-ups to provide more appropriate solutions to ongoing environmental transitions. In this sense, the mobilization of a general evaluation framework such as the NKWM brings a definite added value. It avoids a short-sighted analysis which only points out the favorable elements and also allows the necessary adjustments to be made with the farmers throughout the implementation process.

Data availability statement

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

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. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SD and CR wrote the first draft of the manuscript and reviewing versions. RE, NH, and J-YP provided suggestions to improve the manuscript. All authors approved the final version of the manuscript.

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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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Co-creative research for transitioning toward a fair and sustainable agri-food system in Brussels, Belgium

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After decades of urbanization and agricultural industrialization, the relationships between cities and their agri-food systems have been profoundly transformed, especially in developed countries. To make agri-food systems more sustainable the pressing need to rethink food-related practices in cities has received momentum in the past 20 years across many European cities. Transdisciplinary and participatory research can generate knowledge and promising solutions to facilitate the transition of urban agri-food systems. This article highlights the contributions of six research projects driven by the notion of "co-creation" research for urban agri-food system transition, using Brussels as the research context (program "Co-Create"). The article outlines the main research foci and characteristics of the six "Co-Create" projects funded by this call, how they are embedded in the broader dynamics and initiatives of Brussels, and the theoretical foundations of the notion of "co-creation" research that sits at the intersection of transdisciplinary and participatory action research. Subsequently the paper illustrates how the six Co-Create project brought together different actors in Brussels including researchers, citizens, associations, and government agencies, that were united with a shared awareness of the need for change of the city's agri-food system. The six research consortia targeted different issues across three aspects of the agri-food system: agricultural production in urban areas, food distribution and marketing, and accessibility and democratization of sustainable food. We critically reflect on some common insights generated by the six projects, and particularly (a) a series of recommendations that were drafted for public authorities and called for the acceleration and strengthening of efforts for urgent changes in the agri-food system of Brussels, and (b) findings that address the epistemological and methodological strengths and limitations of conducting co-creative research processes to facilitate agri-food system transition. We also discuss how the Co-Create projects might have created a historical momentum that has encouraged the placing of the transition of agri-food systems on the political agenda of Brussels, and by identifying future challenges for agri-food system transitions in Belgium.

KEYWORDS

participatory action research, co-creation, transition, agri-food system, transdisciplinarity

1. Introduction

Urban regions are now home to more than half of the world's population, and pose significant economic, social, and environmental challenges to the sustainability of the global agri-food system (Brand et al., 2017; Partzsch et al., 2022). Shaped by decades of agricultural industrialization, concentrated supply chains and increasing urbanization, the links between cities and their hinterlands have been profoundly transformed (Hoggart, 2016). The current relationship between cities and agri-food systems is characterized by their increasing geographic distance, economic distance (e.g., multiplication of intermediaries), cognitive distance (e.g., lack of knowledge about food production conditions and the agricultural sector) and political distance (e.g., loss of citizen control over agri-food systems). In addition, many city dwellers are food insecure, in that they face difficulties in gaining physical, economic and/or cognitive access to healthy food (Paturel et al., 2015). This results in the greater vulnerability of current urban agri-food systems, both ecologically (IPES-FOOD, 2021) and socioeconomically.

Faced with these challenges, it is essential to ensure the sustainable future of cities and societies by transforming the functioning of local agri-food systems in order to make them ecologically sustainable, socioeconomically equitable, and less vulnerable (and therefore more resilient) (Servigne, 2013; Sage, 2014; Tornaghi, 2016). Over the past 20 years, food-related practices have been rethought in many countries, from local production to local consumption and distribution. This is evident by the numerous local initiatives that are tackling these issues by proposing alternative and innovative practices that are ecologically and socioeconomically sustainable (Booth and Coveney, 2015). This includes urban agri-food systems, including in several of the major cities of the global North (Vicente-Vicente et al., 2021).

As a result, all over the globe, various new ways and practices have emerged to develop sustainable alternatives to the conventional agri-food system. Many of these initiatives have innovated and proposed "alternative paths" around three sets of practices associated with the functioning of agri-food systems (Forssell and Lankoski, 2015). First, most promote or implement production practices that are environmentally and socially conscious, capable of facing future ecological challenges, and more specifically climate change and the erosion of biodiversity. Such examples include organic, peasant or agroecological production models. Second, in many urban contexts we increasingly observe institutional and citizen-driven experimentation to reconnect agriculture and food through socio-economic innovations and shorter marketing chains.[1] Short and proximity circuits (Praly et al., 2014) have become an archetype of these innovations for urban food supply, and are aimed not only at reducing the geographical distance between food production and consumption, but also the cognitive and information distance. Thirdly, these alternatives attempt to reconfigure the modes of governance of agri-food systems. They question the power relations within food chains and invite the development of a food democracy (Renting et al., 2012). These sectors are experimenting with participatory and cooperative modes of organization and governance, where the actors at the heart of these networks (i.e., producers, distributors, consumers) are trying to make decisions jointly, both to define ways of producing and to rethink food distribution and "eating well". Through access to (and participation in) decision-making processes, and by giving back power to all actors in improving the distribution channels, such alternative food initiatives are working toward building a food democracy, anchored in values of social justice and equity (Lohest et al., 2019).

In most cases, alternative food initiatives combine innovations across several of these three sets of practices to improve the sustainability and resilience of the agri-food system. Indeed, many authors have hypothesized that solving the highly interlinked environmental, health, social and economic challenges related to the functioning of the globalized agri-food system would benefit significantly from the innovations promoted by such alternatives (Marsden et al., 2000; Lamine, 2015; Maye and Duncan, 2017; Chiffoleau and Loconto, 2018; Chiffoleau, 2019). In terms of the environment, these could enable the better preservation of natural resources through more environmentally friendly production methods and reducing the distance between the points of food production and consumption. In terms of the economy, it is expected that a smaller number of intermediaries could improve the distribution of added value and the livelihoods for small producers, as well as facilitate greater financial accessibility at the end of the food chain. Finally, the relational proximity linked to exchange practices could create social links and greater transparency about the quality of food products, allowing for forging and maintaining trust between actors in food chains.

However, the development of alternative food initiatives that seek to catalyse societal transformation would require new modes of inclusive and solutions-oriented research (Gernert et al., 2018). Participatory action research (PAR) and transdisciplinary research, are two such ways of doing research, which although distinct in their origins and epistemological foundations, share many common points and have been used in the context of alternative food initiatives (Hermesse and Vankeerberghen, 2020).

PAR encompasses various approaches with diverse origins (Kindon et al., 2007), and seeks to engage practitioners from academia, non-governmental organizations, associations, public agencies, industries, and commercial enterprises. Academic practitioners often come from very diverse disciplines, particularly within the social sciences (Greenwood and Levin, 2007). Despite some considerable methodological, epistemological, and political differences, most PAR practices share some common characteristics such as (a) the active participation of researchers and societal actors in the co-construction of knowledge, (b) the promotion of critical awareness leading to individual, collective or social change, and (c) the building of alliances between researchers and societal actors throughout the research process (McIntyre, 2008). As a result, PAR sits at the intersection of three fields, namely research (knowledge production), action (experience and transformation), and participation (life in society and democracy) (Chevalier and Buckles, 2013). To achieve this, PAR entails some distinct research mechanisms in which civil society actors and researchers collaborate to produce knowledge in the service of societal transformation. Thus, PAR has the double ambition to promote the participation

1 Frequently cited examples of urban public food transition strategies include the cities of Toronto in Canada (Blay-Palmer, 2009), Belo-Horizonte in Brazil (Rocha and Lessa, 2009), Bristol in the United Kingdom (Reed and Keech, 2017) or Perpignan in France (Perrin and Soulard, 2014). These examples show that the city can be an appropriate scale of action to weave new links between food chain actors and build more sustainable food systems (Sonnino, 2009).

of citizens and associations in research activities and the active engagement of researchers in solving social challenges. As a field, PAR is characterized by methodological plurality, including softer research and engagement mechanisms that consider citizens as "simple" providers of data for science, to stronger conceptions of "participation" understood as an active collaboration between researchers and citizens (Dedeurwaerdere, 2014). In stronger conceptions of participation, the stakeholders directly affected by the research outcomes take an active role throughout the research process and are sometimes called co-researchers (Mackenzie et al., 2012). In such contexts "*it is no longer a matter of extracting observations or knowledge from the citizen in order to feed the researcher's database, but rather of co-constructing adapted research projects with the citizen, the course of which will be characterized by a permanent collaboration leading to a better understanding of the phenomena and to the joint elaboration of solutions, a condition for an effective societal acceptance*" (GDR PARCS).[2]

Similarly, there is no single definition of the term transdisciplinarity (Mobjörk, 2009), or how to approach or engage in transdisciplinary research. There are some recurring commonalities such as "collaboration between academic researchers and social actors", "integration of knowledge", and "an orientation toward concrete problems" (de Jong et al., 2016). Although transdisciplinary research developed primarily around issues related to climate change and environmental sustainability, it has expanded into many other fields such as technology, education, arts, and the social sciences (Bernstein, 2015). Generally transdisciplinary research approaches aim to reconcile scientific expertise from different disciplines, and at the same time bring in the research process expertise from other non-research stakeholders and actors (Popa et al., 2015). By transgressing disciplinary boundaries to bring forth a new form of knowledge (Piaget, 1967), transdisciplinary research seeks to contribute to societal transformations by producing knowledge that is both scientifically sound and socially-relevant (Herrero et al., 2019). Transdisciplinary research approaches are now recognized as possible levers to inform efforts seeking to enhance sustainability and/or achieve transition for different social issues (Hirsch et al., 2006; Brandt et al., 2013; Mauser et al., 2013; Popa et al., 2015). Indeed, this approach and the specific methodological tools are particularly relevant when dealing with complex issues, such as urban resilience or fair and sustainable agri-food systems. Mobjörk (2010) distinguishes two types of transdisciplinary research: consultative transdisciplinarity and participatory transdisciplinarity. The former is understood as interdisciplinary collaboration between scientists who take into consideration the perspective of societal actors. The latter considers scientists and societal actors as equal partners each retaining their expertise throughout the research process, with the knowledge of societal actors fully integrated into the research process (de Jong et al., 2016). This approach is sometimes also referred to as the "strong" conception of transdisciplinarity (Max-Neef, 2005; Rigolot, 2020).

This paper aims to show how participatory and transdisciplinary research can provide valuable insights to inform the transition of agri-food systems. In particular it highlights the contributions of six projects funded under the Co-Create call in Belgium[3] to the understanding of agri-food system transition processes in Brussels. These projects ran from 2015 to 2018–19, and have been part of broader efforts and initiatives implemented and operating for many years. Here we do not present an in-depth analysis of the six Co-Create projects or their specific results.[4] Instead, we seek to bring out some collective reflections by members of the six projects, as we believe this to be the added value of the six action research projects. This is because in some sense these projects have created a historical *momentum* that has encouraged, or even forced, the placing agri-food systems transitions on the political agenda in Brussels.

Section 2 describes the objectives and societal challenges that guided the six Co-Create projects to rethink agri-food systems in Brussels. Section 3 therefore highlights two types of insights that are commonly shared by the six projects. The first consists of a series of recommendations that have been drafted by the six Co-Create projects for public authorities to accelerate and solidify the urgent changes needed in the food sector. The second includes findings that address the epistemological and methodological limitations and strengths of conducting co-creative research processes on food transition. Finally, the conclusion offers a look at the challenges that these six projects raise for leading an urban transition toward sustainable and accessible food supply for all.

2. Contextualization and methodology

2.1. Study site: Brussels and its agri-food system

Like in most cities, the agri-food system of Brussels is largely unsustainable. A study on plant production potential within the Brussels region revealed that only 0.1% of the fruits and vegetables consumed by its inhabitants is produced within the Brussels Capital Region (Boutsen et al., 2018). Moreover, at the Belgian level, the food chain contributes to 31% of the greenhouse gases emitted in Belgium by an average household (Bruxelles Environnement, 2015). Nearly 55,000 Brussels residents rely on social food aid (Myaux, 2019) and an estimated 35% of the city's population is living on or near the poverty line (Observatoire de la Santé et du Social de Bruxelles-Capitale, 2018). These people are often forced to rely on low-quality food items acquired at knock-down prices, and are highly exposed to the health risks by a poor diet (e.g., obesity, diabetes, weakening of the immune system).

In view of these dual challenges of developing a sustainable local agri-food system and enhancing the accessibility to healthy food, there has been in the last 15 years a rich associative and citizen-driven effort to encourage sustainable food consumption and production in Belgium, and more specifically its capital, Brussels (Stassart et al., 2018). One of the most historical actors in the city's agri-food system is the non-profit association *Le Début des Haricots* that has been

2 Refer to: www.gdrparcs.fr.

3 The Co-Create projects are participatory action research projects financed by Innoviris, the Brussels Agency for Research and Innovation. In French-speaking Belgium, this is one of the only calls specifically dedicated to the public funding of co-creation research projects, which makes it both innovative and experimental.

4 A detailed analysis of each of these six projects can be found in the book elsewhere (Vankeerberghen and Hermesse, 2020).

promoting (since its inception in 2005) urban agriculture production that is respectful both to the environment and workers through the implementation of concrete alternatives in the Brussels-Capital Region. Another pioneer in the transition to a sustainable agri-food system in the region is the non-profit organization *Rencontre des Continents* that has been active since the 1980s. This organization has used food as a theme and gateway to the educational approaches it offers to assist Brussels citizens obtain a better understanding of the political, social, economic, cultural and environmental issues at stake.

Together with other actors, these two associations have played a leading role in the consolidation of a policy agenda and programming activities on sustainable agri-food systems by the Brussels association sector. Recently numerous professional initiatives have been integrated in these efforts for sustainable agri-food systems and have been structured into networks that have rapidly gained in scope and visibility. In 2008, wishing to unite their strengths and their various expertise in the field of sustainable agri-food systems, many of the current actors within Brussels (e.g., associations, NGOs, consultancies, hotels, restaurants and cafés sector, distributors, producers, educational institutions) gathered to create the Network of Brussels Actors for Sustainable Food (RABAD—*Réseau des Acteurs Bruxellois pour l'Alimentation Durable*). This network aims to develop a food supply system that is accessible to all, and to an agricultural system that is respectful to the environment and producers (including fair pay). In 2009, another key network was formalized in Brussels, linking producers and consumers: the network of *Groupes d'Achat Solidaire de l'Agriculture Paysanne* (GASAP–I.e., Peasant Agriculture Solidarity Purchasing Groups). This network currently federates and supports more than ninety consumer groups in Brussels and about thirty producers. Its objective is to support small-scale agriculture and local producers using agricultural practices that respect the environment and traditional knowledge (Manganelli and Moulaert, 2018).

In parallel to these efforts, and often under their influence, agricultural production spaces have been emerging in Brussels and its periphery. These areas, mainly market gardens and/or small-scale livestock farms, adopt mostly small-scale farming practices that are local and environmentally-friendly, and supply consumers in Brussels through short value chains (e.g., direct sales, buying groups, restaurants, stores). These agricultural production initiatives are sometimes associated with educational projects or other social purposes.

Furthermore, there is progress on the food distribution sector side. Organic, natural and fair-trade food stores are multiplying, while online sales of local products, often organic and sometimes directly from the producer, are developing with the expansion of digital applications. There have also been changes in more traditional distribution channels, such as supermarkets, for example through the creation of cooperative supermarkets, anchored in their neighborhoods and supplied by local channels.

Numerous initiatives working on social justice, the fight against poverty and the right to quality food for all are also participating in this movement for sustainable food in the city. For example, the CAA (*Concertation d'Aide Alimentaire*), a group working on food aid, has been bringing together organizations active in food assistance in the Brussels Region (and in Wallonia) for more than 10 years to support a real policy that guarantees sustainable access to quality food for all. In addition, citizens, sometimes supported by associations, are setting up horizontal solidarity systems that aim to promote access to and sharing of food with people in precarious situations, while fighting against food waste (for example, by setting up systems to recover, transform and redistribute unsold food). Finally, this urban movement for sustainable food in Brussels is part of (and contributes to) larger initiatives, such as the recent Agroecology in Action (AIA) movement, which aims to gather, support, and multiply the numerous dynamics and projects related to agroecology and food solidarity in Belgium.

2.2. Study projects: Objectives and challenges

2.2.1. General overview

The Co-Create call of proposals and the selected projects employ the term co-creation research (or co-research). This is close to both PAR and transdisciplinary research as it relates to their efforts toward societal transformations (see Section 1). It views co-research as a process in which social actors conduct research in collaboration with professional researchers, as described in its funding program:

> "Co-research is more than involvement, it requires the active participation of those involved in the entire innovation process (from project design to the valorisation of results). [...] It is therefore not a matter of juxtaposing the words research and action, but of real participation by all the participants in a research project rooted in reality. This is not an equality of skills and roles but a complementarity and recognition of multiple and diverse knowledge and abilities" (Innoviris, 2019, p. 9).

Essentially all project partners are considered as knowledge holders and producers. This vision is inspired by the notion of the Third State of research (ALLISS, 2017),[5] which encompasses the multitude of so-called "civil society actors who are generally not involved in innovation and research activities (e.g., associations, communities, small businesses, unions)". In this sense the concept of co-creation in the call comes closer to transdisciplinary participatory research that adopts a stronger conception of participation (Section 1).

Collectively, the six projects funded through the first generation of the Co-Create Call (2015) have actively sought to respond to the challenge of being at the intersection of "research" and "action". Furthermore, as discussed above, they attempted to engage meaningfully everyone involved in the research process as a holder and/or producer of knowledge, adopting a vision of complementary skills. The road between the theory described in the Call and the research implementation of the six projects has been long, fraught with difficulties and paved with trial and error. However, as discussed in this paper, these projects have demonstrated how co-creation research can contribute to agri-food system transition in urban areas, as well as the practical, methodological and epistemological challenges and limitations of this approach.

In more concrete terms, each Co-Create project was carried out by a consortium of partners that brought together different actors (e.g., researchers, citizens, associations, administrations) concerned by the targeted issue. These partners had a shared awareness of the

5 ALLISS is a French network of actors aiming to develop cooperation between civil society and research and higher education institutions.

need for change, which united them around a collective research project. Jointly, they set up exploratory co-research mechanisms that allowed for a dialogue between the different types of knowledge and expertise involved in order to produce knowledge across a common theme and in support of the desired change.[6] They experimented together and learned from it in a reflective approach. Because of the participation of field actors in this research and experimentation process, the knowledge and learning that resulted was supposed to be directly actionable by the research participants.

In its funding program, the Co-Create Call invited the exploration and experimentation of innovations anchored in urban realities. To do so, projects were asked to implement one or more co-experimentation devices anchored in a context (e.g., a place in the city, a neighborhood, a building). In the first version of the call in 2015, these co-experimentation devices were referred to as "living labs". Living labs refer to places of experimentation and co-creation populated by users within a real-life environment where users, researchers, companies, and public institutions develop together new solutions, new services, new products or innovative business models. One of the objectives of living labs is to participate in the development of new innovative systems in which users and citizens become actors of the system and not only passive receivers (European Network of Living Labs, Refer to: https://enoll.org/about-us/).

As mentioned above, at its launch in 2015, the Co-Create Call focused specifically on the theme of sustainable food in Brussels. Six projects were selected, each addressing a specific dimension of this vast issue. Table 1 briefly summarizes the characteristics of the six projects, and the major themes they covered.

In parallel to this first generation of projects, a Co-Create Action Support Center (CACOC, now called *Convergences*) was set up, which is also financed by Innoviris.[7] The partners of the six first generation Co-Create projects participated in activities organized by the Support Center that allowed dialogue between projects and also to provided concepts, questions and common tools around co-creation research and fair and sustainable food.

It should be pointed here, that the original title of the Co-Create call was: "for sustainable food systems in the Brussels Capital Region". During the first year, and as a result of joint reflections between the projects and the Support Center, the title of the call changed, adding the word "fair" to reflect equity (access to sustainable food for all) to the already present notion of sustainability (environmental, economic, societal). This evolution is significant in that it moves beyond the generally observed tendency of thinking food system transition under an environmental lens, to consider dimensions that are often left out such as social justice. The theme of "fair and sustainable food systems" was therefore the one that occupied the first generation of Co-Create projects.[8]

In one way or another, the six projects adopt a systematic thinking about fair and sustainable food: "conceiving objects as systems" (Morin, 1977, p. 100), that is, they see food systems as sets of networks of interdependent actors and elements. It is indeed urgent to reconstruct the reality of agri-food systems, artificially fragmented by professional specializations and public action sectors. Thinking about the sustainability of agri-food systems and building benchmarks for a fair and sustainable food supply can only be done by considering a complex combination of issues. Although the different projects had slightly different foci (Table 1), at the heart of each project was the importance of co-creation of knowledge to enable the emergence of relevant innovations that consider the complexity of food issues.

2.2.2. Spincoop and ultra tree: Enhancing the sustainability of market-oriented garden-based food production in urban areas

As in other urbanized regions, certain dynamics in the Brussels-Capital Region (e.g., associative, professional, or public) support the relocation of agricultural production near the city. Their ambition is twofold: (a) to preserve peri-urban agricultural land from real estate pressures, and (b) to encourage agricultural activities in Brussels and its periphery. Using the perspective of urban food belt development, it is necessary to deploy small-scale agriculture as well as to create a link between producers and consumers. Since about 2015, about thirty new small-scale farmers who are not coming from a family farming background started production in the Brussels Region (Boutsen et al., 2018). This reflects a broader phenomenon observed in the European agricultural sector, namely the emergence of new farming activities that are not family farmers (Sinai A., 2013; Wilbur, 2014), e.g., in France nearly 30% of farming activities are conducted by people <40 years old (Lefebvre, 2009). This occurs in a global context where occupation in the agricultural sector has been reducing rapidly, e.g., in Belgium 67% of farms have disappeared since 1980 (Direction générale des statistiques, 2017). These "neo-farmers" usually turn to organic farming and other forms of ecological farming.

The Spincoop and Ultra Tree projects have sought to shed light on the ways in which these neo-farmers are building the future of sustainable agriculture in Brussels, and the challenges they face. In particular, they addressed the question of the viability of (peri-)urban market gardening models. The Spincoop research collective worked on analyzing (a) the factors influencing the agroecological viability and adaptation of the SPIN Farming model by the Cycle Farm cooperative, (b) the conditions necessary to contribute to the development of fair and sustainable agri-food systems in Brussels.

The Ultra Tree project questioned the sustainability of peri-urban market gardening projects through the design of a concrete tool for

6 The Co-Create Call targets innovations that are anchored in society. This includes (a) having a purpose centred on human needs, (b) responding to new or poorly met societal needs under current market and social policy conditions, (c) placing societal value before profit, and (d) considering the socio-technical components of the innovation and of the problem addressed.

7 The Support Center's mission is to accompany and support Co-Create projects during their implementation, by supporting reflexivity and relational learning (Van Dyck et al., 2018). It offers spaces for exchange and training to share experiences and resources around Co-Create research and urban resilience.

8 Since then, the Co-Create call has undergone several changes. In particular, the fair and sustainable agri-food systems theme has been expanded to include urban resilience, while the concept of the living lab has been abandoned in favour of the term "co-experimentation device in a real context". Beyond these changes, the Co-Create call retains its strong vision of co-creative research seeking to facilitate societal transformations towards a desired and sustainable future in Brussels.

TABLE 1 Characteristics of the six co-create projects.

Field of research/social innovation	Project name	Research objectives	Main publications or others outputs
Agricultural production in urban areas	Spincoop	To analyse the factors and conditions that influence and determine the viability of the SPIN Farming model (Small Plot Intensive Farming) in Brussels as adapted by the Cycle Farm cooperative.	(Plateau et al., 2019; Maréchal et al., 2022).
	Ultra Tree	To effectively support the installation of peri-urban market gardening projects on small areas to satisfy fruit and vegetables demand in Brussels in a sustainable manner.	(Hermesse et al., 2018, 2020) For Spincoop and Ultra Tree, refer to the viability Compass (support tool for producers) (Innoviris, 2019)
Food distribution and marketing	Choud'Bruxelles	To propose collaborative and viable logistical solutions to address challenges facing short-distance distribution channels of local food products in and to the Brussels-Capital Region.	e-CHOUD digital platform (not available online)
	CosyFood	To refine the knowledge about the practices and performances of alternative food distribution channels in Brussels in terms of sustainability, and to improve them through specific tools.	(Lohest et al., 2019)
Accessibility and democratization of sustainable food	Solenprim	To increase in a sustainable manner the freedom of choice and the scope of food uses among underprivileged residents of Brussels by considering innovative schemes and involving the food aid sector in the transition to a sustainable food system.	(Damhuis et al., 2020; Damhuis and Serré, 2021)
	Falcoop	To study the conditions through which the social innovations carried by the BEES Coop supermarket can facilitate the accessibility of sustainable food to all residents of Brussels.	Webdocumentary: *Tous à la même enseigne?* (Online at: https://falcoop.ulb.be/) (Fourat et al., 2020; Fourat and Jankowski, 2022)

For more information about the main outputs and publications, refer to the webpage https://www.cocreate.brussels/projets/.

self-assessing the viability of market gardening activities: the "viability compass" (Hermesse et al., 2018). The team also demonstrated the added value of the territorial anchoring of these market gardening projects for the urban social fabric, as well as the responsibility of public and political authorities in the sustainability of market gardening projects in the Brussels (peri-)urban area.

Although focused on production issues, these two projects did not disconnect their research approaches from ways of distributing production. Instead they explored how to make their economic activities profitable and remunerative, or even to participate in a "democratization" of food *via* innovative governance models and/or hybrid production models (i.e., combining production and education, production and professional reintegration, or production and awareness-raising).

2.2.3. CosyFood and Choud'Bruxelles: Meeting the challenges of alternative food distribution channels

The CosyFood and Choud'Bruxelles projects focused on innovations in alternative food distribution. CosyFood anchored its approach in the abundant literature on alternative agri-food systems (Deverre and Lamine, 2010; Maye and Kirwan, 2010; Tregear, 2011), and set out to evaluate in a participatory way the sustainability promises generally attributed to short circuits and alternative distribution channels. By reconstructing a sustainability framework with the consortium partners, this project implemented an approach to the agri-food system that considered it as an entanglement of sub-systems and networks of actors. Thus, this research highlighted the interdependence between food production, distribution and consumption, and the interactions between them in the context of building a more sustainable agri-food system. The Choud'Bruxelles project focused on one of the major challenges facing alternative food initiatives in general and short circuits in particular, namely logistics. Favoring a collaborative approach to logistics, the project addressed the question of how to co-create new innovative, sustainable, economically viable and adaptable distribution solutions in and to the Brussels-Capital region.

2.2.4. Solenprim and Falcoop: Overcoming the difficulties of a true food democracy

The Falcoop and Solenprim projects originated from the observation that sustainable food initiatives have difficulty in reaching a wide variety of societal segments, reinforcing the growing food divide (Lang, 1999; Paturel and Ramel, 2017). Falcoop has particularly questioned the governance of alternative agri-food systems, specifically not only how to produce food in an environmentally-friendly manner and to distribute locally, but also how to enhance the accessibility to this food. The starting point is that when seeking to re-humanize our agri-food systems, the focus should be on social inequalities in access to alternative food products (Closson et al., 2019). Alternative agri-food systems struggle, among other things, to resolve the tension between producer livelihoods and product accessibility for all, thus challenging the link often established between reducing the number of intermediaries and accessibility. Moreover, alternative food systems encompass certain social and cultural codes that are not representative of a large fraction of Brussels population such as immigrants and/or the socio-economically disadvantaged. For example, such segments of the population are rarely consumers in sustainable food spaces. Thus, improving access to quality food for all, in the vision of a food democracy, has been one of the issues at the heart of the Solenprim project. The project's contribution has been to examine why the numerous initiatives of alternative food systems (and the relevant public strategies) fail to include properly those experiencing food insecurity.

3. Results and discussion

3.1. Involvement in advocacy: Recommendations for policy and practice

The alternative food systems covered by the Co-Create projects reflect a common ambition to experiment and initiate the transitions of agri-food system toward more sustainable and resilient states (Kirwan et al., 2013; Maye and Duncan, 2017; Rossi, 2017). However, as of the writing of this paper, the broader transformative potential of the six projects remains limited, partly due to their local and small-scale actions. Yet, the possible multiplication of such innovative initiatives (especially in urban areas) and their alignment into bigger networks could open up windows of opportunity to accelerate larger-scale transformative change in agri-food systems. For example, many urban-related public strategies and institutional innovations associated with agri-food systems and food governance have been inspired by citizen-based, association-based and professional initiatives, and the new networks they build (Morgan, 2009; Matacena, 2016). While in many cases, the primary concern of such actions is to ensure future food security (Morgan and Sonnino, 2010), their objectives can be quite varied. For example, objectives can include the regeneration of the social fabric *via* food-related public actions, economic development, improved resilience of food supply, improved food security, environmental protection, enhanced public health, or strengthened social integration and food culture, among others (Brand et al., 2017).

Such increased institutional interest on food transitions can also be observed in the Brussels-Capital Region. Indeed, inspired by the engagements of citizens and associations around issues of food production-distribution-consumption, public institutions in Brussels have been developing action strategies around sustainable food since the early 2010s. For example, the Brussels Government set up the Employment-Environment Alliance (2011–2015) aiming at stimulating the economy, creating employment and improving environmental quality within the city (Alliance emploi-environnement, 2014), with "sustainable food" becoming the fourth axis. Subsequently, the strategy "Good Food—Toward a sustainable agri-food system in the Brussels-Capital Region" (2016–2020)[9] was launched in 2016. The vision, principles and actions of this policy were developed in collaboration with about one hundred actors from the food sector. The underlying aim is to place food at the heart of the discourse, by addressing food across the different economic, social and environmental dimensions of the urban system. To achieve this, it intends to encourage and bring together the many relevant initiatives in the city in order to fulfill a twofold ambition. The first is "producing better" (i.e., growing and processing healthy and eco-friendly food locally) and the second is "eating well" (i.e., making a tasty and balanced diet available to all, composed of mainly local products). To achieve its objectives, the Good Food strategy proposes financial support instruments (*via* calls for projects), sets up food label and support innovative projects. The years 2015–2016 were particularly pivotal for these efforts as the public institutions in Brussels confirmed their investments in the theme of sustainable food. In 2015, Innoviris (the Brussels agency for research and innovation) opened a call for research projects on co-creation (Co-Create) with the theme "the development of sustainable food systems in the Brussels-Capital Region". This call was essentially included in the framework of the "Sustainable Food" axis of the Employment-Environment Alliance (see above), and aimed to create a space in which research can experiment with scenarios that draw alternative paths to the current agri-food system. In other words, the call sought to allow the many existing food-related innovations to self-reflect, improve their actions and find solutions to the challenges they face, while producing actionable knowledge for the development of a fair and sustainable agri-food system at the regional level. This first Co-Create Call also supported the research dimension of the Good Food strategy, as the selected projects have, in various ways, contributed to this public strategy their thoughts, findings and recommendations.

Overall the six projects funded by the Co-Create program generated research that produced knowledge and learning that responded to the need to achieve change in agri-food systems, and more broadly achieve their transition. Nevertheless, the first generation of Co-Create projects also acknowledged that the implementation of their research results and proposals for action was not always possible in the current context, as they faced institutional, legislative or economic barriers.

Based on their findings and reflections, the projects have collectively developed and published a plea that includes proposals for action for agri-food system transition aimed toward food actors and public authorities (Centre d'Appui de l'Action Co-Create et les Projets Co-Create 2015–2018, 2018). This emphasizes the important role of policies in supporting and implementing alternative food systems: not only through financial support but also especially through support for legislative, institutional and societal change. Such changes are indeed necessary to achieve a real transition toward fair and sustainable agri-food systems so that these alternatives do not remain only niches of innovation reaching a limited public.

First of all, this call for action highlights the need to anchor these structural, political or institutional changes in the reality of Brussels. To do so, it is essential that public policies rely on existing or emerging transformation efforts, and their experiences and networks, in order to make the most of current knowledge and avoid "reinventing the wheel". Supporting these initiatives involves, among other things, removing certain legislative barriers that prevent the full implementation of the results and proposals for action of these initiatives. Examples could be to facilitate access to land for farmers (Spincoop and Ultra Tree), implement logistical or technical innovation (Choud'Bruxelles), or recognize and value the multi-functionality of agricultural spaces by allowing volunteer assistance (Ultra Tree). The call for action also points that it is essential to reflect on the conditions and modalities of realizing a fair and inclusive agri-food system transition, in order to build collective and solidarity-based solutions to enable a real implementation of the right to food. Several avenues have been identified by the projects, such as supporting the community approach in social work (Falcoop) and creating local food collectives at the neighborhood level (Solenprim). However, with one point of attention: any approach aiming at a real implementation of the right to food can only really bear fruit if it is part of a public program to fight against social inequalities

9 This public policy was launched at the initiative of the Brussels Minister of the Environment, Agriculture and Quality of Life. It is supported by the Brussels Environment and the Agriculture Unit of the SPRB (Brussels Regional Public Service).

and the structural causes of poverty (Gottlieb and Joshi, 2010). To achieve this, it is particularly important to involve "populations in the development of responses to the difficulties they encounter with regard to food" (Devlésaver, 2018, p. 17).

Secondly, a point of attention commonly raised by the six projects is the importance of pooling resources within the fair trade and sustainable food sector, as well as the need to federate its actors (from production to distribution and consumption) in common structures to facilitate exchanges. Indeed, as the individual projects have shown, agri-food systems are complex and we must take into consideration the interactions between its different components. Nevertheless, this will only be made possible through the decompartmentalization of public policies and funding. In particular as quoted in the call for action:

> "*As food is at the interface of many competences (social, health, economy, environment, agriculture, research, education, culture, mobility...) that are not coordinated and distributed between the different levels of power (federal, community, provincial, regional, communal), it would be necessary to be able to mobilize and involve these different competences in order to elaborate, as far as food is concerned, coordinated and coherent political strategies and action programs, based on a global and systemic vision*" (Centre d'Appui de l'Action Co-Create et les Projets Co-Create 2015–2018, 2018, p. 59; excerpt from the 11th proposal of the advocacy).

In order to avoid reproducing social or environmental injustices, it is necessary to consider the political conditions of knowledge production and use as well as their consequences by promoting a reflexive approach to science and research. To do this, it is essential that research funding agencies recognize the importance of this type of approach, whose results, knowledge and learning cannot always be evaluated according to the usual research standards[10] (Hermesse and Vankeerberghen, 2020). Indeed, the purpose of research on food transitions cannot be limited to technical and practical solutions, as collective and reflexive learning is a fundamental driver of these change processes (Van Dyck et al., 2018).

3.2. Methodological and epistemological lessons learned

There is a real need to implement appropriate methodologies and engagement processes to enable the effective collaboration among all relevant stakeholders (e.g., researchers, citizens, associations, administrations), to contribute effectively to co-creation research processes through their individual expertise. The experience gained from the six Co-Create projects suggests is that there is no ready-made recipe for effective stakeholder collaboration that can be transposed from one project to another (let alone other geographical and thematic contexts). Such points for transdisciplinary research have been made elsewhere in the literature (Nicolescu, 2014).

Overall, in each of the six Co-Create projects the partners had to creatively build co-creation methodologies adapted to the specificities of each project and its actors. Moreover, the experience gained across several projects shows that such methodologies must be able to evolve and adapt to the changing realities of co-creation research. Similar points regarding the importance of adaptative methodologies in co-creation research has been made elsewhere in the literature (e.g., Lang et al., 2012). In order to facilitate the transition toward more equitable and sustainable agri-food systems in Brussels, the co-creation research approaches of the six Co-Create projects attempted to integrate the diverse expertise of the actors engaged in the specific themes. However, this active participation of the stakeholders concerned in the whole research process poses many challenges. Some of the main challenges identified in the literature, include among other asymmetries of power (Barnaud et al., 2016; Godrie et al., 2021). Below we discuss in more detail some of the critical lessons learned from the six Co-Create projects for co-creation research and the effective stakeholder engagement more generally.

First, it is necessary to put into perspective the notion of active participation of those involved in a co-creation research process. Indeed, when engaging in co-creation research it does not necessarily mean that all of the involved actors participate (or should participate) permanently in each step of the project. The length and type of participation should be variable and modulated according to the needs of the project and the actors involved. For example, the Choud'Bruxelles project set up a two-phase methodological framework to enable co-creation within the consortium: (a) an internal co-creation process for the consortium partners, and (b) an extended co-creation process that includes more widely actors interested in sustainable agri-food systems (see next point also). This type of staged approach does not entail the equal contribution of all research participants in co-creation research activities (i.e., equality of contribution) but attempts to combine the diversity of partners in the co-creation process, with each contributing through their skills and expertise (i.e., equality of recognition). For this reason, the term "co-researcher" is sometimes used to designate the participants involved in the co-creation research process. While this term has the advantage of recognizing the contribution of an equally legitimate and relevant knowledge and expertise in the research process, it might raise concerns to some participants. For example, its use tends to erase the specificity of each actor's contribution to the process. It is indeed necessary to recognize this specificity of skills and expertise, which is crucial to the development of co-creation research and projects.

For this reason, some Co-Create projects preferred to maintain a distinction between "researchers" and "stakeholders". At the same time they avoided splitting theory on the one hand and implementation on the other, as such a view would be the very antithesis of the commitment of participatory action research (McTaggart, 2001). The point here is that whether research participants are professional researchers or practitioners, each has specific skills that enables them to contribute to the research process. In this sense involvement in a co-research project requires a shift in perspective that is not, however, without difficulty. For

10 For example, a consultation of the field actors involved in the Ultra Tree project undertaken in May 2022 made it possible to realise the extent to which the Open Source tools created within the framework of the project are still being used four years later. These included, among others the "viability compass" to support coaching in market gardening and the "good practice guide" to inform individuals interested in a professional approach to market gardening. The analysis about the multi-functionality of urban agriculture was also instrumental for a political plea and the establishment in 2020 of a Brussels Federation of Urban Farmers.

researchers, it requires breaking with common research approaches, and instead share research activities with all project partners and propose methodological approaches that enable the integration of non-scientific expertise in the research process. For stakeholders, it requires understanding the issues at stake during the research process, and taking ownership of them in order to define their specific role within this process. Such points about the need to change the usual mindsets of research participants in co-creation processes has been raised extensively in the transdisciplinary research literature (Mauser et al., 2013). Yet, despite their necessity, these shifts and learning processes take time.

Second, the effective participation of non-academic actors in co-creation research is also closely intertwined with the issue of remuneration, especially when considering that non-academic partners are often requested to engage in kind thus diverting significant time from their professional activities (Barnaud, 2013). One of the innovative aspects of the Co-Create projects was that majority of the partners in the six consortia, whether coming from the research community or not, have been funded by the respective projects. This was considered important to ensure the strong commitment of the partners to the projects and to professionally value the skills of the actors, however diverse. For example, the Spincoop project hired the two market gardeners engaged in the project as part-time employees. However, other projects involved at certain moments of the co-creation process actors from outside the consortium that were therefore not paid within the framework of the project. This was the case, for example, for the market gardeners in the Ultra Tree project, food aid beneficiaries in the Solenprim project, or food producers in short food supply chains within the Choud'Bruxelles project. These experiences of Co-Create projects reaffirm the difficulty of involving unpaid actors in co-creation research processes, despite being important for the process. For example, the producers engaged in short value chains of fair and sustainable food often suffer from the weak economic viability of their produce, as in a sense they carry on their shoulders the economic distortions induced by large-scale distribution of cheap food on the real costs of food production. Their motivation to engage in such unpaid research processes often emerges from the conviction that these processes can bear fruit and contribute toward a slow but certain transition of the agri-food system (and possibly an improvement of their work).

The above reflect well one of the presuppositions of co-creation research, namely that the research output is directly beneficial to the actors involved and can be acted upon by them. Actually many actors from Co-Create projects have shared how these research experiences have brought out learnings that can contribute to improving their daily practices.[11] In addition, several actors testified that they were satisfied with these collaborations over the 3 years of the Co-Create projects, as it led to the better recognition of their work. For example, producers involved in the CosyFood project said that they had "stuck out" in the co-creation process thanks to increasing the recognition of their work among consumers. Market gardeners involved in the Ultra Tree and Spincoop projects proudly expressed that their aspiration toward achieving a fair and sustainable agri-food system was a key element driving their efforts to ensure the viability of their operations. Nevertheless, the often unstable and difficult economic conditions in which they operate essentially limit their participation in research processes, as their available time and energy are devoted to maintaining their activities, or even surviving. In order to respond to this constraint in a creative way, the Ultra Tree project created two "in-between" positions beyond the two categories mentioned above: (a) participants outside the consortium that were paid within the framework of the project as they played the role of transmission belt between the researchers and (b) unpaid stakeholders, namely market gardeners that contributed during the process of setting up the project but had very little time available to devote to the project.

Finally, beyond the practical, temporal, and economic dimensions of the co-creation research process, we must also take into consideration some equally important social, cultural, symbolic, and educational dimensions, which may cause inequalities in access to participation in this type of research process. The Solenprim project chose to work with consumers in precarious situations, as the consortium was keen to tackle the delicate issue of participation by vulnerable groups. In addition to the ethical considerations already mentioned (e.g., engaging an economically disadvantaged group in co-creation research), there was also the question which conditions would allow this stakeholder group to participate fully in the research process. Concerned about this issue, the Solenprim project team worked on developing methodological approaches aimed at avoiding standardizing the definition of "eating well". To achieve this, the project leaders set up initially research approaches to bring together only food aid beneficiaries. This reveals how crucial it is for the projects (and the Co-Create call more broadly) to think about these differences in access to participation in research processes and to set up adequate mechanisms to remedy them, in order not to exclude certain groups from transitions toward fair and sustainable food. This challenge resonates with crucial questions: Who are the actors absent from research on food agri-system transition? Why are they absent? How can they access these research opportunities? This issue about the need to engage properly "invisible" actors in co-creation processes has been discussed extensively in the transdisciplinary research, both related to food systems (Jacobi et al., 2021) and more broadly (Godrie et al., 2021).

4. Conclusion

This article contributes to the understanding of agri-food system transition processes and the actions or avenues that could facilitate them. As there is still a long way to achieve real transitions toward fair, sustainable and accessible agri-food systems for all, it is necessary to build the conditions for such transitions now. This paper describes how six transdisciplinary and participatory action research projects funded through the Co-Create call in Belgium, worked on agri-food system innovations in the same geographical and historical context (Brussels between 2015 and 2018). These six projects targeted different issues and aspects of social innovations for agri-food systems transitions, specifically falling within the categories of agricultural production in urban areas, food distribution and marketing, and accessibility and democratization of sustainable food. Beyond outlining some of the tangible research results in the paper,

11 For example, some market gardeners participated in the five days of collective interviews during the Ultra Tree project shared how the collective analysis of their practices was a driving force for changing certain agricultural practices.

here we have focused on some of the cross-project collaborative activities between the participants of the six projects. By putting the projects' results into perspective and identifying future challenges it was possible, on the one hand, to place the transition of agri-food systems on the political agenda in Brussels. On the other hand, this collective work supported by the Co-Create Action Support Center made it possible to emphasize the need for a systemic approach to achieve transitions in agri-food systems, considering that food production, distribution and consumption patterns are interconnected within agri-food systems.

Despite the difficulties of implementing co-creation projects, particularly in terms of citizen participation, the concomitance of the six projects and the collective workshops initiated by the Co-Create Action Support Center have generated communicative enthusiasm and a certain dynamism about agri-food system transitions in Brussels. This is evidenced, among other things, by jointly drafting the recommendations contained in the plea to the political authorities of Brussels about the transition of agri-food systems. Furthermore as change in agri-food systems involves not only the transformation of practices but also the transformation of people (with the latter remaining largely invisible in the literature, scientific reports, and project evaluations), the collective and reflexive learning of the six co-create projects enabled many individuals to become actors of change for agri-food systems transition in Brussels. Furthermore, it allowed the research teams of the six projects to question certain risks of normativity in the definition of what is a fair and sustainable agri-food system, as well as the risks inherent to any political, citizen or research program or project on this field.

Efforts to enable agri-food system transitions in Brussels could benefit from the dynamism and will of its inhabitants. Citizens are a major component of the innovations studied within the six projects, and can thus become a formidable lever for enabling transitions toward a fairer and more sustainable agri-food system. However, citizen enthusiasm is not enough to enable changes in the dominant agri-food model dominated by conventional agricultural production and mass distribution channels. Niches are crucial for such transitions because they provide the seeds of systemic change. For this reason, all six research projects described the socio-technical lock-ins to innovations**.** It is therefore essential that public authorities collaborate in ongoing efforts to question the ethics and governance of current agri-food systems, and participate in the implementation of new policies for sustainability transitions. Armed with recommendations from researchers and practitioners, public actors to assume their share of responsibility.

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

JH coordinated the writing of the paper. AV, FL, and AT collaborated on the writing of the paper.

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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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Setting-up place-based and transdisciplinary research to foster agrifood system transformation: Insights from the Aliment'Actions project in western France

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Many agrifood systems around the world can be characterized as unsustainable. Research is increasingly required to inform the necessary radical transformations of the ways we produce, process, transport, and consume food. This article presents the research approach and methods of an ongoing project carried out at a long-term social–ecological research site, the Zone Atelier Plaine and Val de Sèvre (western France). The research project presented here, Aliment'Actions, started in 2018 and within 10 years of its implementation seeks to study and trigger transformation to enhance the sustainability and resilience of the regional agrifood system. Its research agenda contains four types of actions: (a) backdrop actions that enhance communication and trust between researchers and local stakeholders, (b) targeted actions that are conducted in specific villages with a wide range of stakeholders to elaborate and implement various transformation levers, (c) assessment actions evaluating the effects of different interventions, and (d) communication and result from dissemination actions. Overall, these actions aim to co-produce knowledge, raise awareness regarding challenges in the food system, envision new interactions between stakeholders, collectively generate innovative ideas, and catalyze actions oriented toward agrifood system transformation. The project implementation is adaptive and iterative, from theory to practice. This Methods paper puts this ongoing project into the perspective of other place-based research initiatives and provides insights on how to foster the engagement of non-academic actors in transdisciplinary research supporting agrifood system transformation.

KEYWORDS

place-based research, agrifood system, food system transformation, transdisciplinary research, social-ecological system, resilience (environmental)

1. Introduction

Our global agrifood system[1] is responsible for ~60% of global terrestrial biodiversity loss, 24–30% of greenhouse gases emissions (depending on whether forest clearance is included), 33% of degraded soils, and the overexploitation of 20% of aquifers (Hajer et al., 2016). Much of these environmental impacts are driven by high-input industrial agriculture, and global supply chains largely are controlled by a small number of multinational agribusiness and food retail companies, generating power asymmetries between farmers and industrial actors (IAASTD International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009; Howard, 2021). Long supply chains also increase the number of intermediaries and create a physical and cognitive distance between producers and consumers (Bricas et al., 2013). The pressure posed by the agrifood sector on natural resources and biodiversity is consequently accentuated by the lack of consumer awareness of how their consumption practices affect ecosystems (Berkes et al., 2006; Godfray et al., 2010).

As the pressure on ecosystems increases, the excessive concentration and internationalization of agrifood systems increase their vulnerability to environmental, meteorological, health, or economic shocks, as well as their dependence on fossil fuels (Tendall et al., 2015; Blay-Palmer et al., 2020). These cascading processes ultimately impede the agrifood system's resilience[2] and highlight the fact that ecological and human systems cannot easily be separated. Understanding how the resilience of agrifood systems may be restored (or at least improved), therefore, requires us to consider them as social–ecological systems or SES (Sundkvist et al., 2005; Ostrom, 2007; Foran et al., 2014), which offers an integrated perspective of humans-in-nature (Folke et al., 2016). The social side refers to the diverse facets of the human dimensions of these systems including economic, political, technological, and cultural aspects. The ecological side refers to the biosphere, biodiversity, and ecosystems. SES, thus, encompass all living beings, including humans, and their dynamic interactions with the dynamics of the earth system, including the biogeochemical cycles (Cockburn et al., 2018).

Considering agrifood systems as SES means that interactions, not only among humans but also within ecosystems and between social and ecological components, must all be considered and cannot be understood independently (Ericksen, 2008). Social components of agrifood systems include all related policies, laws and regulations, sociocultural norms, infrastructures, and organizations. Ecological components include water, soils, air, climate, and ecosystems and genetics (Nguyen, 2018, p. 3). This consideration calls for interdisciplinary approaches in which ecology, agronomy, food sciences, and social sciences tackle co-constructed research questions. It further calls for transdisciplinary research[3] that relies on collaborations among scientists from different disciplines and non-academic stakeholders from business, government, and civil society (Kates et al., 2001; Hadorn et al., 2006).

At the same time, the unsustainable trajectory of our agrifood system requires the implementation of transformative approaches (Olsson et al., 2017; O'Brien, 2018). However, although the idea of SES transformation has recently become more prominent, particularly within the scientific community, there is no clear consensus as to what the concept means in practice and how SES transformation can be triggered, implemented, and evaluated (Nalau and Handmer, 2015; Ziervogel et al., 2016). Importantly, transformation may not always be desirable with O'Brien (2012) underlining the need for "deliberate transformation" to consciously create an alternative future that explicitly includes ethics, values, and sustainability. Deliberate SES transformation implies that the stakeholders acquire "transformative capacity" (Olsson et al., 2010), that is, "the capacity of individuals and organizations to be able to transform both themselves and their society in a deliberate, conscious way" (Ziervogel et al., 2016, p. 2).

This is especially important insofar as resilience is often understood in a normative manner (Fallot et al., 2019). However, it is also important to define what resilience is about and by whom it is needed. When we refer to the resilience of an agrifood system, are we focusing on the system as a whole or its components (e.g., farms, organizations, and sectors)? Thinking about and building resilience of agrifood systems can be considered at different spatial and temporal scales and different levels of an organization, whether social or biological. Moreover, there are many possible ways to increase the resilience of an agrifood system and many possible resilience criteria. Every stakeholder of the system should be able to position himself/herself with regard to the trajectory of the agrifood system (Fallot et al., 2019). Beyond the need to cross-compare the different perspectives and to foster learning from trial and error, it seems important not to consider resilience as a given property of the system, the boundaries and conditions of which would be perfectly known, but rather to consider it as an "object" of collective design and elaboration (Berthet et al., 2022).

The above suggests that enhancing the resilience of agrifood systems requires not only interdisciplinary research but also additionally transdisciplinary and transformative research to generate change and engage diverse stakeholders in the process (Feola, 2015; Nalau and Handmer, 2015; O'Brien, 2018). Until recently, however, most proposals addressing these issues have remained conceptual, with little work on how to move from the theory to the practice of transformation at the scale of SES. As Cockburn et al. (2018) highlight, to achieve this, there is a need to move toward place-based empirical experimentation and active learning about the practice of SES transformation.

In this study, we present such an ongoing initiative, the Aliment'Actions project in France, which specifically aims to empirically study agrifood system transformation toward improved

1 Agrifood systems "encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, and parts of the broader economic, societal and natural environments in which they are embedded" (Nguyen, 2018, p. 1).

2 Resilience is defined as the way systems "absorb disturbances and reorganize while making changes in ways that retain essentially the same functions, structures, identities, and feedbacks" (Walker et al., 2004, p. 2).

3 Lang et al. (2012, p. 26) define transdisciplinarity as a "reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge".

resilience within a long-term and large-scale research infrastructure. In this Methods paper, we mainly present the background and objectives of the project, the study region and consortium, the research strategy, and ongoing actions. We provide some initial results and finally critically discuss and position the main features of this project within the wider literature on transformative research that targets SES resilience.

2. Methodology and research approach

2.1. Background and objectives of the Aliment'Actions project

Aliment'Actions has been underway since late 2018 and is planned to run for 10 years. It was launched as part of a long-term place-based research program conducted in an agricultural region in western France by the CEBC Resilience research team[4] (Bretagnolle et al., 2018b; Berthet et al., 2022). Several decades of environmental policy implementation and collaborative research with farmers in this area have demonstrated that nature-based solutions (IUCN, 2012; Faivre et al., 2017), such as increasing bee abundance to increase rapeseed yield, are an effective and economically realistic alternative to agrochemical use in the broader region (Catarino et al., 2019a,b). However, at this particular site, as in many other parts of the world, biodiversity decline continued to accelerate (Bongaarts, 2019) while a conventional agricultural model, mainly relying on crop or animal genetic improvement, high use of chemical inputs, and mechanization, remains overwhelmingly predominant. Scientists concluded that public policies and scientific knowledge production were not sufficient to implement an agroecological transition at the agrifood system scale (Kleijn et al., 2019; Berthet et al., 2022) and that other levers had to be explored. The research focus, thus, shifted from analyzing agroecosystem functioning toward achieving a better understanding of the conditions of SES transformation to enhancing system sustainability and resilience. Understanding the causes and process of transformation at the SES scale has become an important research front (Barnes et al., 2017; Pereira et al., 2020b). The research team adopted a transformative research approach and mindset (Schneidewind et al., 2016), following a two-fold aim "to contribute to societal transformation by experimenting with potential solutions" and "to produce scientific evidence about the social robustness of solutions as well as about their scalability and transferability"(Schäpke et al., 2018b, p. 86–87).

Aliment'Actions is actually a part of a larger long-term intervention-based research project named Transform'Actions, which encompasses three research axes: (a) agroecology mainly based on on-farm experimentation and surveys on biodiversity and farmers' practices (Gaba and Bretagnolle, 2020); (b) food mainly covered by Aliment'Actions, and (c) ecohealth, which focused on the chain of the "pressure-exposure-impact" of pesticides on both humans and other species in this rural landscape (Mougin et al., 2018). Therefore, in this broader long-term project, food issues are addressed in conjunction with agriculture, environment, and health issues.

Transform'Actions, and essentially Aliment'Actions, adopts an SES approach thoroughly analyzing jointly (a) ecological processes and biodiversity in the local agroecosystem, (b) interactions between farming management actions and ecological processes, (c) interactions between agricultural production and food consumption

4 CEBC refers to the Centre d'Etudes Biologiques de Chizé (Centre for Biological Studies of Chizé).

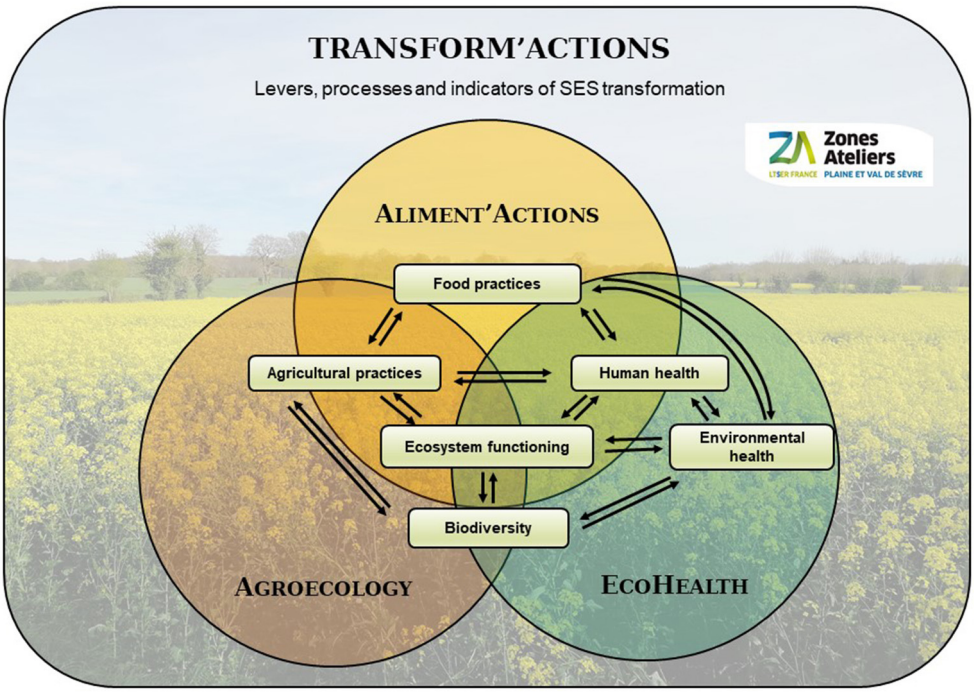

FIGURE 1
Position of the Aliment'Actions project within Transform'Actions.

practices, and finally (d) effects of agricultural and food practices on the local ecosystem and human health (see Figure 1). The research program Transform'Actions articulates three main research questions as follows:

- What are the triggers of SES transformation (at an individual, collective, and system scale)?
- What are the relevant indicators and protocols to monitor SES transformation?
- What are the upscaling processes from individual change to global change through changes in social groups and at the SES scale?

Within Transform'Actions, Aliment'Actions specifically applies the questions related to SES transformation to food, and particular topics are as follows: (a) What are the triggers that can lead consumers to change their food consumption practices? (b) What are the relevant indicators and protocols to monitor the transformation of individual and collective food consumption practices, and ultimately the agrifood system transformation? (c) How can individual and collective transformation of food practices lead to an agrifood system transformation toward greater resilience?

Addressing these questions requires studying either an ongoing agrifood system transformation process toward enhanced resilience or one that is complete. In France, where agriculture is mainly intensive, specialized in crop or cattle production, and export-oriented, quite a few initiatives have sought to enhance agrifood system resilience, and even fewer have achieved an effective transformation. Our research team, therefore, opted for an intervention-based research approach[5] (Hatchuel, 2000) designed to initiate, support, and monitor agrifood system transformation. As part of the transformative science movement (Schneidewind et al., 2016), the Aliment'Actions project, thus, aims to catalyze and analyze the transformation of food practices within a region, by supporting the relocation of the agrifood system and promoting more environment-friendly farming. Here, the term "catalyze" means that the project team stimulates, facilitates, or accelerates initiatives led by local actors but does not replace them in the design or implementation of these initiatives. The local actors may be operating at an individual or collective level, e.g., local non-profits or municipalities.

To achieve this, we propose a research project at the regional scale focused on three levers of transformation of agricultural practices identified by the project consortium: (a) re-connecting consumers to producers, (b) re-thinking how individual food consumption directly affects food production, and (c) relocating the agrifood system. Regarding the latter, the objective is not only to aim for a food self-sustaining region but also rather tilt the balance toward food relocation vs. export. Aliment'Actions ultimately aims to make the transformation of food practices into a lever for the transformation of agricultural practices based on the principles of agroecology (Wezel et al., 2011), as a means of enhancing agrifood system resilience. The idea behind this strategy is that using the lever linked to food demand can be more effective in transforming the food production system than trying to change each component of the system, e.g., the agricultural component (BajŽelj et al., 2014). The project, therefore, mainly targets consumers and farmers that are currently present in the region, without neglecting other agrifood system actors (Lamine, 2015).

2.2. Core characteristics of the Aliment'Actions project

After 3 years of project implementation, we identify five main features of Aliment'Actions that we will outline in more detail below (see Figure 2). Aliment'Actions (a) is a place-based research project anchored in a long-term and large-scale research infrastructure, (b) adopts an SES perspective, (c) is carried out by a transdisciplinary project consortium (where not only several scientific disciplines are represented but also non-scientific actors are also involved in various ways), (d) is carried out following an adaptive, iterative, and reflexive process, and (e) has a research design based on experimentation and monitoring.

2.2.1. Place-based research

First and foremost, Aliment'Actions is anchored in a well-defined region, which is also a long-term and large-scale research infrastructure. In particular, it is linked to the long-term social–ecological research (LTSER) "Zone Atelier Plaine & Val de Sèvre" (ZAPVS), located in the south of the city of Niort (Nouvelle-Aquitaine Region, western France). This research infrastructure is a large rural region (~435 km^2) encompassing ~400 farms and covering 40 villages (c. 24 municipalities) totaling 34,000 inhabitants (Figure 3). The broader area is representative of agricultural intensification and specialization in France and is characterized by extensive pesticide use and landscape simplification due to the removal of hedges, the enlargement of crop fields, the simplification of crop rotations, and the decline of mixed farming in favor of cereal farming. The agrifood system of this region has become more and more globalized, as agriculture relies on imported resources (e.g., fertilizers, pesticides, and seeds), while ~60% of its agricultural output is exported internationally. Furthermore, the area is remarkably rich in biodiversity, while for geological reasons, it is particularly sensitive in terms of water resources (Berthet et al., 2012). As a result, agricultural intensification poses considerable environmental problems in this region with regard to water quality and biodiversity.

Since 1994, the ZAPVS acts as an observatory of the agroecosystem, where long-term surveys are undertaken to obtain an understanding of SES dynamics due to agricultural modernization. Regular (yearly) surveys are conducted by the research team and included the monitoring of land cover, the status of biodiversity, implementation of farming practices (Bretagnolle et al., 2018a,b), and more recently, tracking of food consumption (Berthet et al., 2020). Each year, the local farmers who participate in experiments or allow scientists to monitor biodiversity and ecological functions in their fields are surveyed on their farming practices during the cropping season of interest. Information on soil management practices (type, date), use of pesticides and fertilizers (type, date), sowing (date, cultivar), and harvest (date, yield) is collected. Such information

5 Intervention-based research is a transdisciplinary approach consisting in producing knowledge on collective action by contributing to its transformation. The researcher is thus an actor and stakeholder of collective action.

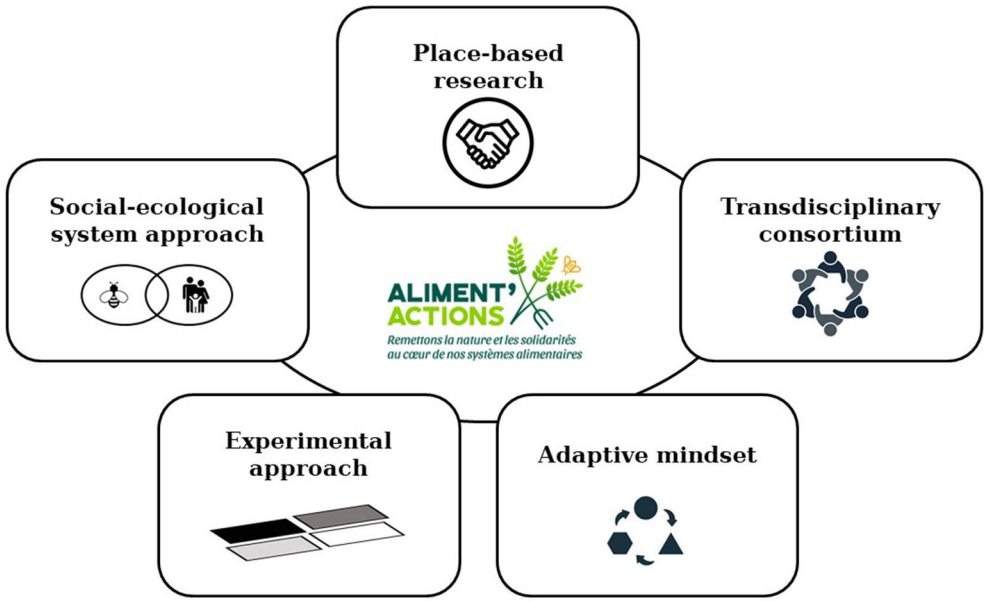

FIGURE 2
The main features of the Aliment'Actions project.

is then used to relate biodiversity, ecological functions, and their relation to yield (see Perrot et al., 2022 for an example). The survey on food consumption is presented in Section 2.4.2. Research programs have been carried out for more than 10 years with farmers, cooperatives, NGOs, municipal councils, and schools (Berthet et al., 2016; Gaba and Bretagnolle, 2020; Houte et al., 2020).

2.2.2. Social–ecological systems perspective

Aliment'Actions, as part of the broad and long-term project Transform'Actions (Section 2.1), considers the local agrifood system as an SES whose various dimensions are addressed through the nexus of food-agriculture-environment-health. This research focuses on a clearly delimited region in which ecological, agricultural, food consumption, and (soon) health parameters and their interactions are monitored in the long run. Furthermore, this research project specifically studies transformation toward ecosystem-based management and governance (Olsson et al., 2008), involving stakeholders in the development and dissemination of nature-based solutions (Faivre et al., 2017; Berthet et al., 2022).

2.2.3. Transdisciplinary consortium

The research conducted within the Aliment'Actions project is transdisciplinary, in the sense that not only a wide range of scientific disciplines is represented (e.g., life sciences, management sciences, and social sciences) but also that non-academic actors concerned by these issues are involved in different ways within the research process. The project consortium is composed of academic and non-academic actors with diverse and complementary expertise such as researchers in ecology, agronomy, agroecology, and social sciences, as well as a social enterprise. In addition, various partners contribute to the project on an *ad hoc* basis according to their competencies and the needs of the project, particularly agricultural development associations and municipal councils. These actors contribute to developing the research questions and providing data. Their initiatives influence the course of the research project, and they are invited to provide feedback on preliminary results during public presentations. Key interactions between researchers and local stakeholders are further detailed below (see Sections 2.3 and 2.4).

The project, therefore, brings together actors with complementary approaches, such as citizen engagement, rural development, and transdisciplinary research. In terms of the actual transdisciplinary research process, we broadly follow the approach of Lang et al. (2012) that conceptualize it as a sequence of three phases, namely, (a) collaborative problem framing and collaborative research team development (Phase A), (b) co-production of solution-oriented and transferable knowledge through collaborative research (Phase B), and (c) (re-)integration and application of the produced knowledge in both scientific and societal practices (Phase C). Aliment'Actions encompasses all these phases, but rather than sequentially, they take place simultaneously and in parallel.

2.2.4. Adaptive research process and consortium

The research process and project partnership are adaptive in that they change along with the project's life. The project team meets on a weekly basis to discuss the ongoing actions as well as the evolving context. In addition, project seminars are held several times a year to discuss the project strategy. This strong interaction between the project leaders allows for the timely exchange of information, fluidity of interactions between researchers and local actors, and reactivity. Collectively, these enhance flexibility in the research design, data collection, and action implementation.

This reflects more than just a transdisciplinary research approach, as the scientists adopt a post-normal posture, which is appropriate in cases where "facts are uncertain, values are under debate, stakes are high, and decisions are urgent" (Funtowicz and Ravetz, 1993, p.

10). The project, thus, takes into account the uncertain nature of the agrifood system trajectory in response to climate change, biodiversity degradation, and the complex socioeconomic disruptions it faces. The researchers, together with non-academic actors, regularly discuss the research objectives, implementation approach, and outcomes. Based on these discussions, the researchers adapted the research strategy either by modifying the experimental design (see Gaba and Bretagnolle, 2020) or the boundaries of the system under study (e.g., to include relevant stakeholders or add other taxa) (see Bretagnolle et al., 2018b; Berthet et al., 2022). In addition, the ZAPVS is a platform where various research projects and actions can be implemented and articulated. Agrifood systems by default include multiple actors, such as farmers, consumers, decision-makers, and food processing firms and retailers, which are heterogeneous in the sense that they have different values, expectations, functions, power, or constraints (Moragues-Faus et al., 2017). Hence, there is no single optimal method to involve this large diversity of actors in a collective design process (Blay-Palmer, 2016). In this context, the non-academic facilitators contribute significantly to weaving relationships between the regional stakeholders by (a) constantly creating links (i.e., between the researchers themselves, between the researchers and the regional stakeholders, and between regional stakeholders) and (b) by ensuring that the "territorial rhythm" is effective (i.e., one of the four types of targeted actions discussed below are implemented at least once a quarter in each selected village).

2.2.5. Research design based on experimentation and monitoring

Another major aspect of the Aliment'Actions project is its experimental nature. Arguably, the need to develop and mobilize a diversity of experimental tools and approaches is essential to build trust, frame the issues at stake, develop and discuss imaginaries or values, foster social learning, and facilitate interactions, discussions, and exploration of ideas. The methods and protocols applied are presented in Section 2.3.

2.3. Types of actions implemented within the Aliment'Actions

The project consortium developed an iterative research agenda distinguishing four types of actions. The first is "backdrop actions" that are led at the ZAPVS scale and aim to increase mutual knowledge, trust, and collaboration between researchers and local stakeholders throughout the project. The second is "targeted actions", which in contrast to "backdrop actions", built upon a spatial design and conducted in targeted villages with the aim of generating or stimulating changes in the practices and behaviors of inhabitants (thus following an experimental design model). The third is "assessment actions", which track the effects of backdrop and targeted actions through monitoring and surveys. The fourth

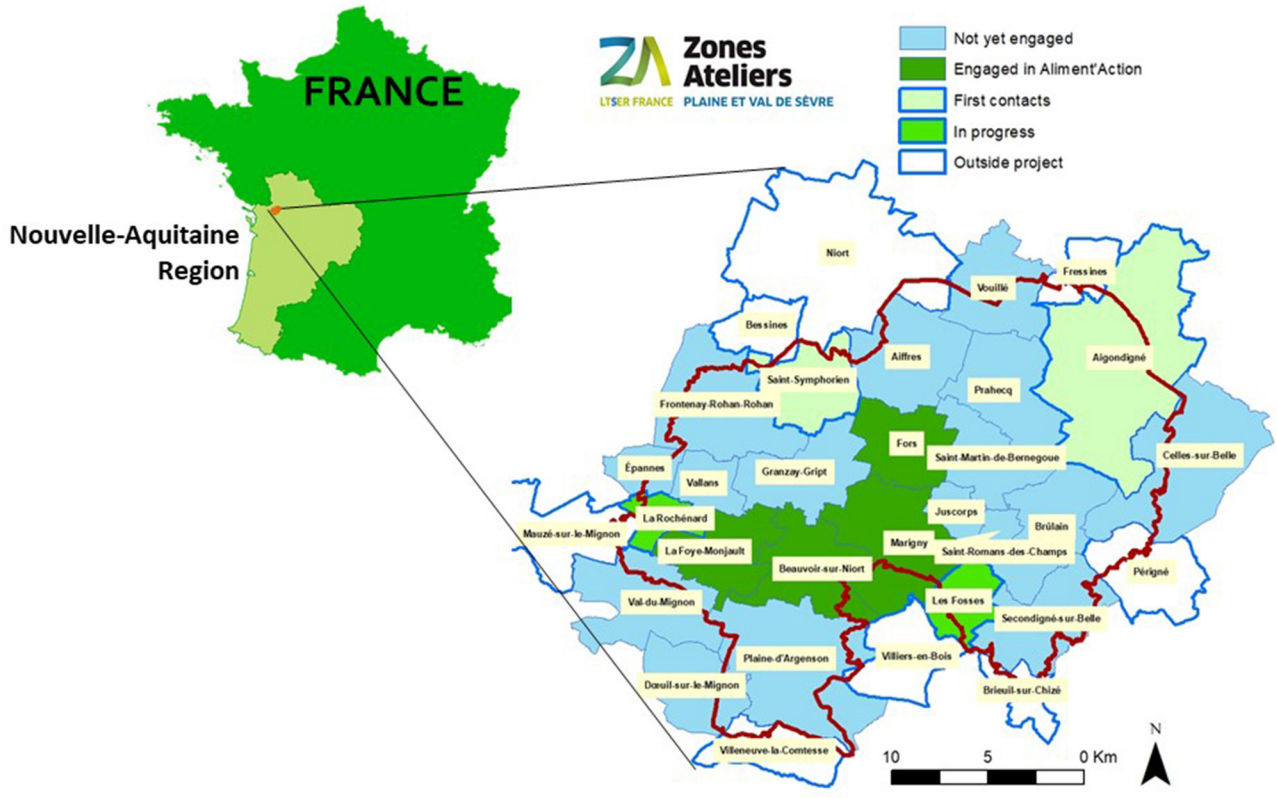

FIGURE 3
Study area of the Aliment'Actions project. The figure highlights all municipalities that intersect with the Zone Atelier Plaine and Val de Sèvre (ZAPVS). Municipalities involved in the project (as of 2021) are indicated in green, while those not yet involved as of 2021 (but that will be within the 10-year project duration) are indicated in light blue. Municipalities usually include several villages, which means that the 24 municipalities actually encompass 40 villages in total.

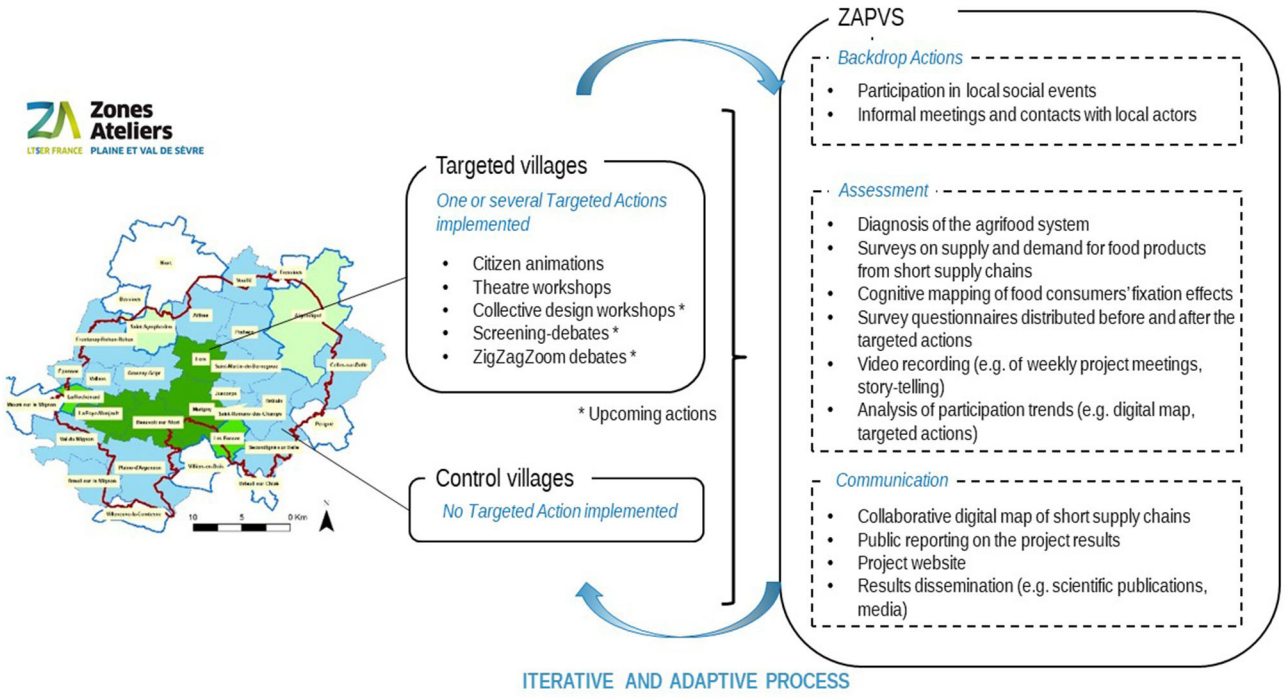

FIGURE 4
The different actions implemented in the Aliment'Actions project.

is "communication actions" that encompass the dissemination of results and exchanges with the public, stakeholders, and scientists, which ultimately may shape or reshape backdrop, targeted, and assessment actions (see Figure 4 for a general description).

Backdrop actions are carried out all over the ZAPVS, systematically, opportunistically, or randomly, depending on the situation. They contribute to collecting information on (and improving the understanding of) the interests and needs of the region's residents, fostering their trust and commitment, and creating and maintaining relationships between residents and the research team. Such actions are essential to ensure that the project is accepted, endorsed, and promoted. They are also aimed at creating a fertile ground so that the "seeds" sown later by the consortium or other actors (e.g., elected officials, associations, and citizens) can germinate and develop in concrete actions. These "seeds" are both the targeted actions described below and the local stakeholders' initiatives. Backdrop actions often entail the participation of the project members in local events as well as informal and formal meetings with residents, farmers, local authorities, or other types of stakeholders.

Targeted actions are implemented at the village level. They are designed to test individual or collective transformation levers (the "triggers" of research question 1; see above) to accelerate the transformation of the agrifood system. More specifically, these actions first contribute to raising awareness about food issues, then to increasing local stakeholders' capacity, and finally to catalyzing stakeholders' initiatives[6] to involve them in a democratic way in the transformation of the regional agrifood system. We adopt the targeted actions to the societal context, given that this context can change quickly, which significantly modifies the perception, behaviors, and mobilization of the actors, as witnessed, for example, during the COVID-19 pandemic. The villages, in which targeted actions are implemented, are selected following a spatial design. By spatial design, here, we refer to the fact that action protocols differ between "targeted" villages (in green in Figures 3, 4) and "control" villages, where no targeted actions are implemented (in blue in Figures 3, 4). The type and number of targeted actions vary according to the characteristics of the village and the triggers to be tested and are described in more detail in Section 2.4. Actions are, thus, differentiated in space, allowing the identification of contrasts between villages that are monitored and analyzed. The spatial design that informs the decisions over the implemented targeted actions is essential to enable comparisons between villages, even if it is not always feasible to achieve an "all things being equal" condition. As Bergmann et al. (2021, p. 545) highlight, "*a critical task relates to the context-specific nature of experiments with only limited, participatory control of many factors, which challenges the generation of comparative and transferable insights*". Several types of targeted actions have been implemented up to now, which are presented in Section 2.4. We report some preliminary results in Sections 3.1–3.3.

Assessment actions seek to assess the effects of backdrop and targeted actions. Assessment is crucial to understand the project's impacts and answer the three research questions presented in Section 2.1. Assessment actions are facilitated by long-term place-based

6 Stakeholders' initiatives may be conducted at the individual, collective or municipal scale. Examples of initiatives at the individual level include changing one's diet such as to reduce meat consumption. Initiatives at the collective level include setting up an educational garden in a school. Initiatives at the municipal scale include the provision of municipal land to a vegetable farmer, who then sells its products to the inhabitants.

research and information on the SES transformation trajectory. To understand how the various actions affect the trajectory of the local agrifood system and to ensure that successful solutions can be transferable in other agrifood systems and/or transdisciplinary projects, we perform an overall assessment of the conditions of action implementation, reception, and impacts. To this end, we document the processes operating along with the way (e.g., project meetings/events and evolution of partnerships) and analyze the key aspects of success or failure, difficulties, and questions. The assessment follows a diversified project monitoring approach, which includes (a) qualitative surveys of the reactions and viewpoints of the actors and social groups of the ZAPVS concerned by the project, (b) a video library that contains the recording of all weekly videoconferences about the evolution of the project since March 2020, (c) "story-telling" videos developed by the project's facilitators, (d) reports of the events organized within and outside the project by facilitators or observers from the research team, and (e) survey questionnaires distributed before and after the workshops. The assessment also includes quantitative monitoring of participation in the surveys and citizen engagements, as well as the dynamics of the digital map of short supply chains outlined below (e.g., number of outlets on the map, website traffic). The consortium also plans to co-construct relevant indicators with local stakeholders to monitor individual and collective transformation trajectories, relating for instance to food practices, representations, or knowledge among others.

Communication and result dissemination actions are very diverse. A wiki-type website features a collaborative map of local short food supply chains, serves as a platform to gather the different project outputs (e.g., texts, reports, photos, and videos), and aims to create a dynamic space where local actors can express themselves and interact with one another. The reflexive follow-up and collaborative dissemination of the project (involving non-academic actors) are envisaged to promote the uptake of the project and the themes it addresses. The research team organizes the different village activities that disseminate to the local residents and the publicly released reports, which are then followed by discussions. Scientific publications and studies delivered at conferences that present the project (and its results) are beginning to be produced, as of the writing of this study. Finally, a communication strategy targeting various media (e.g., press, radio, and Internet) is also being developed.

2.4. Details of targeted actions and monitoring activities

As outlined above, the Aliment'Actions project has been implemented since 2018. Its first phase, which we qualify as the project launch and calibration, has ended, and a new one has started in January 2022. For the sake of clarity, in this Methods paper, we only present the main targeted actions and assessment actions that are either implemented or upcoming as of the writing of this study.

2.4.1. Ongoing and upcoming targeted actions

The main ongoing and upcoming targeted actions include (a) citizen engagements, (b) theater workshops, (c) ZigZagZoom debate sessions, (d) collective design workshops, and (e) conference debates (see Table 1). Below, we briefly outline their key aspects.

The citizen engagements are set up by two mediation professionals. They are designed to encourage citizens to engage with food issues and to motivate all the participants (e.g., consumers, elected officials, and producers) to actively get involved and cooperate with each other (e.g., shared gardens, short cereal-meal-bakery chains). So far, six municipalities have been involved with an average of two new ones added each year (e.g., two were planned for 2022) (see Figure 4). In each village, the citizen engagements start with a standardized sequence consisting of a Samoan Circle and then an Open Forum to which we add customized formats [e.g., Six thinking hats (De Bono, 2017), specific engagements for a school public, etc.] based on the first observations, reactions, expectations, and initiatives. These engagements started in November 2018 and continued in 2020 and 2021, despite the COVID-19 pandemic. Since the launch of the project, and as of the writing of this study, 56 such targeted actions took place in six municipalities, reaching over 1,000 individuals. This constitutes what we name the "territorial beat", that is, in reference to heartbeat: a succession of events that builds trust and supports changes in mindsets. These engagements involve citizens in the identification of what may be a desirable trajectory for their agrifood system. There have also been some emerging actions led by citizens or municipalities, including for instance new food markets established in three villages.

The theater workshops collectively create original plays on specific controversial or socially relevant issues. For the participants, the aim is to relate complex and sometimes divisive issues and to develop the imagination to change representations (Fournout and Bouchet, 2019). This methodology of collective creation was first implemented within the project in October 2020 with the theme: "Farmers and inhabitants, citizens of the same region: what relationships?" Its purpose is to enable farmers and other citizens to transpose the relationships between them in a play of which they will be the authors, stage directors, and actors. This allows them to put into perspective their preconceived ideas, questions, and desires for the future. They identify new avenues for individual or collective action in a way that, far from being only an intellectual or linguistic endeavor, it will be as in "real life", namely, embodied, emotional, existential, and creative. A survey questionnaire that was distributed before and after the theatrical performance, gave participants the opportunity to describe the effects of the diversion through the imagination, particularly in terms of the recommendations for action that may emerge. The results of the survey clearly show that the participants perceived the theatrical collective experiment as an opportunity to "let go" of mental postures and stereotypes. A theater troupe spirit emerged with a wish to perform the plays again in other villages. As one of the participants suggested, "we meet by the market and play something fun, then we have a big Citizens Assembly to put into debate the street show". Although this has not been possible during the COVID-19 pandemic, new theater workshops are planned given that the public health situation allows it again. The target is to hold one or two such events per year given the difficulty to recruit participants who are not theater professionals and may not immediately feel comfortable engaging in such activities. Previous experiments that followed the same methodology (Fournout and Bouchet, 2019) showed that although it is not easy to convince the participants to start the process, once there is momentum and proper help from professional mediators, the participants feel secure

TABLE 1 Summary of the targeted actions.

Targeted actions	Citizen engagements	Theater workshops	ZigZagZoom debate sessions	Collective design workshops	Conferences-debates
Aim	Encourage citizens and local authorities to engage with the food issue and cooperate	Create original plays on a specific societal issue Use the imaginary to change representations and enhance dialogue.	Use a dialogic protocol to enhance debates on controversial issues. Identify points of convergence on which to build actions	Apply a collective design method to help participants develop innovative projects to enhance agrifood system resilience	Alert local residents and actors to the crises posed by the Anthropocene. Talk about potential initiatives and solutions they could implement
Number planned	2–4 citizen engagements per year in each targeted village	2 plays per year	2 debate sessions per year in each targeted village	10 workshops in total	5 conference-debates in total
Number implemented	39	2	0	0	0
Scale	Village	Set of three villages	Village	School or village	Village
Number of engaged individuals per session	5–50	10–15	15–30	15–30	30–50

TABLE 2 Summary of the diagnosis and monitoring actions.

	Food system diagnosis	Local food offer and supply	Diagnosis of fixation effects on food practices
Aim	Produce knowledge about the agrifood system components, functioning and dynamics	Confront food and demand trends in the region	Determine fixation effects for children, teenagers and adults on how to improve food consumption
Number of interviews	32	c.700 (in Sept. 2022)	325 children (from 9 to 16 years old)
Number of targeted people	>30 diverse actors within the agrifood system	>20–30% of households in each village	1,000 children, teenagers and adults
Theoretical framework	Social networks. Multi-level perspective	NA	Cognitive psychology. Innovative design theory
Method	Semi-structured interviews	Structured interviews	Creativity tasks and questionnaires

and more eager to contribute and have a good time together. The prospect of performing the play in front of a real audience acts then as a strong incentive.

ZigZagZoom debate sessions will be organized in the near future among farmers, consumers, scientists, local politicians, and other regional stakeholders. ZigZagZoom is a dialogic protocol inspired by the approach promoted by the Braver Angels[7] Organization in the United States to improve debates between democrats and republicans. A ZigZagZoom debate session can be held either online or with in-person attendance. It lasts for 90 min and starts with a "yes/no" shared question. An equal representation of "yes/no" answers to this shared question is agreed upon among the participants before the session. A dialogue facilitator leads the exchanges and the points of view alternate with questions from attendants taken between each intervention. The theoretical underpinning of these debate sessions is rooted in the work of Habermas (1991). The protocol of the ZigZagZoom debate sessions for the Aliment'Actions project was created and tested throughout 2021 and the beginning of 2022 by two consortium members that have implemented 17 such sessions in contexts other than the ZAPVS. Within the Aliment'Actions project, this engagement will be conducted to tackle collectively divisive questions such as "should we stop using pesticides in the fields next to our village?".

Collective design workshops will be implemented in a semi-experimental way in several villages across the ZAPVS to determine the extent to which implementing a design method can increase consumers' openness to change. These workshops have two objectives: (a) to accompany the regional actors in the elaboration of their projects that aim to enhance agrifood system resilience and (b) to produce data that enable a better understanding of the impediments and determinants of the food transition in a comparative way through workshops. We will apply the Knowledge-Concepts-Proposals (KCP) method (Hatchuel et al., 2009), which has been proven to enhance design capacities (Hooge et al., 2017). However, the implementation of KCP in a context where such groups do not necessarily already exist is original and challenging. Questionnaires will be circulated before and after each design workshop to assess the impacts of the workshops on participants' ability to overcome their entrenched beliefs and increase their agency (e.g., transform their ideas into projects and increase their self-confidence).

Conferences-debates are planned in different municipalities as of the writing of this study to alert the local residents and actors about the shocking consequences of the Anthropocene and discuss possible initiatives they could potentially implement to increase the resilience of the agrifood system. These talks will be based either on short films generated through the biodiversity- and agroecology-related research conducted within the ZAPVS or on scientific studies of the state of the world facing the Anthropocene and its diverse

7 Refer to: https://braverangels.org/.

environmental challenges. These scientific talks are intended for the general public and focus on key concepts, such as global change, the Anthropocene, tipping points, or transformative change. Before and after the talks, short inquiries, as well as interviews with the participants, will be organized to ascertain whether the talks (and in particular which key points) have elicited positive emotions (defined as triggers that support collective action toward a more sustainable or desired future). There will also be efforts to offer such talks for teenagers and children.

2.4.2. Monitoring actions

The main diagnosis and monitoring actions presented here are the food system diagnosis, the assessement of local food offer and supply and the diagnosis of fixation effects on sustainable food practices (see Table 2). First, to enhance the resilience of an SES, a fortiori and agrifood system, there is a need to have deep knowledge about its components, functioning, and dynamics. Toward this end, a diagnosis of the local agrifood system was carried out in 2021 (Berthet and Deroche-Leydier, 2022), drawing on 32 interviews with local stakeholders. These included representatives of local authorities, farmer cooperatives, groceries, consumer associations, food supply chains, mass catering, and restaurants. Furthermore, we conducted surveys with farmers and consumers in the frame of the Aliment'Actions project, as well as participant observation and document analysis. This sociotechnical diagnosis combined three complementary analytical frameworks sociotechnological transitions (Geels and Schot, 2007), social networks (Scott, 1988), and SES (Berkes et al., 2000). Some results are presented in Section 3.1.

A qualitative and quantitative survey about the supply of food products from short supply chains was launched in early 2019. This survey sought to identify the producers selling food products through short supply chains in the ZAPVS, their production, development prospects, and possible difficulties. This assessment also targeted intermediate actors. At the end of 2022, we have identified more than 100 producers whose market at least part of their food products through direct sales and are either situated in the ZAPVS or market their products in the region. This is equivalent to ∼15% of the farmers in the region (not all producers who sell directly are necessarily farmers). Based on this survey, meetings, and word of mouth, the project consortium enriched, made interactive, and finally put online a map of short supply chain outlets, which had originally been developed in 2017 (refer to: https://aliment-actions.fr/?CarteProducteur). This digital map is collaborative insofar as each resident in the region, whether a producer or not, can inform it. Moreover, the survey is carried out iteratively with a series of telephone interviews conducted during and after the COVID-19 lockdown in the spring of 2020. This involved ∼20 actors of short supply chains.

Second, an evaluation of the demand for short supply chain food products is underway. The intention is to conduct interviews with a large proportion (30–50%) of households in 24 municipalities. In May 2022, four of these municipalities have been surveyed (Les Fosses, Marigny, Fors, La Foye-Monjault). In total, 603 individual interviews were conducted accounting for 30.3–56.7% of the inhabitants in these four municipalities. The objective here is to quantify the current food habits and uses in the region, as well as expectations around short supply chains including obstacles and possible levers of action to overcome them. The findings of these surveys are disseminated during public presentations (in person or remotely, depending on the constraints posed by the COVID-19 pandemic) to encourage reflection and action by respondents and to motivate them to increase the consumption of local food products.

Third, the literature on creativity and design highlights the fact that a major obstacle to idea generation is the fixation effect, i.e., "the fact that some knowledge about existing or obvious solutions is spontaneously activated and constraints the generation of new solutions" (Agogué et al., 2014): (1). To identify consumers' fixation effect, we draw on previous research that combined cognitive psychology with design sciences, first to determine fixation effects for specific individuals on specific subjects and second to test levers to overcome them (Agogué et al., 2014). For this, we assess knowledge and map ideas about how to increase sustainable food practices for a large number (target: 1,000) of consumers in the ZAPVS (from children to adults). We will use this fixation effect mapping in combination with the collective design workshops to test two types of inputs that may increase creativity and transformation in consumer projects: (a) targeted ecological knowledge (beyond common knowledge) and (b) innovative examples of cooperation between farmers and consumers (outside pre-identified fixation effects).

3. Results and discussion

3.1. Identifying actors' strategies and needs for cooperation in the agrifood system

Our system diagnosis (Section 2.4.2.) revealed various stakeholder strategies with regard to the agrifood system dynamics in the study region, such as enhancing food relocation, developing organic farming, or maintaining current trends (BAU scenario). It also helped to understand the nature of the relationships between the stakeholders, as well as the strength of these relationships. This system diagnosis highlighted, in particular, various strategies of innovation niche building such as the development of consumer associations to promote peasant farming or online marketplace for local and organic food products. Furthermore, it pointed to the hybridization between some of these niches and the dominant regime, this hybridization is the outcome of both policy pressure and consumer demand. Some examples are the provisioning of school catering through both short and long supply chains or farmer cooperatives that target both local and international markets. Such types of coexistence and confrontation of food system models have been observed and analyzed in other regions over the world (Gasselin et al., 2021), highlighting that various actors of food systems, be they farmers, cooperatives, or retailers, hybridize long and short supply chains for various reasons, notably to spread the risks.

In addition, despite highlighting the active involvement of some innovation intermediaries, our agrifood system diagnosis also showed a lack of connectivity between some niches. For instance, our social network analysis highlighted two "cliques[8]", one in Niort (∼60,000 inhabitants) and one in Melle (∼ 6,000 inhabitants), these cities being 30 km apart. Both "cliques" have distinct compositions and functioning and have little interaction between them. The first "clique" (Niort) gathers mainly institutional actors linked with formal

8 In the social sciences, a clique is a group of individuals who interact with one another and share similar interests (Lazega, 1998).

arrangements and is quite centralized. The second "clique" (Melle) gathers more diverse types of actors (e.g., local authorities, local food retailers, associations, and farmers) who interact both formally and informally, relying on trust relationships and shared values. Each municipality builds its own "territorial food project" in a quite redundant way. In addition, as most retailers or canteens build their own provisioning networks, our study showed the lack of visibility of the adequacy between local food offer and demand in the region. Overall, our findings highlight the interest in a transversal organization that would better coordinate short supply chains at a regional scale.

3.2. Assessing the local demand for food products from short supply chains

In the four municipalities where surveys were conducted up to the writing of this study (see Section 2.4.2.), ∼57–72% of the respondents in each municipality stated that they regularly buy local food products (excluding food self-provision), i.e., they bought at least one item in the last month. This is consistent with a national survey[9] indicating that 64% of French consumers bought products from short supply chains at least once a month in 2020. Most purchases are done directly at farms or on open-air markets (Figure 5).

The main motivations for purchasing food items through short supply chains include the quality and traceability of the products and better remuneration for the farmers. This is consistent with other studies that mention the quality and traceability of food products as major motivations for purchasing food from short supply chains, amidst concerns over health and the environmental impact of food (Chiffoleau and Dourian, 2020). Similarly, the fair compensation of farmers has emerged as a topic of concern among many food consumers in the EU, as the low prices often received at farm gate are considered unfair in view of price escalation by intermediaries (Lappo et al., 2015; Chiffoleau and Dourian, 2020). This high interest in purchasing food from short supply chains is also reflected in ∼80% of respondents that did not report buying food locally claimed, they were prepared to do so within the next months.

However, the surveys also identified some obstacles to engaging in such purchasing behavior, including the additional economic cost, lack of time, mobility problems, and lack of information on the sales outlets. Similar constraints have been identified in other studies (Maréchal et al., 2019).

3.3. Upscaling the place-based approach

The decision to anchor the Aliment'Actions project in a delimited and well-defined region draws upon the assertion that transformations toward sustainability are generally triggered at the local scale. As Balvanera et al. (2017, p. 2) pointed out, "*place-based research (…) is uniquely positioned to explore the interplay between the local and the global scales, by recognizing the distinctiveness of local entities, while addressing the impacts of global dynamics on them*". Place-based approaches are also advocated by Sonnino and Milbourne (2022) who underline their potential to address the complex entanglements of relations within food systems, the

9 This study was conducted from 15 to 22 April 2021 on the Kantar Profiles panel with a representative sample of the French population (1,000 individuals).

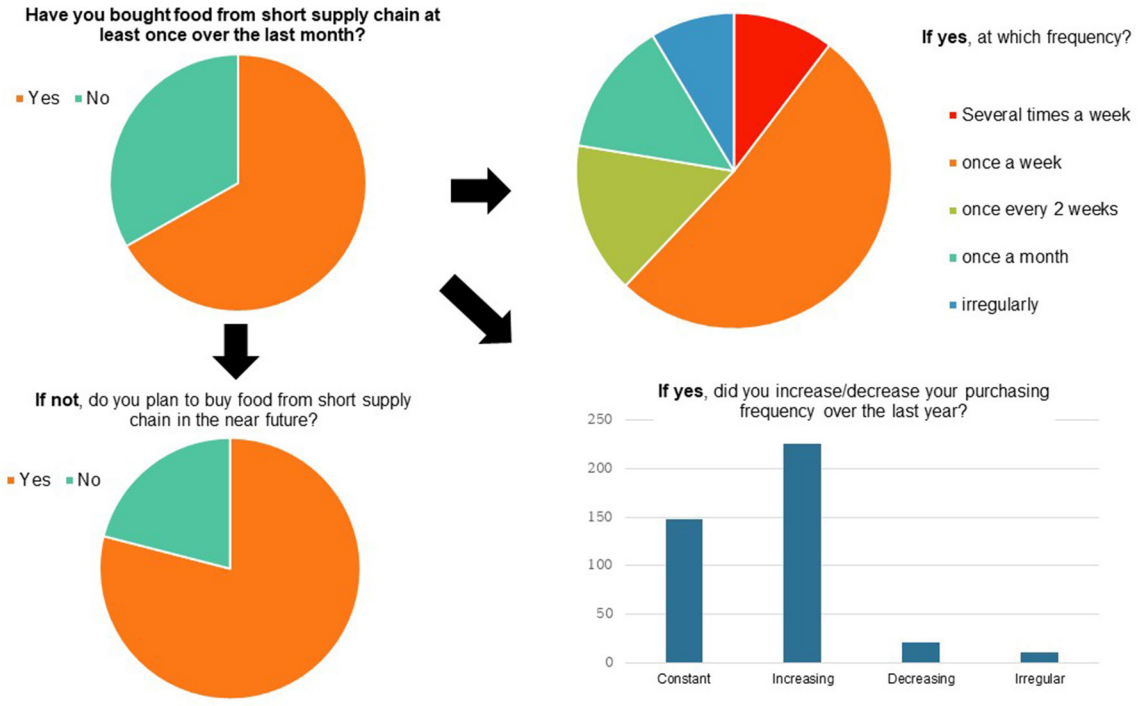

FIGURE 5
Preliminary results of consumer surveys (n = 603).

stakeholders' diverging views, as well as the coevolution between different human and non-human interacting elements. Balvanera et al. (2017) highlight the strengths, challenges, and opportunities of place-based research, with the main challenges being transferability (as they are context dependent and may rely on place-based knowledge) and upscaling (taking into account interactions between various governance levels). Balvanera et al. (2017) also highlight the need for new theoretical frameworks that would advance our understanding of how to assess multiscale dynamics.

Agriculture in the ZAPVS is typical of Western and Northern Europe, where agriculture has been intensifying and specializing in crop farms, which are mostly family-operated. As this type of agricultural landscape and agrifood system may not necessarily reflect those encountered in many other parts of the world, possibly the results of Aliment'Actions are not directly transferable outside Europe. However, we argue that our experimental approach could be transferrable in other contexts, as long as there is a commitment to long-term research and collection/analysis of a large volume of data to inform the food system transformation trajectory.

3.4. Engaging various stakeholders for an experimental approach at the regional scale

Sustainability challenges are complex and even wicked, which often makes linear and technocratic approaches insufficient (Sonnino and Milbourne, 2022). In such contexts, there is a need for an experimental turn in research (Overdevest et al., 2010). An important challenge, when carrying out experimental research at the regional scale, is not only to ensure scientific rigor but also the democratic involvement of stakeholders (Sonnino and Milbourne, 2022), as well as the transferability of results/approaches in other regions (Balvanera et al., 2017). As discussed throughout this study, the processes of experimentation, evaluation, learning, and innovation carried out by Aliment'Actions with the participation of actors outside academia are intended precisely to facilitate societal transformation (Loorbach et al., 2017).

However, conducting transdisciplinary research raises a series of challenges regarding both the effective involvement of non-academic actors and the emergence of conflicts due to differing values, conflicting interests, dissimilar claims of legitimacy, and diverse knowledge claims (Siebenhüner, 2018). The Aliment'Actions project developed several strategies to cope with these challenges, such as (a) build and maintain trust with local stakeholders, particularly through backdrop actions and the frequent interventions of the project team facilitators in the region, (b) conduct in parallel diverse activities with various stakeholders to enhance participation and account for multiple perspectives (here, although diverse types of consumers were the main targets, the project team involved producers, local authorities, and various other economic actors in the project), and (c) put forward approaches that foster mutual consideration and dialogue.

Indeed, in contexts characterized by uncertainty, it is legitimate that science should experience controversy where arguments in search of proof and facts confront questions from society (Callon et al., 2001). While such differences of viewpoints prove useful for scientists in search of a consensus, it is often magnified as irreconcilable positions in the public arena. Someone in the audience of a theater workshop production puts it: "I wanted to thank you for taking the risk to get together and expose something else than conflict, as it is staged every day by the predominant media" (quoted by Fournout and Bouchet, 2019, p. 93). Furthermore, within the Aliment'Actions project, the various engagement tools (e.g., theater workshops and ZigZagZoom debates) seek to give a chance to procedural ethics of discussion and to foster collective imagination for tackling the ecological challenges posed by current food production and consumption practices. This would require more than knowledge and facts and calls for creative, imaginative, and experiential ways of thinking, communicating, generating change, and creating new narratives (Galafassi et al., 2018).

Nevertheless, involving diverse actors in a transdisciplinary research project is challenging, with the COVID-19 pandemic generating added unprecedented difficulties. The Aliment'Actions project team is, thus, continually adapting, enriching, and renewing these strategies to facilitate stakeholder engagement to catalyze and foster agrifood transformation in the study region.

3.5. Rethinking the role and positionality of researchers in transformative science

Up to now, the Aliment'Actions project has been pioneering not only in terms of its wide geographical and temporal scope but also of the role and positionality of the involved researchers. The approach is not overhanging but aims at catalyzing and analyzing local initiatives, in close interaction with citizens and actors from the associative and entrepreneurial worlds. Engaging with stakeholders in this process, encompassing the diversity of relevant actors and creating a shared understanding of the problems, can arguably change the way researchers learn about SES. The focus is, thus, shifting from a rather "positivist" and reductionist approach to a more "constructivist" and holistic approach (Hazard et al., 2020), and from a knowledge-transfer perspective to a post-normal science perspective (Ainscough et al., 2018). This reflects the fact that research addressing wicked problems faces a double epistemic uncertainty (Hazard et al., 2020, p. 5): "*The first is the result of the imperfection with which science tackles societal problems: a single original and clear research question cannot adequately represent the fuzziness of an indeterminate situation. The second uncertainty arises from the unpredictability of the effects of scientific knowledge when introduced in a complex situation*".

Planning the project for at least 10 years (2018 onwards) enables the implementation of what Ansell and Bartenberger (2016) describe as "generative experimentation", as distinguished from "controlled experimentation" and "Darwinian experimentation". Similar to controlled experimentation, generative experimentation focuses on a single experiment but rather than seeking to determine causal chains, it aims to stimulate the generation and analysis of information about the actual experiment by the participants themselves, with the overall aim of achieving collective learning (ibid). Here, the boundary between observers and participants is abolished, which opens the way to achieve a richer collaboration. Generative experimentation is similar to Darwinian experimentation in that it takes place in real-life conditions, but while the latter focuses on "populations of experiments", the former focuses on a single experiment (ibid). This single experiment is essentially seen as an evaluation in progress where iterative improvements occur to

find solutions to the problems that arise until a (always transitory) solution is found.

3.6. Developing a research infrastructure for transformative governance

As part of its effort to transform the regional agrifood system, the Aliment'Actions project seeks to foster new alliances and solidarity within the agrifood system in the study region (i.e., between producers, processors, distributors, consumers, and municipal councils). These alliances participate in the (re)construction of a peaceful dialogue between the actors of this rural region and aim to co-construct individual, collective, and region-wide solutions to enhance agrifood system resilience. As discussed throughout this study, Aliment'Actions deploys various actions to achieve this (e.g., workshops, citizen engagement, and surveys) that collectively contribute to the development of adaptive governance of the agrifood systems. Along with the way, the impact of the proposed innovations to enhance the resilience of the agrifood system (in terms of the value chain, governance, food production, and consumption practices) is analyzed, and the plan is to disseminate the results through various channels.

In this sense, the ZAPVS could become a part of a new research landscape that has a methodological focus on real-world experiments to understand sustainability problems and develop possible solutions through science–society collaboration (Bergmann et al., 2021). A broad array of research approaches fit this long-term and transformation-oriented research landscape, including urban and sustainable living labs (Liedtke et al., 2015), transformative spaces (Pereira et al., 2020a), and real-world labs (Schäpke et al., 2018a). Arguably, the ZAPVS echoes the five characteristics of real-world labs described by Schäpke et al. (2018a, p. 86): *"(1) [aim] to contribute to societal transformation, (2) [use] experiments as core research method and (3) transdisciplinarity as core research mode, (4) [have] a long-term orientation and seek scalability, and transferability of the results while (5) building on learning and reflexivity"*.

However, Aliment'Actions has some additional original features. First, it has a longer span, as some monitoring actions in the region started more than 25 years ago and have continued without any interruption. Second, the close collaboration between academic and non-academic actors throughout the duration of this project is seldom encountered within most other transdisciplinary projects, where interactions between scientists and local stakeholders are limited to information or consultation (Bergmann et al., 2021). Finally, to our knowledge, the spatial design of the targeted actions, which allows for experimentation and comparison, is unique. We argue that all these features distinguish Aliment'Actions from other research efforts that seek to transform agrifood systems and are not only critical to experiment with an innovative research project governance but also SES transformative governance.

4. Conclusion

This Methods article presents the research agenda and geographical setting of the Aliment'Actions research project that was initiated in 2018 in the LTSER zone Atelier Plaine & Val de Sèvre (Western France). This project has been planned to run for at least 10 years at the regional scale. It aims to achieve a better understanding of the factors and conditions that can catalyze agrifood system transformation to increase its sustainability and resilience. Throughout the research processes, the researchers both study and are involved in an ongoing transformation process. The project entails various actions seeking to understand transformation processes in the agrifood system, facilitate the engagement of stakeholders, monitor the different interventions, and communicate the main findings. The Aliment'Actions project has five main overarching features, namely, it adopts an SES perspective, it is place-based, transdisciplinary, adaptive, and iterative, and its research design is based on experimentation and monitoring. As the project is ongoing as of the writing of this paper, our aim here has been to share its approach, methodology, preliminary results, as well as how the research team addressed some of the research challenges. As many of the features of this pioneering project were developed along with the way, we believe that its overall approach may be useful for other transdisciplinary projects aiming at transforming agrifood systems.

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.

Author contributions

EB, SG, CB, and VB conceived the ideas and designed the methodology. EB, SG, CB, MG, OF, and VB implemented project-related actions and collected the data. EB, SG, CB, MG, OF, NB, and VB analyzed the data. EB, SG, and VB led the writing of the manuscript. All authors wrote parts of the article, contributed critically to the drafts, and gave final approval for publication.

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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.

Publisher's note

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Mobilizing participatory approaches to introduce transdisciplinary research elements when exploring the interface of commodity crop production and food security in Sub-Saharan Africa

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The production of commodity crops such as oil palm, sugarcane, cotton or cocoa has important ramifications for sustainability at multiple spatial and temporal scales. Food security is among the most heavily debated impacts of commodity crop production, especially in developing regions characterized by high rates of malnutrition and food insecurity such as Sub-Saharan Africa (SSA). Studies have identified diverse pathways through which commodity crop production can have positive or negative impacts on the different pillars of food security. This Methodology paper outlines how different participatory approaches can be mobilized to introduce transdisciplinarity research elements when exploring the adoption and impacts of commodity crop production, especially in developing regions such as SSA. It draws from the lessons learned during the design and implementation of five research projects that explored the food security outcomes of commodity crop production in different countries of SSA. Collectively these research projects mobilized very diverse participatory approaches such as expert interviews, Focus Group Discussions (FGDs), participatory mapping, mediated modeling, and participatory scenario analysis. Beyond being instrumental for data collection, these participatory approaches served multiple other research functions. In particular they helped (a) identify research priorities, knowledge gaps, and underlying phenomena, (b) formalize impact mechanisms and develop methodology, and (c) interpret data and validate findings. Furthermore, they contributed to the credibility and relevance of the research, and to a lesser extent to the legitimacy and effectiveness, all of which are considered important principles of transdisciplinary research. Through these diverse contributions they were instrumental in integrating valuable insights from stakeholders holding very complementary expertise in commodity crop value chains at different scales. In this sense they can act as valuable entry points to introduce transdisciplinary research elements in projects exploring the interface

of food security and commodity crop value chains (or food systems more broadly), especially in contexts that truly transdisciplinary research is not feasible or desirable.

KEYWORDS

expert interviews, Focus Group Discussions, mediated modeling, participatory scenario analysis, transdisciplinary, sustainability, cash crop, industrial crop

1. Introduction

Commodity crop production is a significant agricultural activity in many parts of Sub-Saharan Africa (SSA). Some commodity crops[1] such as cocoa, coffee, and cotton, have been produced for centuries in different parts of the region. Others such as jatropha, sugarcane and oil palm have received substantial attention in the past decades for bioenergy or input in the food industry (Gasparatos et al., 2015; Ordway et al., 2017). The selection, promotion, and production of commodity crops often experiences boom-and-burst cycles, due to various national and international circumstances (Brown and Gibson, 2006; Clough et al., 2009). Despite these cycles, commodity crops have been promoted for radically different reasons between countries and can have radically different impacts at different spatial scales across the region, as discussed below.

A common reason driving the promotion and adoption of commodity crops is the perceived competitive advantages of producing countries (Ahmed and Gasparatos, 2021a), as well as efforts to modernize the agricultural sector and integrate SSA countries into the global economic system and farmers in global value chains (Van Vliet et al., 2015; Mellor and Malik, 2017). Sometimes, commodity crop production dominates the agricultural sectors and national economies of some countries, e.g., cotton for Burkina Faso (Vitale, 2018), cocoa for Ivory Coast and Ghana (Breisinger et al., 2008), and sugarcane and tobacco for Malawi (Chinangwa et al., 2017). Commodity crops are often seen as cornerstones of (a) national economic growth, (b) foreign exchange and employment generation, and (c) rural development and poverty alleviation (Schoneveld, 2014; Gasparatos et al., 2015). Sometimes they have become focal points in coordinated efforts to enhance energy security (e.g., sugarcane in Malawi) (Gasparatos et al., 2015).

However, commodity crop production in not uniform. It can be undertaken in different types of landscapes and through different models, both in terms of extent (e.g., large-scale plantations, smallholder-based production), market orientation (e.g., local use, sales in national and international markets), or intensification. Crops such as cotton, cocoa, coffee and tobacco are overwhelmingly grown by smallholders, relying on rainfed conditions and unimproved techniques (UNCTAD, 2015). Other crops such as oil palm and sugarcane can be produced ether in smallholder settings or large plantations, but their production tends to benefit from the economies of scale facilitated by large plantations (Gasparatos et al., 2015; Hall et al., 2017). In terms of markets, as they cannot mostly be consumed directly for food[1], they are produced for sale in national and international markets. Thus they are essentially cash crops produced for income generation after integrating farmers in national and international value chains (Achterbosch et al., 2014).

Commodity crop production has multiple impacts at different scales, that can be positive or negative depending on the crop, production model, scale of analysis and political, socioeconomic and environmental context. Usually, land mediates most of local impacts through land use change (Hess et al., 2016), sometimes associated with deforestation and/or the loss of ecosystem services and biodiversity (Strona et al., 2018; Ordway et al., 2019; Semie et al., 2019). Conversely, commodity crops offer income opportunities to smallholders and plantation workers in rural contexts that lack such formal opportunities. However, the actual income and employment generation potential depends substantially between crops and models, especially for low-value crops with unstable/immature markets (e.g., jatropha) (Romijn et al., 2014; Hall et al., 2017). Often the engagement and the outcomes of commodity crop production are contested and gendered (Fonjong, 2017).

Food security is perhaps the most controversial impact, as in SSA many of the rural and national contexts of commodity crop expansion in SSA are characterized by high rates of malnutrition and food insecurity. Critics point to the fact that by diverting staple food crop production, commodity crops reduce food availability at the local and the national scale, while the proponents point that by providing stable alternative income sources, commodity crop production improves food security by enhancing access to food (Jarzebski et al., 2020). In reality there are many more context-specific mechanisms mediating the food security outcomes of commodity crop production (Jarzebski et al., 2020). From enabling food crop yield gains due to better access to credit, irrigation and agricultural inputs (von Maltitz et al., 2019) to shifting gender dynamics and norms in areas of commodity crop

1 Commodity crops are defined in this paper as those crops that either have no food-related uses (e.g. cotton, tobacco, jatropha, coffee, cocoa), or are components of the food industry without being staple food crops (e.g. sugarcane, oil palm). Some of the non-food uses include bioenergy (e.g. jatropha, sugarcane), fiber (e.g. cotton) or recreation (e.g. tobacco). Sugarcane and oil palm are very multi-functional commodity crops that beyond their central position in the food industry, they can be used for bioenergy or biomaterials. Commodity crops are overwhelmingly grown for selling to external markets, rather than own use within the producing households. In this sense they have the characteristics of cash crops, with the added characteristic that their production has the potential to cause direct and indirect competition for land, resources and labor with staple food crop production.

production (Fonjong, 2017), improving infrastructure (Smalley, 2013) or affecting food prices.

This large impact variability is partly due to the fact that multiple stakeholders are involved in commodity crop value chains, as producers, consumers or facilitators (e.g., Hunsberger, 2010; Dompreh et al., 2021c). For example, producers include from smallholder family farmers producing commodity crops as a secondary livelihood activity, to specialized smallholders, parttime/fulltime plantation employees or large commercial producers (Hall et al., 2017; von Maltitz et al., 2019). There is also a high diversity of intermediaries and ancillary players (e.g., from government, civil society, certification agencies, international organizations, academia) with very different vested interests in commodity crop production. Such actors facilitate or hinder industrial crop production by, for example, creating amenable policy conditions (or barriers), providing funding, knowledge or engaging in advocacy activities (Hunsberger, 2010; Dompreh et al., 2021c).

Considering this multiplicity of uses, modes, impacts, and stakeholders, some scholars have argued for the need to adopt transdisciplinary research (TDR) approaches to both understand the characteristics, adoption and impacts of commodity crop production systems and value chains in SSA, as well as design appropriate interventions (Musvoto et al., 2015; Phiri et al., 2020; Schut and Giller, 2020; Vincent et al., 2020; van Ewijk and Ros-Tonen, 2021; Thompson et al., 2022). Some approaches have included multi-stakeholder dialogues and workshops (Minh et al., 2020), t-labs (Pereira et al., 2018; van Zwanenberg et al., 2018), participatory modeling and scenario analyses (Enfors et al., 2008; Schmitt Olabisi et al., 2018), and participatory mapping (Webber and Hill, 2014). By definition, TDR entails the integration of multiple disciplinary perspectives (interdisciplinarity) and the inclusion of stakeholders in the process of knowledge production and mobilization (Lang et al., 2012) (see Section 2.1 for a deeper explanation). However, despite this emerging literature, TDR research approaches have very rarely been employed at the interface of commodity crop production and food security in SSA. The underlying reasons are not clear but based on the experience of the authors they likely reflect resource constraints, fragmentation of expertise and the often controversial nature of the topic for some crops (e.g., biofuel crops), which collectively makes challenging to engage meaningfully relevant stakeholders at different levels in truly transdisciplinary research. However, even if it is challenging to undertake purely transdisciplinary research in some contexts, it might be possible to introduce certain transdisciplinary elements.

The aim of this paper is to critically discuss how the mobilization of participatory approaches can introduce transdisciplinary elements in research that explores the interface of commodity crops and food security in SSA. We draw lessons from five international and interdisciplinary research projects conducted between 2011-2022, which though not transdisciplinary in the strict definition of the term, they engaged heavily with stakeholders through various participatory approaches (Section 2). The paper has three research questions (a) how can *different* participatory approaches provide research functions beyond data collection that are considered central in transdisciplinary research, (b) how can *different* participatory approaches strengthen research principles that are considered essential for transdisciplinary research, and (c) how can participatory approaches be mobilized better to achieve the two points above. To meet (a) we outline how different techniques were used to (i) identify research priorities, knowledge gaps, and underlying phenomena (Section 3.1), (ii) formalize impact mechanisms and develop methodology (Section 3.2), (iii) interpret data and validate findings (Section 3.3). To meet (b) we reflect how the mobilization of different participatory approaches contributed to the relevance, credibility, legitimacy, and effectiveness of the research (Section 3.4), all of which are considered important principles of quality for transdisciplinary research (Belcher et al., 2016). To meet (c) we critically discuss some of the lessons learned implementing these techniques (Section 4.1), as well as the challenges, opportunities and future research trajectories to use them to unravel phenomena at the interface of commodity crop production and local sustainability, as well as design interventions to enhance their performance (Section 4.2).

Before embarking to this Methodology paper we need to point that we do not perceive transdisciplinary research as inherently superior to other research approaches (e.g., disciplinary, multidisciplinary, interdisciplinary). The selection of a research approach should depend on the questions and the complexity of the problem at hand, as transdisciplinarity is especially relevant for so-called "wicked" problems[2] that lack clarity in both their aims and solutions (Pohl et al., 2017). Instead, here we distill the lessons learned on how the mobilization of participatory approaches can provide some of the benefits of transdisciplinary research in contexts that truly transdisciplinary research is not feasible or desirable.

2. Methodology

2.1. Research approach

The five projects used to draw experiences in this paper, adopted research approaches that were broadly anchored in the field of sustainability science. In particular, all five projects adopted the four key aspects of sustainability science (Kates et al., 2001; Komiyama and Takeuchi, 2006; Kates, 2011), namely (a) a lens that clearly links the ecological and social components of the study systems, (b) a problem-based and solutions-oriented approach, (c) an interdisciplinary and (less so) transdisciplinary mindset, and (d) an open mindset to include knowledge from different knowledge systems (e.g., modern science, experiential knowledge, traditional and local knowledge).

In more detail, for (a) the starting point of all projects was the understanding that commodity crop production is a major driver of landscape transformation, which has a series of economic, social and environmental impacts for different groups (Section 1). At the same time in each area the decision to engage in commodity crop production and the mechanisms mediating impacts (and their effects to different groups) reflected the different socioeconomic

2 Wicked problems occur especially when stakeholders' values are contrasted and knowledge is incomplete or contradictory, which has been described as the context for "post-normal science" (Funtowicz and Ravetz, 1994).

and political circumstances in each context. For (b) all projects had a clear mandate to engage in research on socially-relevant challenges and at the same time generate novel and state-of-art knowledge that can be useful for policy and practice (see also Section 2.2, Supplementary Box S1). For (c) the research team comprised of experts from the social and natural sciences, and used highly interdisciplinary terms (e.g., food security, ecosystem services) and mixed-methods (Section 2.2). For (d) we engaged throughout the project with different knowledge holders such as practitioners, bureaucrats, and local communities to elicit and integrate their unique insights in the research.

Although all projects espoused many of the ideals of transdisciplinary research such as an attention to problem orientation, stakeholder engagement, and epistemological integration (Belcher et al., 2016), they were not purely transdisciplinary in the sense that they did not co-design, co-create or mobilize actual solutions on the ground in order to reduce the negative impacts and/or enhance the positive impacts of commodity crops (Sections 2.2 and 4.2).

When looking critically at the conceptual framework of transdisciplinary research for sustainability science proposed by Lang et al. (2012), these research projects engaged in Phase A (problem framing) and Phase B (knowledge generation), but not with Phase (C) (re-integration and application of knowledge). Although participatory approaches were expected for the design stage to provide critical information for each project (i.e., act as a source of information), they were also seen as avenues to inform certain research tasks commonly associated with Phase A and B. This expectation was based on the significant literature suggesting that beyond information gathering participatory methods can offer multiple other benefits within the sphere of control of research projects [i.e. project activities and outputs that are (mostly) under the control of the project] (Belcher et al., 2016).

The above suggest a certain overlapping but also the clear distinction between the concepts of a participatory approach and transdisciplinary research. By definition, transdisciplinary research requires the participation of stakeholders at all stages of the process of knowledge production, from the definition of projects' objectives to knowledge co-production and implementation (Lux et al., 2019). Stakeholder's participation at these different stages can have diverse objectives, from political action and empowerment to more functional aims such as involving end users such as farmers in the process of technology development (Neef and Neubert, 2011). Similarly in Arnstein's ladder of citizen participation (Arnstein, 1969), stakeholders' engagement can be equally diverse, from information gathering or dissemination of research findings only, to high degrees of social learning (Collins and Ison, 2009). Transdisciplinary research aims to achieve the deepest levels of stakeholder engagement at all research stages, as this can make more diverse contributions to knowledge and social processes, and have a greater influence across more impact pathways (Belcher et al., 2019). However, this often raises a number of difficult challenges (Kok et al., 2021), which means that though transdisciplinary research can offer many advantages it is not always feasible or desirable.

Based on this premise, in this paper we distill the lessons learned about the ancillary benefits of participatory approaches when mobilized beyond simple data collection and dissemination. In particular we focus on how they can introduce valuable transdisciplinary research elements to projects that were not designed to be transdisciplinary per se.

For the first research question (i.e., how can *different* participatory approaches provide research functions beyond data collection that are considered central in transdisciplinary research) we draw from the transdisciplinary research framework proposed by Lang et al. (2012). Upon reflection and collaborative discussions, the research team inductively identified three major such functions, namely to (a) identify research priorities, knowledge gaps, and underlying phenomena (Section 3.1), (b) formalize impact mechanisms and develop methodology (Section 3.2), and (c) interpret data and validate findings (Section 3.3). The first function mainly relates to Phase A of transdisciplinary research, while the latter two functions mainly relate to Phase B. In Section 3.1-3.3 we offer critical reflections of the extent to which the *different* participatory approaches mobilized in the five projects can contribute to each of these three functions.

For the second research question (i.e., how can *different* participatory approaches strengthen research principles that are considered essential for transdisciplinary research) we use the Transdisciplinary Quality Assessment Framework (Belcher et al., 2016, 2019), that focuses on the principles of relevance, credibility, legitimacy, and effectiveness.[3] According to this framework these four principles are fulfilled if a series of actions are implemented during the design and implementation of a research project. In Section 3.4 we cross-map how each type of participatory approach contributed to such actions, and as an extent to the desirable principles of transdisciplinary research.

For the third research question (i.e., how can participatory approaches be mobilized better to achieve the two points above), we critically reflect on the design and implementation of the participatory approaches within the five projects. We elicit in Section 4.1 some of the lessons learned on how to improve the design and implementation of participatory approaches for the functions and principles outlined above.

We need to acknowledge two important points at this stage. First, the extent to which different participatory approaches contribute to research functions (Research Question 1) and principles of transdisciplinary research (Research Question 2) reflects the collective perspective of the author team during the development of this paper. Although to some extent this is subjective, it still elicits rather well the collective experiences of

3 Relevance refers to the "importance, significance, and usefulness of the research project's objectives, process, and findings to the problem context and to society", which includes the "appropriateness of the timing of the research, the questions being asked, the outputs, and the scale of the research in relation to the societal problem being addressed" (Belcher et al., 2016, p. 8). Credibility refers to "whether or not the research findings are robust and the knowledge produced is scientifically trustworthy", which includes "clear demonstration that the data are adequate, with wellpresented methods and logical interpretations of findings" (Belcher et al., 2016, p. 8). Legitimacy refers to whether "the research process is perceived as fair and ethical by end-users" (Belcher et al., 2016, p. 12). Effectiveness refers to research that "contributes to positive change in the social, economic, and/or environmental problem context (Belcher et al., 2016, p. 8).

TABLE 1 Main foci of the five research projects.

Project	Main concepts/impacts	Main focus	Crops/sites	Deliverables
ESPA1	- Ecosystem services	- Impacts at local level	- Jatropha (Malawi, Mozambique)	- Primary empirical research on ecosystem services (von Maltitz et al., 2016). - Reviews and conceptual advances (von Maltitz et al., 2014; Gasparatos et al., 2015).
ESPA2	- Ecosystem services - Food security	- Impacts at local level	- Jatropha (Malawi, Mozambique) - Sugarcane (Eswatini, Malawi)	- Primary empirical research on land use change and ecosystem services (Romeu-Dalmau et al., 2018; Nyambane et al., 2020), livelihoods (Mudombi et al., 2021), poverty alleviation (Mudombi et al., 2018) and food security (Gasparatos et al., 2022). - Reviews and conceptual advances (Gasparatos et al., 2018b; Schaafsma et al., 2021). - Data descriptors (Gasparatos et al., 2018a)
Belmont Forum	- Food security	- Impacts at local level - Potential of upscaling at national level	- Cocoa (Ghana) - Coffee (Kenya) - Cotton (Eswatini, Ghana) - Jatropha (Ghana, Malawi) - Tea (Kenya) - Tobacco (Malawi) - Oil palm (Ghana, Guinea) - Rubber (Guinea) - Sugarcane (Ghana, Eswatini, Malawi)	- Primary empirical research on land use change and ecosystem services (Ahmed et al., 2018a), livelihoods (Ahmed et al., 2019a; Dompreh et al., 2021a), poverty alleviation (Ahmed et al., 2019a; Dompreh et al., 2021a), energy poverty (Ahmed and Gasparatos, 2020a), gender equality (Ahmed and Gasparatos, 2021b) and food security (Dam Lam et al., 2017; Balde et al., 2019; Dompreh et al., 2021b). - Institutional analysis (Chinangwa et al., 2017; Ahmed et al., 2018b, 2019b,c; Boafo et al., 2018; Ahmed and Gasparatos, 2020b; Gasparatos et al., 2021) - Reviews and conceptual advances (Ahmed et al., 2017; von Maltitz et al., 2019; Jarzebski et al., 2020)
ESPA3	- Ecosystem services - Food security	- Impacts at local and national level	- Sugarcane (Malawi)	- NA
Asahi Glass Foundation	- Food security - Livelihoods	- Adoption of sustainable practices at local level - Impacts at local level	- Cocoa (Ghana) - Jatropha (Ghana) - Oil palm (Ghana) - Sugarcane (Ghana)	- Primary empirical research on livelihoods (Ahmed et al., 2019a; Dompreh et al., 2021a), poverty alleviation (Ahmed et al., 2019a; Dompreh et al., 2021a) and food security (Dompreh et al., 2021b). - Institutional analysis (Dompreh et al., 2021c)

the team after designing, implementing and interpreting these participatory approaches over a decade. Second, and allied to the previous point, it does not mean that the specific participatory approaches cannot contribute to other functions or principles, if mobilized in other ways or within projects that have different aims (e.g., projects that include a knowledge reintegration element, Phase C). If anything, the findings within this Methodology paper reflects the needs, structure, and functionalities in the context of the study projects, and should be kept in mind when generalizing the reflections of this study in other research contexts.

2.2. Study projects

In this paper we share the observations generated during five multi-partner international and interdisciplinary projects that explored the impacts of different commodity crop production systems on ecosystem services, livelihoods and food security in SSA. Collectively these five projects focused on providing empirical evidence about the local-level impacts of different commodity crops throughout SSA. The projects were highly interdisciplinary using a series of concepts and tools from the social and the natural sciences. Table 1 contains the basic characteristics of each project, with more detailed information found in Supplementary Boxes S1–S5. Figure 1 shows the distribution of the study sites among the different projects.

These projects resulted in the three major sets of academic deliverables (Table 1). The first set consisted of peer-reviewed papers and book chapters reporting primary empirical evidence for a series of impacts. The second set of deliverables consisted of peer-reviewed papers and book chapters that combined institutional analysis, expert interviews and sometimes fieldwork to elicit rich qualitative information about different phenomena deemed interesting at the interface of commodity crop production and sustainability in the different study countries (see also Section 3.1). The third set of deliverables consisted of peer-reviewed papers that generated conceptual advances, including through narrative and systematic reviews.

When looking critically at their funding sources and calls, all these projects were essentially academic in nature. In other words, the main selection criterion was the potential to generate innovative research through interdisciplinary teams. However, a common underlying theme in research calls was the "request" to develop novel policy-relevant knowledge that could help generate social impact. In other words, while the development and implementation of actual interventions to solve sustainability issues on the ground was not a requirement of these calls, it was expected that the generated knowledge could inform and guide the development and implementation of such interventions. In order to facilitate

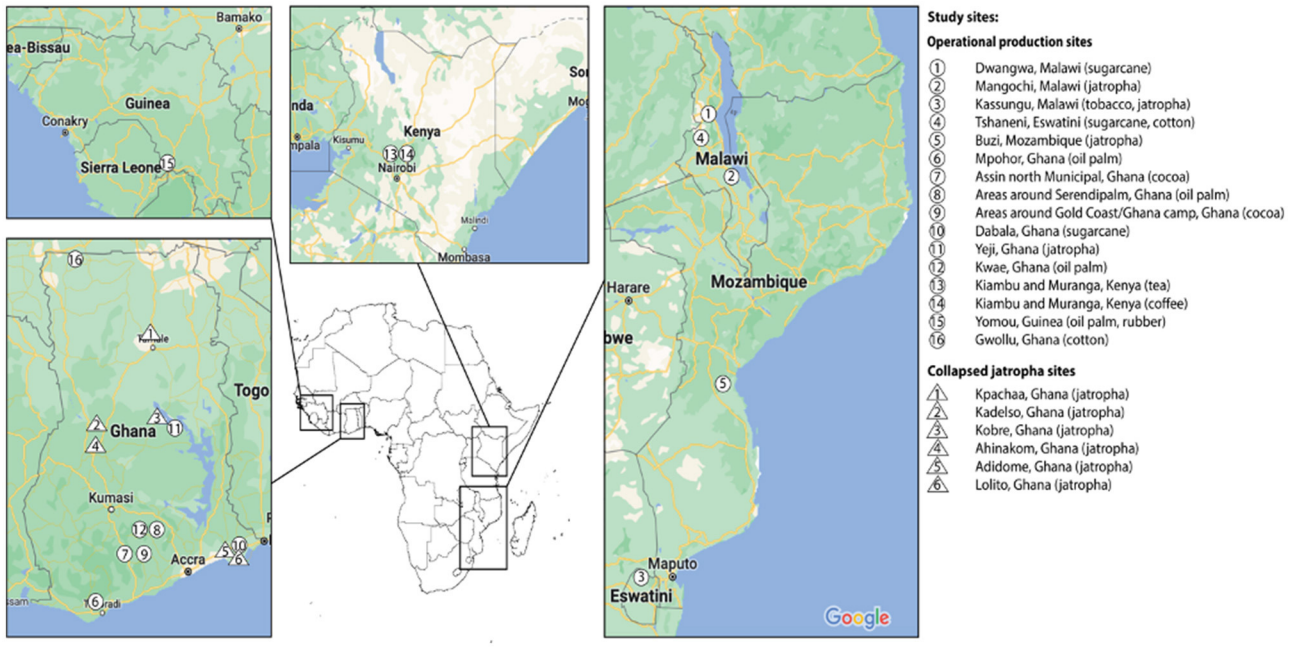

FIGURE 1
Case study locations and crops.

the generation of socially-relevant research there was a conscious effort to partner with different knowledge users in the ESPA2 and Belmont Forum[4] projects, including the Roundtable for Sustainable Biomaterials (RSB), BonSucro, the New Partnership for Africa's Development (NEPAD), CleanStar, and Solidaridad. These organizations helped the research team identify research priorities and existing knowledge gaps and needs to help frame better the research.

The underlying research projects received ethical approval from the University of Tokyo Life Sciences Committee (reference: 15–186) and the University of Oxford Central University Research Ethics Committee (CUREC).

2.3. Participatory approaches

Between them the different projects contained a very diverse set of participatory approaches that engaged different stakeholders (Table 2). Overall, the different participatory approaches served very different research functions such as to: (a) identify research priorities, gaps, phenomena, (b) inform methodology development, (c) interpret data and validate findings. Below we briefly summarize the main characteristics of each of these participatory approaches, with more information in Supplementary Boxes S2–S6. Sections 3.1–3.3 outline how they were employed to perform the three functions mentioned above, and in Section 3.4 our reflections of how they contributed to strengthen research principles that are considered essential for transdisciplinary research.

Expert interviews[5] were in depth discussion with individual stakeholders and/or community members engaged in, affected by, interested in or otherwise knowledgeable in commodity crop value chains. Usually, the interviewed stakeholders were identified through comprehensive institutional mapping exercises that systematized the main institutions associated with commodity crop value chains (e.g., policies, organizations, initiatives). Supplementary Box S2 outlines the general approach followed for expert interviews, the research questions they usually focused on, and related publications.

Focus Group Discussions (FGDs) entailed semi-structured groups interview/discussions that involved several community members in the different study areas experiencing commodity crop production. FGDs usually engaged 5–12 local community members that could provide general information about the social-ecological context of the study area, the history of commodity crop production, and the impacts and persons affected. Despite their functionality as primary data collection instruments, FGDs mostly served to provide a good understanding of the different study sites and the possible linkages between commodity crops and the studied

4 For example, the Belmont Forum puts some emphasis on social implementation, transdisciplinary research and stakeholder participation. Refer to: https://www.belmontforum.org/about.

5 Expert interviews can be found in several forms in the literature, such as key informant interviews or personal interviews, among others. For the purpose of this paper, we use the concept of expert interviews to show the good knowledge of the interviewed participants in relation to the specific topic. In other words, these interviews did not elicit perceptions over a topic that the participants had a peripheral engagement and/or knowledge, but instead they sought to elicit deep insights from participants holding different types of knowledge (e.g. scientific, practical, experiential).

TABLE 2 Participatory approaches employed in the different projects.

	ESPA1	ESPA2	Belmont Forum	ESPA3	Asahi Glass Foundation
Expert interviews	✓	✓	✓	-	✓
FGDs	✓	✓	✓	-	✓
Participatory mapping	-	-	✓	-	✓
Mediated modeling	-	-	✓	-	-
Participatory scenario analysis	-	-	-	✓	-

impacts (i.e., mechanisms). For this reason, with the exceptions of the studies mentioned above, FGDs results were not widely reported in the different project outputs. Supplementary Box S3 outlines the general approach followed for FGDs, the research questions they usually focused on, and related publications.

Participatory mapping was conducted with groups of local community members in some of the study areas, and especially areas containing large plantations established in the recent past (e.g., 10–15 years before fieldwork). The participatory mapping exercises largely had a similar functionality as the FGDs in that it they helped the research team obtain a good understanding of the study areas, and especially some of the land use change dynamics and the benefits that local communities obtain from the landscape (e.g., ecosystem services) compared to some previous state (e.g., prior to plantation development). Overall participatory mapping exercises helped in eliciting rich qualitative information that could supplement remote sensing analysis, especially providing information that could not be obtained from satellite pictures (e.g., parts of the landscape exploited for different uses). Supplementary Box S4 outlines the general approach followed for participatory mapping, the research questions it usually focused on, and related publications.

Mediated modeling, also referred as "group modeling building," (GMB) in the literature (Antunes et al., 2006)– approaches created a space of collaboration between the research team and experts from outside the consortium. They created a space for structured dialogue and joint understanding to inform specific research elements, and, in particular, to formalize the main impact mechanisms to be considered in the study and to inform methodology development. This was done through the co-development of causal loop diagrams (Sterman, 2000; Meadows, 2008; Inam et al., 2015; Coletta et al., 2021) that depicted the main impacts of commodity crops and how they were expected to be unfolded at the local level (i.e. mechanisms). The underlying logic of mediated models is that, by providing the conditions for stakeholders to collectively disclose, visualize and confront their "mental models" regarding a complex problem, it is possible to reach a deeper and common understanding of the problem's elements, interactions and trade-offs (Antunes et al., 2006; Eker et al., 2018). In particular, causal loop diagrams (CLDs) are qualitative tools belonging to the system dynamics modeling family of techniques (Sterman, 2000), that constitute a key output of mediated modeling (Stankov et al., 2021). While simple enough to be understood by non-academic stakeholders, CLDs allow for the recognition of patterns in the behavior of a given system (i.e. complex problem constituted by elements and their interactions) through the identification of balancing or reinforcing feedback loops, and in turn, identify potential points of intervention (Eker et al., 2018; Purwanto et al., 2019). The use of the CLD allows for the mapping and visualization of interactions within complex systems in an unambiguous and easily understandable manner. This allows for a facilitate discussions between non-technical local experts, other stakeholders and researchers in a way that allows for a verified and common identification of issues and interconnections between issues. It further ensures that a holistic view is develop around problems where all the interlinkages can be identified (Inam et al., 2015) The use of CLDs also aids in the identification of complex interactions and feedbacks that could destabilize a system but that are not radially apparent (Groundstroem and Juhola, 2021). Supplementary Box S5 outlines the general approach followed for mediated modeling and the research questions it mainly focused on.

The participatory scenario exercise was designed following an established approach (see Reed et al., 2013a,b), customizing it to fit the study context (i.e. impacts of sugarcane production) and locations (i.e., Malawi and Dwanga). The underlying logic is that scenario analysis can enable the exploration of possible causal relationship, drivers of change and future uncertainties (Wollenberg et al., 2000; Frittaion et al., 2010; Carlsson et al., 2015), by encouraging critical thinking, improving stakeholder exchanges, broadening the understanding of current situations, and anticipating future changes (Wollenberg et al., 2000). In this sense, scenarios can help identify potential trade-offs or conflicts between different activities, including in the bioenergy sector (Haatanen et al., 2014; Sterling et al., 2017). Participatory scenario analysis was integrated in four dissemination workshops in Malawi during the ESPA 3 project. Supplementary Box S6 outlines the general approach followed for participatory scenario analysis and the research questions it mainly focused on.

3. Findings and observations

3.1. Identify research priorities, knowledge gaps and underlying phenomena

Expert interviews were conducted in each study country before moving for the local-level fieldwork at the study areas (Figure 1). These expert interviews essentially occurred during the early parts of the research in each country. These interviews were a key avenue to understand some of the local context and identify research priorities and knowledge gaps by putting

into perspective the information identified in the literature[6] and the previous experiences of the members of the research team. Beyond their importance for receiving concentrated information about national dynamics, these expert consultations were also somewhat justified by the fact that all funding schemes implicitly "requested" the generation of policy-relevant knowledge that can have societal impact. In this sense engagement with policymakers and practitioners was viewed as a necessary pre-condition to appreciate the main priority research areas, and how our research can/should contribute.

For example, the literature reviews conducted at the beginning of the ESPA1 project (early 2011), coincided with the rapid expansion of bioenergy crop production in SSA (Gasparatos et al., 2011, 2015). This period was characterized by a general lack of comparative understanding and robust assessments about the impacts of bioenergy crops (and their mechanisms) at the local level, especially between those crops (i.e., jatropha vs. sugarcane) and production models (i.e., large-scale vs. smallholder-based) considered as the most relevant in the SSA context. Expert interviews at the beginning of the project reaffirmed that the lack of this comparative understanding is a major research gap and a research priority at the regional level. It was pointed by several experts that such information is essential in informing the then ongoing discussions throughout the region about whether/which of the different bioenergy options are sustainable, and if/how they should be promoted through national policies and on-the-ground projects. The broad insights generated from these early expert interviews influenced the team to expand the scope of subsequent projects (ESPA2, Belmont Forum) and seek to capture impacts for multiple crops and production models. Such multi-crop and multi-model impact assessments that follow comparative, cohesive and robust methodological protocols became the main output of the different projects, spanning impacts such as carbon storage (Romeu-Dalmau et al., 2018), ecosystem services (von Maltitz et al., 2016; Ahmed et al., 2018a; Nyambane et al., 2020), livelihoods (Ahmed et al., 2019a; Dompreh et al., 2021a; Mudombi et al., 2021), and food security (Dam Lam et al., 2017; Balde et al., 2019; Dompreh et al., 2021b; Gasparatos et al., 2022), among others.

A second example is how expert interviews helped appreciate better certain national research gaps and priorities during the early phases of subsequent projects (i.e. Belmont Forum, Asahi Glass). These included, among others, (a) why is jatropha production collapsing and whether there can be future in southern Africa and Ghana, (b) whether there is differentiation in the promotion, uptake and performance of oil palm and cocoa certification in Ghana, (c) whether there are acceptable market-based instruments to reduce land use change and deforestation from tobacco and sugarcane in Malawi (and how they might look like), (d) why has the cotton sector collapsed in Ghana but flourished in neighboring Burkina Faso, (e) how land consolidation processes and traditional institutions have mediated the impact of commodity crop production in Ghana. Compared to the broader regional-level gaps and priorities outlined above, these constitute gaps/priorities that are much more relevant in the specific national contexts. As such they were included in the research agenda, and were treated in dedicated publications exploring jatropha collapse and future prospects in Ghana and southern Africa (von Maltitz et al., 2014; Ahmed et al., 2019b), oil palm and cocoa certification differences in Ghana (Dompreh et al., 2021c), acceptability and architecture of possible PES schemes in Malawi (Chinangwa et al., 2017) and differentiated performance of the cotton sector in Ghana and Burkina Faso (Boafo et al., 2018).

A third, example is how FGDs offered reality checks that the knowledge gaps and research priorities identified at the regional and local level, were also relevant at the local level. As FGDs were one of the main data collection mechanisms they were conducted in tandem with household surveys in the study areas, but serving different purposes. However, in contrast to household surveys that entailed the exhaustive elicitation of quantitative information (see Gasparatos et al., 2018a for the actual protocols), FGDs provided a livelier discussion opportunity where community members provided information about the history, modalities, and impact of commodity crop production in each study site. During FGDs it was not uncommon to hear skepticism and uncertainty about the viability of jatropha projects (even around operational at that moment projects in Ghana, Malawi, and Mozambique), especially considering the emerging records of collapse in the respective national and regional contexts. Furthermore, there were concerns of how to enhance the performance of such crops or market viability. Although the participatory encounters during FGDs did not shape the research agenda to the same extent as the expert interviews, they provided valuable reality checks that indeed the explored topics are important in the local context. Furthermore, they informed dissemination actions by providing insights about which results are locally relevant.

Beyond their centrality for identifying research priorities and gaps, expert interviews and FGDs helped the research team to appreciate some underlying phenomena that upon closer examination mediated very strongly the local impacts of commodity crop production but were not initially flagged as important from the literature review or the conceptualization process. These mainly reflected institutional issues such as (a) land rights reconfiguration, lack of compensation, or (often unconstructive) mediation of traditional authorities during large-scale land acquisition processes (e.g., Ahmed et al., 2018b, 2019c; Ahmed and Gasparatos, 2020b), (b) land consolidation and differentiated access to irrigation infrastructure (e.g., Roland, 2019; Gasparatos et al., 2021), or (c) payment structures and modalities between different groups engaged in commodity crop production, e.g., certified vs. non-certified smallholders (Dompreh et al., 2021a,b), outgrowers vs. independent growers (Ahmed et al., 2019a). The early identification of such underlying phenomena was essential to understand ultimately how the actual impacts

6 The research team undertook extensive literature reviews to (a) understand the research landscape about the drivers and impacts of commodity crop expansion in SSA (e.g. Ahmed et al., 2017; Gasparatos et al., 2017; Jarzebski et al., 2020), (b) systematize the impact mechanisms and move the state-of-art in the conceptualization of the links between commodity crops with ecosystem services (Gasparatos et al., 2011, 2018b) and food security (Jarzebski et al., 2020). These literature reviews and conceptualization exercises were conducted at different points of the span of the overall research, but usually coincided with the early stages of the respective projects (i.e. ESPA1/ESPA2 for ecosystem services, Belmont Forum for food security).

TABLE 3 Contribution of participatory approaches to major research functions.

	Identify priorities, gaps, phenomena	Develop methodology/formalize impact mechanisms	Interpret data/validate findings
Expert interviews	++	+	+
Participatory mapping	+	+	+
Focus Group Discussions	+	+	++
Mediated modeling	+	++	-
Participatory scenario analysis	+	-	++

(++) Implies that a participatory approach can have a major contribution for a specific research task, (+) that it has a smaller contribution, and (–) that it has no or minimal contribution.

are mediated. Although this did not significantly affect the development of the main research instruments (i.e., household survey, see Section 3.2) it provided a valuable lens as to how to put into perspective and interpret the elicited differentiated impact levels between groups across some (or all) of the study sites.

When looking more critically the contribution of the different types of participatory approaches to the identification of priorities, gaps and phenomena, we find different potential and ability among approaches (Table 3).

3.2. Formalize impact mechanisms and develop methodology

Mediated modeling exercises constituted the main participatory approach used to select and formalize the main impact mechanism to be included in the study, and inform the development of the main methodology for primary data collection, namely the household surveys. Mediated modeling was only used during the Belmont Forum project, as the size of the funding did not enable this option in the other projects.

The mediated modeling exercise with international experts followed an iterative process, starting with the development of a "straw" model by members of the research team depicting the impact mechanisms expected to be studied and how they unfolded. This was mainly informed by previous literature reviews (see Section 3.1) and the accumulated experience of team members from previous projects (i.e., ESPA1 and ESPA2) and other research experiences. Subsequently this was refined through the joint exchanges between the research team with external experts. In particular, following multiple breakout sessions and plenaries the participants jointly elaborated the initial "straw model," developing in the process two refined models linking commodity crop production and food security, one for large-scale production and one for smallholder-based production. This dialogue helped achieve a shared understanding between the research team and the external experts (but also interestingly between members of the research team) of: (a) which impacts are important to study, (b) what are the mechanisms mediating these important impact, (c) in which scale to study the impacts, and (d) how broader commodity crop production systems and value chains operate.

Regarding (a) and (b) Figure 2 illustrates the final versions the causal loop diagrams co-developed by the research team and external experts. Some of the main mechanisms identified were: (a) cropland displacement and/or natural vegetation loss (negative effect on food security), (b) development and maintenance of infrastructure (positive effect on food security), (c) improved access to agricultural knowledge (positive effect on food security), (d) improved access to markets, both via local crop production diversification and better access to transportation (positive effect on food security), (e) changes in water access via improved irrigation (positive effect on food security) or water diversion to plantations and processing industries (negative effect on food security), (f) policy distortions such as economic incentives or taxes for commodity crops (variable effect on food security), and (g) income generation and changes in household budget control through different pathways (generally positive effects on food security). It is worth noting that although some new impacts and/or mechanisms were identified during the mediated modeling exercise that were not included in the "straw" model, there were not many alterations from the original.

Regarding (c) the international mediated modeling exercise was instrumental in binding the spatial scale of analysis (local level) and what impacts/mechanisms are relevant locally and which are relevant in different scales (i.e., national, international). Furthermore, it was agreed that the unit of analysis was the household, meaning that within-household food security impacts would not be a research focus, nor the overall impacts on national food self-sufficiency. Furthermore, it was agreed that the focus of analysis would be the small-scale farmers directly impacted by commodity crop production either as smallholders or resident in areas affected by the industrial crop expansion (i.e., control groups) and plantation employees. As such, it was decided not to specifically look at non-farmers within the case study areas (i.e., salaried workers or businesses with no direct link to agriculture), or impacts in urban areas as secondary consequences of the industrial crop expansion (e.g., effects of improved energy security or fuel switch to nutrition).

Regarding (d) we realized that there were many other factors at the interface between commodity crops and food security that were not exactly impacts or components of the impact mechanisms. These we named "drivers of model outcomes," as they could somehow effect the interactions between commodity crop production and food security. These were divided into policy drivers and other drivers. Due to the hugely complex nature of how these drivers could interact with other aspects of the model, we did not attempt to show the linkages. However, listed these drivers (and in some cases how some drivers interact with each other) (see Figure 2). These drivers are, in essence, variables that may

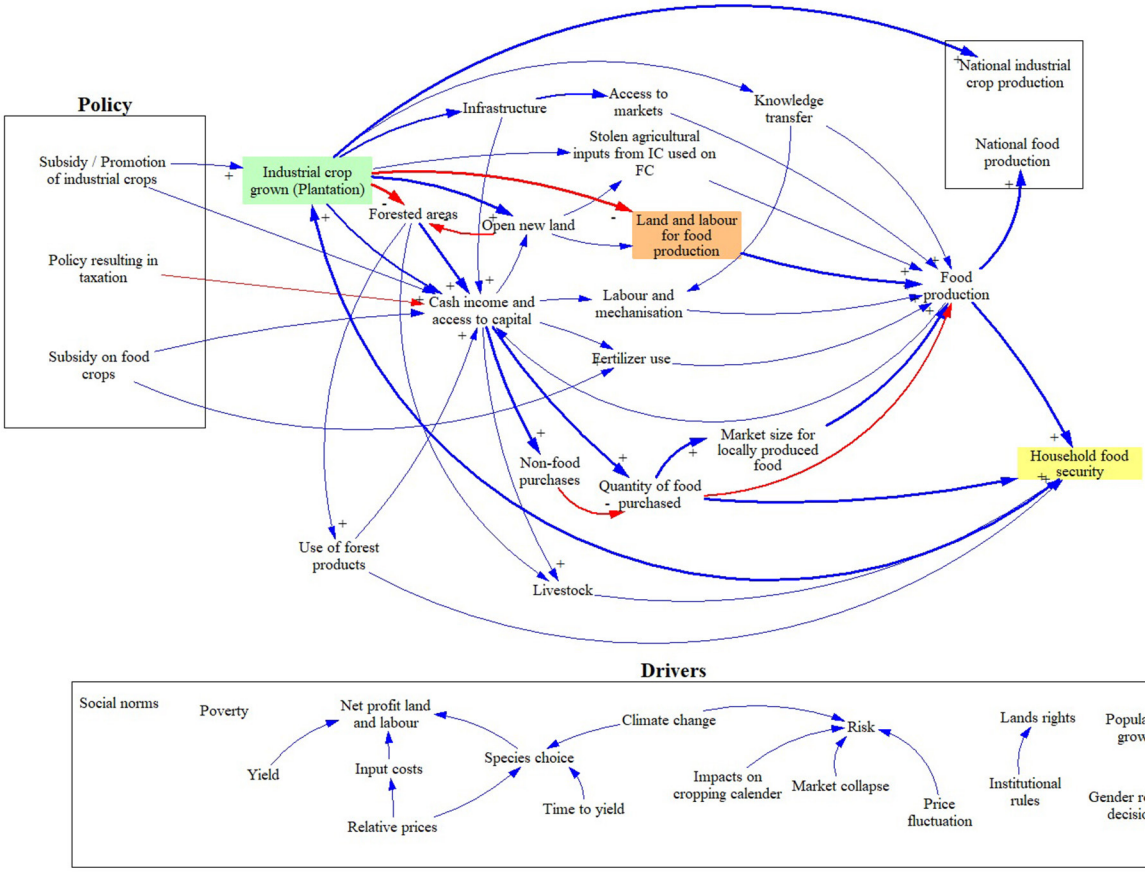

FIGURE 2
Sample causal loop diagram depicting linkages between commodity crop production and local food security for large-scale production systems.

change the magnitude or direction of the food security outcomes of commodity crop production, and was important to understand whether they were at play in the different study contexts. This was usually done through expert interviews and FGDs.

The follow-up mediated modeling exercises at the local level refined and customized the causal loop diagrams developed through the international expert workshop. The focus here was specifically sugarcane and tobacco production. The need for local exercises (and for the specific crops) was based on the emerging understanding within the research team (which was reinforced by the international expert workshop) that the hybrid plantation-smallholder models have certain complexities due to their broad area effects, while the tobacco smallholder sector has particularly unique contractual agreements (see below examples for both). The refinement process was undertaken through four fieldwork sessions (two in Malawi and two in Eswatini), where local experts and stakeholders were engaged individually or in groups to refine the causal loop diagrams with members of the research based on their understanding. It should be noted that in contrast to the international workshop, many of the local experts and stakeholders provided insight only into particular segments of the overall causal loop diagrams, based on their specific expertise, knowledge or interest. Some local expert/stakeholder engagements happened in the field, and thus was not always possible to conduct the real time refinement. This required very detailed note taking, and verification from the expert.

These local mediated modeling exercises helped identify important context-specific impacts and drivers that needed to be considered in the specific studies. For example, one key refinement for sugarcane reflected the fact that due to the large investment required for sugarcane production, sugarcane projects inject significant amounts of capital to areas with little money circulation. As shown in Figure 3, this can lead to new opportunities for entrepreneurs to generate wealth via other spin-off businesses (this was also confirmed with expert interviews that indicated new forms of wealth generation). These included opportunities linked directly to the sugar cane production process such transportation drivers as well as unrelated businesses such as grocery shops and food stalls that became profitable due to the salaried employment in the projects. Furthermore, the perceived benefits of the sugarcane sector were identified as an important (but abstract) variable in the causal loop model, which although not physically measurable it is an important factor in this system.

Collectively these exercises informed the development of the household survey, which was the main data collection tool for the Belmont Forum project. By agreeing on and systematizing the impact mechanisms, scale of analysis, and possible influencing factors, these exercises practically dictated the measurable variables

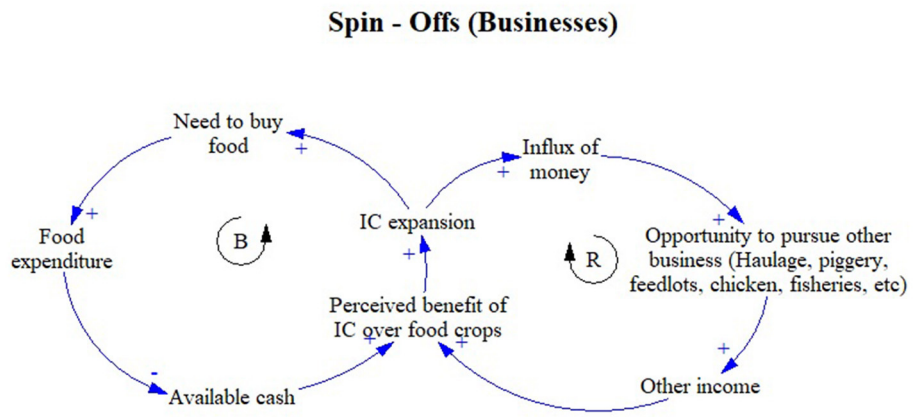

FIGURE 3
Example of diagrams refinements/additions through local exercises in sugarcane areas.

to be integrated in the survey, the statistical tests to be used for analysis, and the overall experimental design. Furthermore, these exercises were instrumental in identifying new tools that were not previously used by the research team, such as anthropometric measures that could capture long-term food (in)security more robustly.

However, beyond their huge contribution for methodology development, the mediated modeling exercises had several "intangible" research benefits. In particular they forged: (a) a common understanding and consensus within the research team about the focus of the research, (b) a sense of certainty within the team that the study phenomena have been identified and captured properly, and (c) a "common language" for the various study phenomena. The utility of the last point is not to be underestimated for the effective operation of our interdisciplinary research group, whose individual members initially defined and understood key research terms such as "food security" or even "impact" through disciplinary lenses. The common "definition" of such terms during the deliberations at the international workshop (where all team members were present), arguably improved the communication within the research team and essentially helped the cohesion of the actual research.

We should note, that expert interviews and FGDs helped to a lesser extent identify and formalize the impact mechanisms. This was particularly true for the non-Belmot Forum projects, for which it was not possible to conduct mediated modeling exercises. For example, depending on the context of the expert interviews or FGDs, on some occassions there were specific questions to elicit which impacts were deemed important (or how they unfolded) while in others this was elicited by using information from multiple questions. Similar to the mediated modeling exercises, some of this information informed directly our methodology by, for example, reconsidering certain methodological choices or adding new methodological elements. An example of the former is the reformulation of questions regarding ecosystem services impacts around a jatropha plantation in Mozambique (ESPA1/ESPA2 projects), as engagements with local experts and FGDs pointed to the very different local understanding and values around nature compared to other study sites. An example of the latter was the addition of an additional fieldwork round in Malawi and Swaziland (Belmont Forum project) to understand how the then ongoing El-Nino effect affected the commodity crop-food security interface by disrupting some of the initially identified mechanisms.

Such participatory approaches have certain benefits and challenges. One of the benefits is that during expert interviews respondents did not feel constrained to speak freely as in group settings, while both expert interviews and FGDs can provide very context-specific information. Conversely, expert interviews might insert biases due to personal views of what are the most important impacts or the uncertain elicitation of impact mechanism due to incomplete understanding. In the case of mediated models, facilitation is key to guarantee equal participation and to avoid dominance of specific stakeholders during the construction of CLDs, specially when lack of consensus exists (e.g., polarity of relationship between two variables).

Similar to Section 3.1, different participatory approaches contributed in different extents to formalize impact mechanisms and develop methodology (Table 3).

3.3. Interpret data and validate findings

Although expert interviews, FGDs and participatory mapping are inherently data collection mechanisms, they can also be used to provide deep insights about some of the observed patterns. In this sense the expertise and experiences of the engaged participants (whether as groups or individuals) can be mobilized by the research team to help interpret research findings. In our case we often used expert interviews and FGDs to explain the direction of some associations between variables and/or identify the possible factors mediating these associations. This was mainly geared toward the highly quantitative variables for the livelihoods and food security impacts.

Before explaining how this was done, it is important to appreciate why it was necessary. As mentioned above the main data collection instrument was a household survey that elicited the impact of engagement in different types of commodity crop activities, namely smallholder-based production, plantation employment or no engagement (i.e. control households). This approach was selected because it was not possible to have for the same household accurate quantitative data for the main livelihood and food security impact variables prior to engagement. This meant that the impact of engaging in commodity crop production at the household level was achieved through group comparisons using different statistical tools such as Propensity Score Matching (PSM), Inverse Probability Weighting Analysis (IPWA) or Endogenous Treatment Effect Regression (ETER) (e.g., Balde et al., 2019; Dompreh et al., 2021a,b; Mudombi et al., 2021; Gasparatos et al., 2022). However, although such approaches provided robust information about the impact of engagement, they fail to clearly explain why some of these patterns emerge. One such example was the differentiated performance of two indicators of food security (one measure of diet diversity and one measure of perceived hunger) for some group comparisons, such as plantation workers vs. other groups in a sugarcane plantation in Malawi. Through expert interviews it was possible to identify that the possible factor mediating the different performance of these two indicators were concern over job security (see Gasparatos et al., 2022). Another example was differentiated performance of livelihood indicators among independent and contracted oil palm smallholders in Ghana, which was linked to different payment modalities and market options (see Ahmed et al., 2019a; Dompreh et al., 2021a,b).

The participatory scenario analysis helped partly "validate" some findings. The underlying logic of the participatory scenario exercises was to (a) enable participants to absorb the research results during the dissemination presentations of the morning sessions, (b) critically assess the relevance/validity of these results considering their own experience and understanding of the situation on the ground, and (c) utilize the research results fully or partially if considered valid. In particular, for each of the thirteen impacts considered in each of the four scenarios (see Supplementary Box S6) we developed narratives that depicted the impact mechanism and possible outcomes, as identified through our empirical research. The narrative varied for each of the combinations of scenario-impact in terms of impact direction and possible outcome. For example, for sugarcane expansion scenarios the impacts related to livelihoods and employment impacts were positive and improving and environmental impacts were negative and worsening. Conversely the opposite narratives were used for sugarcane collapse scenarios. By asking the participants to rate the likelihood and magnitude of these impact based on these narratives for each scenario, in a sense we received some short of qualitative feedback about the validity of some research findings. During the group rating exercises the teams were asked to justify each of their decisions, including whether the narrative made sense or needed to change if deemed erroneous. This process provided important concentrated information about the nature and mechanisms of each impact, which helped validate these research findings. In this sense this process essentially enabled us to receive deeper and more active feedback about our findings compared to a standard Q&A session after the dissemination presentations. However, we need to point the possibility of inserting some bias in this process, as some of the ratings might have been affected by the information provided during the presentations. To reduce this likelihood during the group justifications, we always asked whether the narrative made sense according to the experience of the participants.

Finally, similar to the previous sections, the different participatory approaches contributed in different extents to interpret data and validate findings (Table 3).

3.4. Strengthen transdisciplinary research principles

Table 4 cross-maps how each type of participatory approach contributed to actions/tasks associated with the four main principles of transdisciplinary research, namely relevance, credibility, legitimacy and effectiveness (see Section 2.1). We note that different participatory approaches have different capacity and ability to strengthen these principles of transdisciplinary research.

The mobilized participatory approaches where particularly valuable in helping define the social-ecological context, identify social relevance, improve engagement of the research team with the problem context, and enhance relevance/appropriateness of research objectives and design. Furthermore, they contributed to enabling broad preparation, facilitating clear research problem definition, facilitate statement of objectives and ensuring fitness-for-purpose. The above are related mostly to the credibility and relevance principles.

The mobilized participatory approaches did not strengthen substantially to the legitimacy and the effectiveness of the research. This is not surprising considering that all research projects mainly undertook activities related to Phase A and Phase B of transdisciplinary research, rather than Phase C (Section 2.1). However, participatory approaches such as mediated modeling and participatory scenario analysis contributed to some extent to the legitimacy and the effectiveness principles (Table 3).

4. Discussion

4.1. Lessons learned and research recommendations

4.1.1. Involve appropriate experts and stakeholders

We believe that there is generally no silver bullet approach to involve experts and stakeholders, but it is highly context-specific. In our case this required a strong reflection from the part of the research team before each participatory approach to understand what was expected (e.g., identify priorities/gaps, inform methodology, interpret data). Hence, fitness-for-purpose was the main guiding criterion employed to identify and engage experts and stakeholders, especially when considering that their participation was often unfunded and challenged by their generally busy schedule. The second key guiding criterion was to achieve

TABLE 4 Contribution of participatory approaches to transdisciplinary principles.

Principles	Task/criterion	Expert interviews	FGDs	Participatory mapping	Mediated modeling	Participatory scenario analysis
Relevance	Define clearly social-ecological context	+	++	++	-	-
	Identify societal relevance	++	++	-	++	-
	Improve engagement with problem context	++	++	++	++	-
	Create explicit theory of change	-	-	-	-	-
	Enhance relevance/appropriateness of research objectives and design	++	+	+	++	-
	Ensure appropriate project implementation	-	-	-	++	-
	Enable effective/appropriate communication	-	-	-	+	++
Credibility	Enable broad preparation (i.e., integrated foundation)	+	+	+	++	-
	Facilitate clear research problem definition	++	++	+	++	-
	Facilitate statement of objectives	+	+	-	++	-
	Enhance project feasibility	+	+	-	-	-
	Improve the competencies of the research team	-	-	-	++	-
	Ensure fitness-for-purpose of the research	++	++	+	++	-
	Enable clear presentation of arguments/findings	-	-	-	-	+
	Facilitate transferability/generalizability of research findings	-	-	-	+	+
	Improve statement of limitations	-	-	-	+	-
	Enable ongoing monitoring and reflexivity	-	-	-	-	-
Legitimacy	Facilitate disclosure of perspective	+	+	+	++	-
	Enable effective collaboration	-	-	-	++	++
	Facilitate genuine and explicit inclusion	+	+	+	++	++
	Confirm ethics of research	+	+	-	++	-
Effectiveness	Build social capacity	-	-	-	-	++
	Contribute to knowledge	-	-	-	+	++
	Facilitate practical application	-	-	-	-	+
	Facilitate significant outcomes (i.e. solution of targeted problem)	-	-	-	-	+

(++) Implies that a participatory approach can have a major contribution for a specific task/criterion, (+) that it has a smaller contribution, and (–) that it has no or minimal contribution.

inclusivity, in order to ensure the comprehensive and multi-dimensionality of the input generated from the different processes. This need for diversity in terms of disciplinary lenses, ways of knowing, and type of engagement has been pointed extensively in the transdisciplinarity literature (Leventon et al., 2016; Ghodsvali et al., 2019; Kok et al., 2021; Lawrence et al., 2022). For FGDs particularly, as a matter of community entry strategy, there is the need to engage neutral first points within existing social conflicts. This will help gather knowledge from the different sides of the community stakeholders without artificially putting you into existing factions. Whiles this process may be laborious, it is important to take appropriate steps to start on the right person.

As argued by Klerkx et al. (2017), the institutional context plays a major role, leading to very contrasted degrees of propensity and preparedness for participatory approaches. It remains difficult to identify appropriate participants from some types of organizations, especially for some of the more technical tasks such as method co-development. Such an example are government agencies where the political personnel generally remain in the posts for short durations of time (quick turnover), which precludes achieving the necessary deep expertise for some issues. To overcome this particular problem we tried to engage with bureaucrats/civil servants rather that political personnel, as they tend to have a lower turnover and opportunities to gain deeper knowledge and understanding of the issues at stake (e.g., OECD, 2017). Generally, we tended to engage mid- or senior-career practitioners and bureaucrats/civil servants that were senior enough within their organizations to understand well the issues at hand, while at the same time being able to reflect the position of their respective

organization beyond their personal understanding/expectations. One challenge here was to prevent self-censoring or fear of expressing opinion considering that commodity crops were a rather contentious topic in most study countries (see Section 1). We tried to achieve this by clearly explaining the purpose of each participatory engagement, the expected type of contribution from them, and how it will be used internally (i.e., within research team) and externally (e.g., publication). In individual settings we gave them the opportunity to talk off the record if they felt it necessary, but in reality only few participants used this option and for few topics. This means that as much we received valuable information from relevant stakeholders, there are possibilities of self-censoring without necessarily, prompting the research team.

4.1.2. Be aware of social differentiation, positionality and vested interests

This is because of conscious or unconscious efforts to either bias answers, provide a fragmented understanding, or even manipulate for own interest the gap/priority identification or co-design. This has been pointed in several studies in the transdisciplinarity (Akerlof et al., 2020; Lawrence et al., 2022). We believe that this is largely an offshoot of their different engagements in commodity crop value chains, and is only logical to emerge considering that in many cases we asked deliberately the participants to reflect the perspective of their organization. This very fine line between asking participants to reflect their organization's perspective but at the same time prevent/identify possible biases (Lawrence et al., 2022). In our case it required a constant process of reflection from the part of the research team.

Here we need to point that social differentiation and vested interests can cause major challenges, especially in local contexts where the participants engaged in participatory approaches actually experience the impacts of commodity crops. Practically, in all study areas some participants benefited from commodity crops (e.g., producers, staff of commodity crop companies), others faced negative impacts (e.g., control groups) and some groups had very differentiated benefits (e.g., independent smallholders vs. outgrowers). The research team needed to be well-aware of such differentiated experiences, especially before the community-based participatory approaches (i.e. FGDs, participatory mapping), to avoid creating further social tensions (see Thompson et al., 2017). For example, in most cases the FGDs and participatory mapping participants were divided between commodity crop producers and non-producers or when not segregated the participatory approach sought to avoid contentious topis by framing the process accordingly. The issue here was how to synthesize the different outcomes of the participatory approaches, as it was not possible to obtain consensus for some issues (e.g., research priorities). This need to keep in mind the social tensions in community participatory exercises has been re-iterated in many studies (Thompson et al., 2017), and is arguably particularly relevant in the context of food systems or social-ecological systems in developing countries where local communities rely substantially on natural resources for their livelihoods.

4.1.3. Ensure inclusivity in participatory approaches

That said, even though it is important to ensure the proper representation of participants (Section 4.1.1) and understand their positionality and vested interests (Section 4.1.2), it is equally important to enhance inclusivity through trust and ensuring that all voices are heard. This is particularly important for participatory approaches in local settings, which can be characterized by complex community dynamics, pre-existing social conflicts, or certain gender norms (see also Section 4.1.2). For example, reflecting the large body of literature showing that women and men engage differently with landscapes and commodity crop chains in many parts of rural SSA (e.g., Fonjong, 2008; Kiptop, 2015; Tantoh et al., 2021; Duguma et al., 2022) and that women might feel reluctant to be vocal in mixed gender groups, we divided local participatory approaches such as FGDs and participatory mapping by gender. Furthermore, language selection was a very important consideration in local participatory approaches and needed to be thought very well to avoid creating preconditions for exclusion, especially in areas that have very unique dialects. This was the case in several of our study sites, where the local languages were different to the predominant national language (and sometimes did not have a written form). This required very careful moderation of local participatory exercises through partnering with local institutions and hiring local facilitators and enumerators.

While language and gender norms might not be a constraining factor in more technical exercises such as participatory scenario analysis, mediated modeling or even interviews with national experts, there should be a clear explanation of the focus of the participatory exercises and good moderation from the research team. These go a long way to ensure that participants feel safe to express their opinions, especially in situations where group consensus is not always possible (Lawrence et al., 2022). Clear examples of lack of consensus were observed in the participatory scenario analysis, where participants with different vested interests viewed the emergence and severity of some impacts through very different lenses, especially if their organizations were somehow responsible or affected (e.g., irrigation demand and agrochemical use by large plantations, loss of communal land for local authorities). In such cases it was important to enable these differences in opinion to be heard, capture them, and at the same time not manipulate or close the debate, as it might convey to participants that the research team has certain biases. In these contexts careful moderation/facilitation is necessary, whether from members within the team or even external to the research project (see also Hoffmann et al., 2017).

4.1.4. Manage expectations for the participatory approaches

Although participatory approaches can generate a lot of excitement to some stakeholders, it is important to be clear about their aim, approach and expected outcomes. This is necessary for avoiding creating unreasonable expectations or demands, both

from the side of the stakeholder and the research team (Thompson et al., 2017; Lawrence et al., 2022; Veisi et al., 2022).

To prevent unreasonable expectations from both sides, from the onset of the research the project teams were conscious about the possibility of our motives being misunderstood by different stakeholders. For example, local communities or producer associations might have perceived our research as seeking to generate a tangible technology/practical output that could improve their production (i.e. agronomic research rather than impact assessment), facilitate the implementation of interventions directly or by lobbying other stakeholders that can improve their livelihoods (e.g., increase crop prices, provide irrigation/agrochemicals, develop infrastructure) or even lobby other value chain actors to alter their operation (e.g., lobby plantations to stop landscape modification or increase salaries/crop prices). In this case the participatory approaches ran the risk of being perceived as platforms to express demands or grievances, rather than elucidate how commodity crop production unfolds in the specific study areas. This possibility of misunderstanding participatory approaches as opportunities to receive benefits or initiate advocacy has been discussed extensively in the literature (Marshall et al., 2018; Maasen and Dickel, 2019; Kok et al., 2021). Conversely, companies might misunderstand that our impact assessment research sought to criticize or attack their practices, as corporate practices for some commodity crops such as jatropha, tobacco or oil palm had been receiving some criticism at that time. In this case the participatory approaches ran the risk of being perceived as arenas to publicly attack some value chain actors in front of other stakeholders and articulate demand for changes in corporate practices. These are only some examples of how participatory approaches might be derailed from their original aim, if the expectations of participants are not clearly identified and managed through proper information and honesty about the motives of the participatory approach and the roles of the participants (Thompson et al., 2017; Veisi et al., 2022).

The research team also needed to ensure that the requirements engaging in the participatory approaches were not unreasonable. For example, it was important to be very explicit about the expected type of contribution and time investment, as well as possible renumeration. As already mentioned the local participants in the FGDs and participatory mapping exercises (and some expert interviews) were usually poor farmers. Conversely the participants in expert interviews, mediated modeling, and participatory scenario analysis were experts from the government, civil society, academic/research and the private sector, and can be quite busy. For the former, it was necessary to undertake the participatory approaches during periods that do not interfere with their livelihoods (e.g., avoid cultivation and harvesting seasons), while for the latter there it was necessary to be extremely specific about the required time and that their engagement was not a consultancy but voluntary and unpaid. Overall, there was no renumeration for the expert interviews, FGDs, participatory mapping and mediated modeling, and some small renumeration for the participatory scenario analysis. However, for FGDs and participatory mapping we ensured to cover the transport expenses of the farmers, provide food and beverages during the participatory engagement, and offer some small useful gifts such as salt and rice. All of these were made clear at the time of the invitation to avoid misunderstandings. This need about clarity regarding the engagement requirements has been identified as a very important consideration to avoid compromising the participatory approaches.

4.2. Limitations and research recommendations

We need to remind that the major limitation of our research projects in terms of transdisciplinarity was that no intervention or practical solution was co-developed and/or implemented with the engaged stakeholders (Phase C), as a means of enhancing the sustainability of commodity crop production in the study areas (Section 2.1). This was due to two interlinked reasons. First, the projects (and especially the first two ESPA projects) were developed during a period of rapid bioenergy crop expansion in SSA, largely for export to the EU (jatropha projects) or domestic energy security needs (sugarcane projects) (Gasparatos et al., 2017). During this period, which was roughly 2011–2014, there were still very basic research gaps about the impacts of jatropha and sugarcane production, which were considered to be the most promising biofuel feedstocks in SSA (Gasparatos et al., 2017). Although there was a clearly articulated need for this type of research, it was practically impossible to co-develop possible interventions without the clear understanding of the different impacts, their mechanisms, and how they interacted. The second was that the funding calls did not explicitly request the development of particular interventions or practical solutions, and had relatively short durations and available budgets, which made infeasible the co-development and uptake of response options.

As outlined in Section 1, the aim of this paper was not to highlight fully-mature transdisciplinary research, but rather processes, practices and lessons learned that can enhance transdisciplinarity. This is closer to the softer notion of consulting transdisciplinarity (compared to participatory transdisciplinarity) proposed by Mobjörk (2010). This complements previous research which shows some progress on how to foster the contribution of stakeholders to knowledge production and information on the complex relationships between commodity crops production and food security (Musvoto et al., 2015).

Overall, our research and the lessons discussed throughout this paper shows that indeed participatory approaches can play different roles and have different effects in such softer transdisciplinary research projects. Although we did not use all participatory approaches in any single project (Table 2), in retrospect we can reflect how they might be combined effectively to maximize their useful contributions for the tasks outlined in Table 4. First, initial literature reviews and institutional analyses can help outline the main research questions and identify relevant stakeholders. Subsequently, comprehensive expert interviews and a limited amount of local FGDs could inform any possible revisions of the research question(s) and conceptual framework(s). Mediated modeling exercises can then guide methodology development by rationalizing the study phenomena and their importance. Subsequently pilot surveys in local contexts and limited extra

expert consultations can help finetune the final method(s) and data collection mechanism(s). During data collection the bulk of the FGDs and participatory mapping exercises could help obtain useful information about the possible expected causalities and factors affecting the study phenomena. Finally, following data analysis, dissemination workshops with embedded participatory modeling exercises can further help the research team interpret results and validate findings. We need to of course point that the above nested out structure might not be applicable to all types of research projects, but would be ideal for projects focusing on impact assessment and relying on household surveys for primary data collection. Furthermore, and beyond the considerations outlined in Section 4.1, the ultimate selection and sequence of the participatory approaches should reflect the project aims, and in our opinion will depend substantially on the project timelines and the budget/expertise constraints within the research team.

Considering the lessons learned and limitations discussed throughout this manuscript, future studies can mobilize the rich quantitative and qualitative findings elicited from these exercises to undertake transdisciplinary research seeking to design and implement appropriate interventions to enhance the sustainability of commodity crop production in SSA. In such endeavors, particularly useful would be studies that (a) identified the expected impact mechanisms and methodological protocols (e.g., Gasparatos et al., 2018a,b; Jarzebski et al., 2020), (b) established causality between study groups (e.g., see Ahmed et al., 2019a; Dompreh et al., 2021a,b; Mudombi et al., 2021; Gasparatos et al., 2022), and (c) identified the stakeholder acceptability of different production systems and response options (e.g., Chinangwa et al., 2017; Ahmed et al., 2019b; Dompreh et al., 2021c).

Such studies could be designed following some of the emerging transdisciplinary research frameworks (e.g., Kondo et al., 2019; Horcea-Milcu et al., 2022), and promising techniques such as transformation/sustainability labs (Pereira et al., 2022) communities of practices (Matsumoto et al., 2021), multi-stakeholders platforms (van Ewijk and Ros-Tonen, 2021), and Innovation Platforms (Davies et al., 2018), among others. In any case the selection of the appropriate frameworks and techniques should be guided by reflecting important factors such as the aim/focus of the transdisciplinary process, the local acceptability and needs, and the possible constraints in terms of expertise, time, and funding (DeLorme et al., 2016; Belcher et al., 2019; O'Donovan et al., 2022). Such exercises should make every effort possible to engage the most appropriate stakeholders in a safe setting that can ensure that all relevant contributions and perspectives are heard and valued (Section 4.1). This is particularly important but also difficult in the context of commodity crop value chains that are characterized by substantial power and knowledge differentials between actors (Ahmed and Gasparatos, 2021b).

5. Conclusions

In this paper we synthesized the lessons learned from the implementation of different participatory approaches as parts of five research projects that explored the interface of commodity crop production and food security in SSA. In particular, we outlined how mobilizing diverse participatory approaches such as expert interviews, Focus Group Discussions (FGDs), participatory mapping, mediated modeling, and participatory scenario analysis can contribute to such projects beyond data collection, by introducing different transdisciplinary research elements. Our experiences suggest that such participatory approaches can contribute to important functions such as: (a) identify research priorities, knowledge gaps, and underlying phenomena, (b) formalize impact mechanisms and develop methodology, and (c) interpret data and validate findings. Furthermore, they can enhance the relevance, credibility, legitimacy and effectiveness of the research, all major principles associated with transdisciplinary research.

However, the different participatory approaches have different capacity to achieve these. For example, when seeking to identify research priorities, knowledge gaps, and/or underlying phenomena, expert interviews could be ideal, with the rest of the techniques also holding promise. When seeking to formalize impact mechanisms and/or develop methodology, then mediated modeling has the most potential, with most of the other techniques also having some potential. Finally, when interpreting data and/or validating findings, participatory approaches such as FGDs and participatory scenario analysis have the highest potential. Similarly, in the context of this study the participatory approaches mainly strengthened the relevance and credibility of the research, rather than the legitimacy and effectiveness. This is somewhat expected considering the focus of the projects on problem framing (Phase A) and knowledge generation (Phase B), rather knowledge re-integration and application (Phase C).

Finally, although the underlying research projects were not transdisciplinary in the strong sense of the term, the mobilization of these participatory approaches arguably introduced some valuable transdisciplinary research elements by integrating valuable insights from stakeholders holding very diverse expertise in commodity crop value chains at different scales. In this sense such techniques can be very useful for integrating diverse voices when conducting research at this interface. However, according to our experience, in order to maximize their potential, it is important to (a) involve appropriate experts and stakeholders, (b) be aware of social differentiation, positionality and vested interests, and (c) ensure inclusivity in the participatory approach.

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

The studies involving human participants were reviewed and approved by University of Tokyo Life Sciences Committee (reference: 15–186) and University of Oxford Central University Research Ethics Committee (CUREC). Written informed consent for participation was not required for this

study in accordance with the national legislation and the institutional requirements.

Author contributions

AG, GM, AA, ED, MJ, and DLu designed the methods, collected data, and conducted data analysis. MJ and DLo designed the figures. AG wrote the first draft of the manuscript and received the funding for the ESPA3 and Asahi Glass Foundation project. AG and GM received the funding of the ESPA1, ESPA2, and Belmont Forum projects. All authors revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

DLu was employed by World Bank Malawi Office. DLo was employed by WorldFish.

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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1132465/full#supplementary-material

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Developing biodiversity-based solutions for sustainable food systems through transdisciplinary Sustainable Development Goals Labs (SDG-Labs)

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Although biodiversity is a central component of food systems, conventional food systems have become one of the major drivers of biodiversity loss globally. There is an increasing need to transform food systems to provide sufficient and nutritious food, but with minimal negative impacts on the environment and society. One of the possible avenues to enable the sustainable transformation of food systems might be through the development of locally appropriate biodiversity-based solutions. In this paper we report the insights and lessons learned during the design and implementation of transdisciplinary projects that employed the concept of Sustainable Development Goals labs (SDG-Labs) to create biodiversity-based solutions to transform food systems. The six SDG-Labs outlined in this paper were implemented in Armenia, China, Japan, Madagascar, Thailand, and Uganda. Collectively they developed very diverse biodiversity-based solutions that used different components of biodiversity, ranging from novel cultivation systems with endangered plants, to gardens using tree species for wind breaks, or novel tea-forestry production systems. Beyond their ability to leverage different components of biodiversity to transform local food systems (also conserving biodiversity in the process), all solutions had multiple co-benefits such as climate change adaptation/mitigation and livelihoods generation, among other sustainability domains. Through a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis we synthesized the experiences gained during the design and implementation of all six SDG-Labs. The findings suggest the great promise of these transdisciplinary approaches for developing solutions at the biodiversity-food-climate nexus. However, this synthesis paper also points to the multiple context-specific challenges that should be overcomed to maximize the potential

of SDG-Labs to both enable the sustainable transformation of (local) food systems and/or be scaled up effectively.

KEYWORDS

sustainability-oriented experiment, transdisciplinarity, solutions-oriented approach, biodiversity-food-climate nexus, sustainability, co-benefits, agriculture

1. Introduction

Biodiversity plays an essential role for food systems, planetary health, and human wellbeing (Hawkins, 2018; García-Martín et al., 2022). On the one hand biodiversity is crucial for the functioning of agroecosystems and the stability of food production (Crist et al., 2017). For example, biodiversity is essential for soil health and fertility (Frąc et al., 2018) and the stability of the hydrological cycle (Rolls et al., 2018), which are in turn very important for sustainable food production. On the other hand genetic diversity in crops and animals can ensure the production of sufficient and nutritious food (Dawson et al., 2019), and the resilience of agroecosystems against different environmental shocks, including climate change (Martin and Magne, 2015; Córdoba Vargas et al., 2020).

However, biodiversity loss has been accelerating globally in the last decades (IPBES, 2019). There are major concerns that this biodiversity loss could compromise the resilience of food systems and the stability of food production (Roe, 2019), with possible negative ripple effects for food security (Sunderland, 2011; Fischer et al., 2017). In fact many studies have identified that biodiversity loss is one of the main threats for the sustainability of food systems, and essentially for meeting multiple Sustainable Development Goals (SDGs) and targets, such as "No Hunger" (SDG2; Krause and Tilker, 2022).

Paradoxically food systems are one of the major threats to biodiversity (Leclère et al., 2020; Rockström et al., 2020). Modern food systems are the most important driver of land use change (Springmann et al., 2018) and major sources of greenhouse gases (GHGs) emissions (Crippa et al., 2021), both important drivers of biodiversity loss (IPBES, 2019). Beyond land use change and GHG emissions, industrialized agriculture systems have multiple other negative effects on biodiversity through pollution from excessive fertiliser and agrochemical use (Eliasson et al., 2023), agrodiversity loss due to the dominance of few crop and animal species (Zimmerer et al., 2019), and the introduction of invasive species that threaten native (agro) ecosystems (Shabani et al., 2020). There is a vast literature exploring the association between conventional food systems and biodiversity loss: from population growth (Crist et al., 2017) to urbanization and lifestyle changes (Evans and Gawlik, 2020; Pawera et al., 2020).

This creates the paradoxical situation that on the one hand biodiversity is essential for food systems, but on the other hand conventional food systems are one of the most important threats to biodiversity. This calls for an urgent need to transform food systems in order to safeguard biodiversity, and essentially ensure sustainable food supply to meet the accelerating global demand. However, despite the many sustainability initiatives aiming at transforming food systems in a biodiversity-friendly manner, social and economic inequality persist (El Bilali et al., 2021).

In the context of the post-2020 Global Biodiversity Framework, many studies have pointed that biodiversity can indeed provide solutions for sustainable food systems (Gassner et al., 2020; Pimm, 2022). This has been in tandem with the growing popularity of concepts seeking to leverage the role of biodiversity to offer sustainable solutions. One such example is the concept of nature-based solutions (NbS), which refers to the sustainable management and utilization of nature to address sustainability challenges (IUCN, 2020). NbS are inspired and supported by nature, are (often) cost-effective, tend to deliver multiple environmental, social, and economic co-benefits, and could enhance resilience (Haase et al., 2017), while at the same time have the potential to catalyse sustainability transitions (Subedi et al., 2020). In this sense NbS could essentially offer opportunities to generate positive sustainability outcomes and at the same time conserving biodiversity (Chausson et al., 2020). However, there is still no standard way on how NbS should be mobilized, leveraged and used in the real world (Sowińska-Świerkosz and García, 2022).

When looking critically at the above, biodiversity protection and sustainable use could be a "source" of solutions for sustainable food systems. This can arguably provide synergistic 'win–win' opportunities, as well as "co-generate" opportunities for wider sustainability transitions (Jacob et al., 2021). Such 'win-win' opportunities could be initiated and implemented in different scales through the application of innovative technologies and/or the integration of local knowledge (Béné et al., 2019). Despite the fundamental need for broader changes to legal, political, economic, and other social structures at the national and international scale to attain such transitions (Esquinas-Alcázar, 2005; Kaufman et al., 2021), scholars have argued that under the right circumstances it might be possible to unlock and accelerate transitions through local-scale actions (Loorbach et al., 2017). This is because under the right conditions scalable small-scale actions can evolve to "long-term, multi-dimensional, and fundamental transformation processes" that lead to desired sustainability transitions (Markard et al., 2016, p. 956).

As a possible approach for designing such local solutions in real-world context, sustainability-oriented labs have emerged (McCrory et al., 2020). These types of labs have originated in the efforts to conceptualize real-life experiments[1] in the sustainability transitions literature (Sengers et al., 2019). This notion of sustainability-oriented labs encompasses a broad family of participatory, multi-stakeholder and transdisciplinary research approaches seeking to enable transformation

1 There is a wide variety of real-life experiments including "niche experiments," "bounded socio-technical experiments," "grassroots experiments," "transition experiments," and "sustainability experiments." Box S1 in the Supplementary material provides a brief introduction and distinction between these concepts.

(Nevens et al., 2013; Schäpke et al., 2018). According to McCrory et al. (2020), there are seven types of sustainability-oriented labs, namely Urban Living Labs, Living Labs, Real-World Labs, Evolutionary Learning Labs, Urban Transition Labs/Transition Management, Change Laboratories, and Transformation Labs (T-Labs; see Box S2 in the Supplementary material for a brief introduction and distinction). Depending on how they engage with sustainability and their approach to designing and implementing sustainable solutions they can be sub-divided as (a) fix and control; (b) (re-)design and optimize, (c) make and relate, (d) educate and engage, (e) empower and govern; and (f) explore and shape (McCrory et al., 2022; see Box S3 in Supplementary material).

Despite their differences, all these types of sustainability-oriented labs are transdisciplinary venues that test potential solutions to sustainability issues through collaboration between different actors (Bulkeley and Castán Broto, 2013). Their aim is to design and implement bottom-up and context-specific solutions mobilizing the input of different actors, including those that can be generally marginalized from decision-making in some contexts such as women and young people but can be quite innovative and entrepreneurial thinking outside the box (e.g., Aernouts et al., 2020; Wrangsten et al., 2022).

Sustainability-oriented labs have been implemented in very different thematic contexts, including microfinance for youth and clean water (Leist et al., 2018), climate change adaptation (Snyman-van der Walt et al., 2020), or low carbon cities (Voytenko et al., 2016). Similarly wide have been the geographical contexts of such labs, with examples coming from both urban (Bulkeley et al., 2016; von Wirth et al., 2019) and rural settings (Zavratnik et al., 2019), as well as from developed (Voytenko et al., 2016) and developing countries (Leist et al., 2018; Pereira et al., 2022). The above examples clearly show that sustainability-oriented labs have followed very diverse methodological approaches to develop equally diverse solutions (e.g., technologies, agricultural systems, or social institutions). However, what they have in common is the attempt to design context-specific solutions and involve multiple relevant stakeholders.

Sustainability-oriented labs have also been used in the context of food systems. For example, Wolfert et al. (2010) implemented a living lab in the Dutch agri-food sector integrating sustainable farm management through optimal information supply. Pereira et al. (2022) conducted a transformation lab in the Western Cape (South Africa) to identify how local underutilized food products can be used to increase the sustainability and inclusivity of the local food system. Hvitsand et al. (2022) implemented a living lab to strengthen agri-food systems associated with organic vegetables in the Vestfold region in Norway. Gamache et al. (2020) critically discussed through a bibliometric analysis whether agri-food living labs offer support to local transition pathways. Such attempts have emphasized the need of developing context-specific solutions and integrating the perspectives and knowledge of different stakeholders. This inclusivity is particularly important as many studies have pointed the necessity of including very diverse voices and stakeholders in food system transformation towards greater sustainability (Herens et al., 2022; UNEP, FAO, and UNDP, 2023), including young people (Glover and Sumberg, 2020; WFF, 2023).

In the literature there have been few examples of sustainability-oriented labs that use biodiversity as the source of solutions, including for sustainable food systems. Furthermore, when looking at specific types of sustainability-oriented labs (see Box S2, Supplementary material), there have been few efforts in the literature to provide a comprehensive understanding of context-specific approaches to SDG-Labs, let alone in the context of food systems (see below).

Hence the aim of the paper is to synthesise the lessons learned from the design and implementation of very diverse sustainability-oriented labs that developed biodiversity-focused NbS, dubbed as "biodiversity-based solutions," for sustainable food systems. In particular, it focuses on six Living Labs, which emphasized a strong connection to the SDGs as a guiding principle since their inception (Section 2.2; referred to as SDG-Labs for the remainder of the paper). The SDG-Labs were funded and implemented in the period 2020–2021, and here are comparatively analysed. We aim to distil the main insights generated from these transdisciplinary processes, as a means of enhancing their applicability in other contexts and unlocking their potential for transforming food systems through biodiversity-based solutions.

The papers starts with a section that outlines the timeline of the SDG-Labs (Section 2.1) and describes the comparative methodology (Section 2.2). The results section systematizes the objectives (Section 3.1) and transdisciplinary research approaches of the six SDG-Labs (Section 3.2), shows how they contributed to sustainable food systems (Section 3.3) and sustainability more broadly (Section 3.4), and summarizes the lessons learned from their design and implementation (Section 3.4). The discussion (Section 4) critically addresses some the main insights in view of the literature, and offers recommendations for future improvements for tackling sustainability challenges for food systems, biodiversity conservation and sustainability more broadly.

2. Methodology

2.1. Timeline of the SDG-Labs

The six SDG-Labs outlined in this paper were funded through the 8th International Conference on Sustainability Science (8th ICSS). The 8th ICSS was co-organized by the (a) Institute of Future Initiatives (IFI), University of Tokyo, (b) Tokyo College, University of Tokyo, (c) Institute for Global Environmental Strategies (IGES), (d) Stockholm Resilience Centre, Stockholm University, Sweden, (e) Future Earth, (f) Secretariat of the Convention on Biological Diversity, (g) Kunming Institute of Botany, Chinese Academy of Sciences, and (h) International Union of Biological Sciences. The 8th ICSS was held on January 18–20, 2022 (online), and an online Open Call (10 November 2019 to 8 December 2019) invited proposals for SDG-Labs on the broad topic of "biodiversity-solutions for change."

The selection criteria were the SDG-Lab's ability to: (a) find solutions for sustainability problems through leveraging local biodiversity (i.e., through existing local knowledge, innovative solutions or their combination); (b) address multiple SDGs beyond "Life below Water" (SDG14) or "Life on Land" (SDG15), which were the foci of the Open Call; (c) follow a transdisciplinary approach that was defined as "interdisciplinary approach with multi-stakeholder engagement"), and (d) have the capacity to trigger positive change at the local scale (and with the potential to be scaled up). Thematic, disciplinary and geographical diversity were also criteria in the selection process. However, the type of solution, and the format and implementation approach were decided independently by each proposed SDG-Lab.

Ten SDG-Labs were selected for funding (17 January 2020) but only six managed to launch successfully due to the challenges posed

by the COVID-19 pandemic (Figure 1). Each of these six SDG-Labs were awarded USD 5,000 in seed funding in order to undertake their activities. The design and implementation of the SDG-Labs lasted much longer as explained below.

The implementation process of the SDG-Labs sought to enable vertical and horizontal information exchange with international researchers in the form of coaching and presentations at international conferences and between groups (see below). Each SDG-Lab group worked with one coach from the Institute of Future Initiatives (IFI; University of Tokyo), Tokyo College (University of Tokyo), Institute for Global Environmental Strategies (IGES), Stockholm Resilience Centre (Stockholm University), and Future Earth. The role of the coach was to provide advice related to the design and implementation of the SDG-Lab, with all coaches being knowledgeable on aspects related to sustainability science, biodiversity/ecosystem services, and social-ecological systems.

Although each SDG-Lab had the freedom to approach its design and implementation individually, the overall timeline of all SDG-Labs was aligned with the different activities of the 8th ICSS (Figure 2). In particular, each SDG-Lab presented the early results of their activities during a virtual session of the 5th Forum for Biodiversity and the 8th ICSS (23 April 2021). Mid-term reporting occurred in an interactive session of the Sustainability Research and Innovation Congress 2021 (SRI 2021; 3 June 2021). The presentation of the final results was held during a dedicated session of the 8th ICSS (19 January 2022). Each SDG-Lab provided an interim and final report that summarized its characteristics, design/implementation process, and final outcomes.

The originally expected implementation period was January to September 2020, but due to difficulties posed by the COVID-19 pandemic (including the postponement of the 8th ICSS in person in Kunming, China), the implementation of the SDG-Labs was extended up to October 2021. Each SDG-Lab individually negotiated extension periods to allow for sufficient time to complete their activities.

2.2. Data collection and analysis

In this study we provide a comparative synthesis of the main characteristics of the six SDG-Labs, in terms of their (a) thematic focus, (b) transdisciplinarity, (c) outcomes, and (d) lessons learned.

For (a) we summarise the focus and objectives of each SDG-Lab (Section 3.1). For (b) we track the types of stakeholders involved in each SDG-Lab and the methods used for stakeholder engagement (Section 3.2). For (c) we track the characteristics of the biodiversity-based solutions in each SDG-Lab, as well as their beneficiaries, contributions to food systems, climate co-benefits and broader sustainability outcomes (Section 3.3–3.4). For (d) we track the advantages and disadvantages of the SDG-Lab approach through a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis (Ioppolo et al., 2013; Section 3.5). In the SWOT analysis the Strengths and Weaknesses refer to the internal characteristics of the SDG-Labs technique itself as an approach for developing sustainability solutions, while the Opportunities and Threats refer to the wider system characteristics that support or hinder the design and implementation of SDG-Labs for local sustainable transformations (Longsheng et al., 2022).

For (a)-(c) the information is reported for each SDG-Lab individually in appropriate figures and tables. For (d) the SWOT analysis was conducted first for each SDG-Lab and then synthesized for all six labs to identify general patterns.

The reported information is elicited through the critical analysis of the interim and final reporting documents of each SDG-Lab, as well as the insights of the main organisers of each SDG-Lab and the entire process that serve as co-authors in this paper. In particular, AA coordinated the SDG-Lab Armenia, JL coordinated the SDG-Lab China, JK coordinated the SDG-Lab Thailand, BC coordinated the SDG-Lab Japan, R.N.N.A coordinated the SDG-Lab Madagascar, and IO coordinated SDG-Lab Uganda. MJ coordinated the overall SDG-Lab process through the University of Tokyo.

FIGURE 1
Location of the selected SDG-Labs by status of implementation.

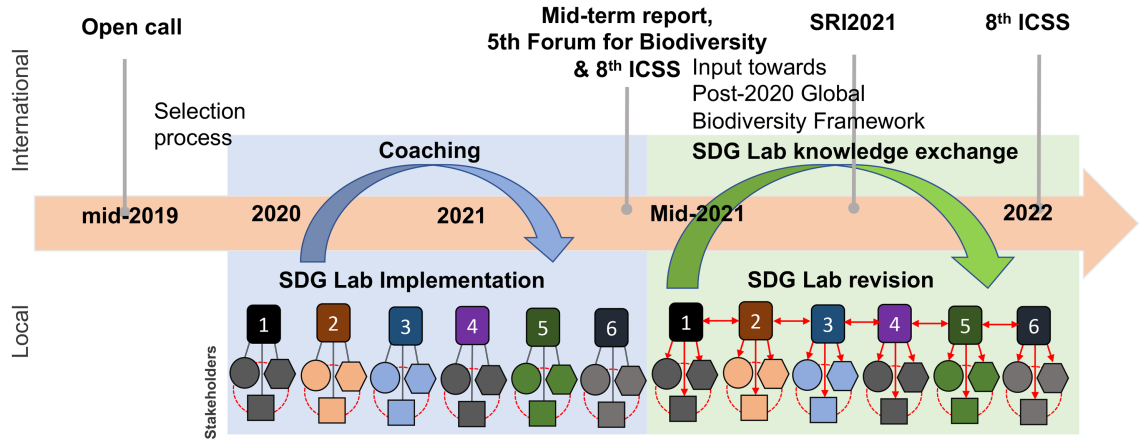

FIGURE 2
Design and implementation processes of the SDG-Labs. For visualization purposes the main arrow length (in pink) is not proportional to the duration of each activity/process.

TABLE 1 Objectives of selected and implemented SDG-Labs.

SDG-Lab	Objectives
Armenia	- Develop an innovative cropping system - Conserve "on farm" wild endangered medicinal plants
China	- Develop forestry-tea garden production models - Use efficiently natural resources and achieve good yields in tea-forestry production models
Japan	- Raise community awareness about homestead windbreaks - Maintain homestead windbreaks and sustain their home garden production
Madagascar	- Develop immersive ecotourism activities
Thailand	- Demonstrate the potential of traditional agroforestry farming systems - Improve livelihoods and food security of local communities through agroforestry
Uganda	- Establish how pastoralist systems contribute to the sustainability of semiarid ecosystems

3. Results

3.1. Thematic focus and objectives of the SDG-Labs

Table 1 outlines the thematic focus and objectives of the six SDG-Labs that were finally implemented. It becomes obvious that although all of them mobilized biodiversity as a source of solutions for sustainable food systems, they did so from radically different angles.

The SDG-Lab in Armenia was named "Biodiversity in Action: Accelerating data digitization for innovative cropping systems." It was led by an academic team and had a two-fold objective. First, was to develop an innovative cropping system based on inter-, over-, and cover-cultivation to increase yield stability (by up to 30%), agroecosystem quality, and sustainability. Second was to enhance the conservation and sustainable use of wild endangered medicinal plant species through innovative "on farm" conservation.

The SDG-Lab in China was named "Forestry-tea ecosystem services and influence on local livelihoods: The case of tea forests in Yunnan, China." It was led by an academic team and had two main objectives, namely to (a) develop forestry-tea garden production models to conserve biodiversity, and (b) to use efficiently natural resources and achieve good yields in terms of quantity and quality.

The SDG-Lab in Japan was named "Conserving biodiversity of homestead windbreaks and home gardens for food security and rural development." It was led by an academic team and had two objectives. First, was to raise local community awareness about the significance of homestead windbreaks. Second, was to maintain homestead windbreaks and sustain their home garden production for food security in remote island regions (Okinawa, Japan).

The SDG-Lab in Madagascar was led by a practitioner and was named "Immersive ecotourism in Tampolo Protected Area towards sustainable development." It sought to develop immersive ecotourism activities by connecting visitors with local biodiversity.

The SDG-Lab in Thailand was titled "Promoting traditional agroforestry farming systems for sustainable watershed forest management in the north-eastern region of Thailand." It was led by a researcher and a practitioner and had two main goals. First, was to explore and demonstrate the potential of traditional agroforestry farming systems for degraded land rehabilitation and management for communities living inside a national park. Second was to improve the livelihoods and food security of the local communities.

TABLE 2 Types and numbers of engaged stakeholders in each SDG-Lab.

	Armenia	China	Japan	Madagascar	Thailand	Uganda	Total
Local communities	4	3	1	4	3	1	16
Private sector	4	6	1	1	0	1	13
Local government	3	2	1	2	3	1	12
NGOs, and other organizations	7	0	1	1	2	1	12
Academia	3	2	1	2	2	1	11
Total	21	13	5	10	10	5	64

TABLE 3 Stakeholder engagement methodologies applied by the SDG-Labs.

	Armenia	China	Japan	Madagascar	Thailand	Uganda	Total
On site interviews*	100	4	20	11	15	5	155
Onsite workshops/trainings	6	3	5	1	1	4	20
Field research**	18	3	20	0	1	1	43
Online interviews*	0	5	0	1	0	10	16
Online workshops	2	2	0	0	0	1	5

*Refers to the number of individuals that participated in the interviews.
**Refers to the number of studies conducted in the field, such as forest inventory, plant species count, etc.

Finally, the SDG-Lab in Uganda was led by a practitioner and was titled "Establish the role of the Karimojong Nomadic Indigenous Pastoralist in the conservation and sustainable use of biodiversity." Its focus was to establish how pastoralists contribute to the sustainability of semiarid ecosystems and the sustainable use of biodiversity.

3.2. Transdisciplinary engagement across the SDG-Labs

A central part of each SDG-Lab was the conscious effort to mobilise and integrate the perspectives of multiple stakeholders from local communities, businesses/private sector, local government, civil society, and academia/research in the design, testing and implementation of the biodiversity-based solutions. Table 2 suggests that almost all SDG-Labs involved at least one stakeholder from each of these stakeholder categories. The only exceptions were the SDG-Lab from Thailand and China that did not involve any stakeholder from the private sector and the local government, respectively. On average, each SDG-Lab engaged >10 stakeholders. The most commonly engaged stakeholder group were local community members ($n = 16$), which is to be expected considering the very local focus of SDG-Labs, and the fact that most of the solutions were geared towards local communities. In order of declining prevalence, the other stakeholders involved in the SDG-Labs came from the businesses/private sector ($n = 13$), local governments ($n = 12$), civil society ($n = 12$), and academia/research ($n = 11$; Table 2).

However, the relative mix of these stakeholders differed between SDG-Labs (Table 2). For example, in the SDG-Lab Armenia, most of the engaged stakeholders came from civil society (33.3%), while in SDG-Lab China came from the private sector/businesses (46.2%). The representation of stakeholder types in SDG-Lab Uganda and Japan was relatively even (though low in absolute numbers, Table 2), and included stakeholders coming from all five categories. Stakeholder representation in other SDG-Labs such as China, Madagascar and Thailand were higher (Table 2), but also more unevenly distributed.

The engagement method for the different stakeholders also varied among the six SDG-Labs. In particular, there was a large variation between SDG-Labs in the type of the participatory approaches employed to engage stakeholders for the co-design and co-development of the solutions (Table 3). The specific participatory approaches included: (a) online and offline interviews; (b) onsite workshops and training; (c) online workshops, (d) field research (forest inventory, plant species count, etc., including a participatory field research), and (e) laboratory experiments.

Similar, to the stakeholder groups, the different SDG-Labs mobilized different participatory processes to engage with stakeholders. For example, while overall the six SDG-Labs applied 6 types of approaches, the SDG-Labs of China and Uganda employed each a total of five participatory methods, and the other SDG-labs employed fewer participatory approaches (Table 3).

The above suggest that although all SDG-Labs adopted highly transdisciplinary approaches, they did not necessarily follow the same template in terms of engagement approaches or data collection/analysis methods. What was important instead across all labs was to select the most appropriate stakeholders and participatory methods to reflect the local problem, needs, and social-ecological system characteristics. For example, the SDG-Labs in Uganda and China adopted many participatory approaches to engage stakeholders in a relatively balanced manner. These SDG-Labs applied interviews onsite and online, workshop online, and field research. Instead, SDG-Labs in Armenia, Madagascar and Thailand tried to adopt different participatory approaches, but with one of them being more dominant (e.g., onsite interviews). Finally, SDG-Lab Japan adopted relatively fewer participatory processes, but with some degree of balance between them, focusing on interviews, field research, and workshops.

3.3. Contribution of the SDG-Labs in the biodiversity-food-climate nexus

The six SDG-Labs have a good variability in terms of ecosystem focus and biodiversity-based solutions (Table 4). In terms of the biodiversity component used for the solutions, species diversity was the most common, and was present across all six SDG-Labs (Table 4). Diversified production systems were also prevalent including diversified cropping systems (e.g., Armenia), diversified agroforestry systems (e.g., Thailand), and diversified home garden (e.g., Japan). Conversely ecosystem diversity and genetic diversity were less utilized in the biodiversity-based solutions (Table 4). In terms of the food system focus, although some SDG-Labs did not target food production systems (e.g., Madagascar), all biodiversity-based solutions contributed to local communities' food and nutrition security. This was mainly through enhanced food availability (e.g., increased or more stable food production) and/or increased food accessibility due to increased income (Table 4). Interestingly, although it was not part of the Open Call (Section 2.1), all SDG-Labs identified climate change as an inherently cross-cutting issue in this interface of biodiversity and food systems. It is worth noting that three SDG-Labs specified their solutions as NbS for climate change mitigation and/or adaptation (Table 4). In this sense, all SDG-Labs contribute to the biodiversity-food-climate nexus in different extent. Below we summarise in detail the biodiversity-based solution for each SDG-Lab and how it contributes to the biodiversity-food-climate nexus (Table 4).

In SDG-Lab Armenia, the biodiversity-based solution aimed at enhancing local food availability through a diverse mixed-species cropping system that generated in the process income for improving farmers' food accessibility (via the sales of endangered medicinal plant to tea making companies or other local markets) and enabled the conservation and sustainable use of wild endangered medicinal plant biodiversity. This latter was achieved through innovative "on farm" conservation approaches. This diversified agro-ecosystem essentially helped to raise the resilience of farmlands toward climate change, which is significant in the Ararat region which was the geographical focus of this SDG-Lab.

In SDG-Lab China, the biodiversity-based solution focused towards conserving biodiversity through mixed-species tree and tea culture through forestry-tea garden models. It was expected that the development of such forestry-tea gardens led to higher yields and better quality of tea, which eventually would generate higher income for tea farmers and employees in the tea industry to improve food accessibility. In addition, the increased abundance and coverage of trees in the forestry area provides shade for the tea plants, reduce temperature and absorb dust, which collectively enhance the adaptation of tea production to the impact of global warming.

In the SDG-Lab Japan the biodiversity-based solution was aimed at creating homestead windbreaks in traditional village landscapes. These were created outside residences and in home gardens inside residences through the conservation of local biodiversity. On the one hand, home gardens with diverse species of leafy vegetables, roots and fruit trees enhances food availability for local residents for self-consumption. Considering that this solution was implemented in a chain of isolated islands, a home garden for local food provision could further reduce the substantial GHG emission from importing food from the mainland. On the other hand, the previously planted homestead windbreaks around the residences were used as a NbS to protect the house from strong typhoons and monsoonal winds during the winter. It was also estimated that homestead trees planted in an orderly line have a high potential for biomass accumulation, carbon sequestration, climate change mitigation and adaptation.

In SDG-Lab Madagascar, the biodiversity-based solution related to utilizing local biodiversity for ecotourism and a series of related ancillary activities. In this case the benefits of the rich local biodiversity (including aquatic and terrestrial) were leveraged by increasing local awareness (including from business and households) about the value of the biodiversity that could be appreciated by tourists, and how it could be translated into income generation for improving food accessibility and alleviating poverty. Furthermore, restoration activities in the protected area will further restore terrestrial and aquatic biodiversity but also increase the potential of carbon storage for climate change mitigation.

In the SDG-Lab Thailand the biodiversity-based solution related to enhancing species diversity in watershed forests, community forests, illegal logging areas and degraded forest areas near local communities through traditional agroforestry farming system, e.g., planting native food crop species and local tree species. This system can increase local food availability as well as food accessibility through income generation from marketable products such as native food plant species like Pak Wan. In the meantime, the promotion of traditional agroforestry farming systems in watershed forests was perceived by local villagers as a NbS for water regulation and drought mitigation, especially during the dry season, which helped local climate change adaptation.

In the SDG-Lab Uganda, the biodiversity-based solution related to the promotion of indigenous pastoral systems that had multiple benefits, including biodiversity conservation. In this SDG-Lab different biodiversity components were used namely genetic diversity (e.g., locally adapted livestock breeds and crop varieties), species diversity (e.g., grass species diversity), and ecosystem diversity (e.g., habitat diversity). This sustainable pastoralism model relying on the different components of local biodiversity enhances, on the one hand, the food availability of pastoralists and generates income from the sales of livestock products that can increase food accessibility. On the other hand, the indigenous knowledge of species, ecosystems and climate were used by the pastoralists to better adapt the pastoral system to disease outbreaks, droughts, and climate change. Furthermore, it was also observed that the vegetation maintained through grazing activities could in turn store carbon, which had positive ripple effects for climate change mitigation.

3.4. Broader sustainability benefits of the SDG-Labs

Figure 3 shows the contribution of the six SDG-Labs to the different SDGs. As discussed in Section 3.3, given their approach of developing biodiversity-based solutions through conservation and sustainable use, all SDG-Labs could contribute to "Life on Land" (SDG15), and some to "Life below Water" (SDG14; i.e., Japan, Madagascar, Thailand; Table 4). Here it is worth noting that by protecting the watershed, the SDG-Lab in Thailand could also contribute to "Clean water and sanitation for all" (SDG6). Furthermore, as climate change was perceived as a cross-cutting challenge in practically all SDG-Lab contexts (Section 3.3), the proposed solutions could also have a positive effect for "Climate Action" (SDG13) via offering opportunities for climate change mitigation and/or adaptation (Table 4). This suggests that the

TABLE 4 Aspects of the biodiversity-food-climate nexus considered in each SDG-Lab.

SDG-Lab	Biodiversity-based solution	Component of biodiversity*	Contribution to food systems	Contribution to climate change adaptation/ mitigation	Beneficiaries
Armenia	- Innovative cropping system and cultivation of endangered plant species	- Species diversity in cropping systems - Underutilised and endangered species for cultivation	- Enhance food availability through diversified crop production - Enhance access to food through increased income	- Climate change adaptation through increased agro-ecosystem resilience	- Local farmers - Local tea producing companies
China	- Innovative and diversified cropping systems	- Species diversity in forest-tea garden production systems - Ecosystem diversity in forest-tea garden systems	- Enhance access to food through increased income	- Climate change adaptation through improved habitat for tea trees	- Local tea farmers - Tea industry employees - Tea industry - Tourists - Local government - Citizens
Japan	- Homestead NbS for hazard mitigation and subsistence	- Species diversity in home gardens - Ecosystem diversity in traditional cultural landscapes	- Enhance food availability for self-consumption through home garden production - Enhance access to food through additional income	- Climate change adaptation through weather and natural hazard mitigation - Climate change mitigation through increased carbon sequestration in homestead trees	- Farmers - Local communities - Small business owners and tourism association - Local gardening companies
Madagascar	- Ecotourism for biodiversity conservation and restoration	- Species diversity through biodiversity restoration	- Enhance access to food through income generation from ecotourism - Develop capacity about local food systems (e.g., fishing, crop cultivation)	- Climate change mitigation through increased carbon sequestration in restored forests	- Farmers - Local communities responsible for forest protection - Protected area managers - Tour and hotel operators - Local government - Tourists
Thailand	- Promotion of traditional agroforestry farming system	- Species diversity in traditional agroforestry farming systems	- Enhance food availability through highly biodiverse traditional agroforestry farming systems	- Climate change adaptation through reforestation - Climate change mitigation through increased carbon sequestration in restored forest	- Local communities
Uganda	- Promotion of indigenous pastoral system - NbS for climate change adaptation	- Genetic diversity in livestock breeds and crop varieties - Species diversity in biodiversity management - Ecosystem diversity in drylands	- Enhance food availability and accessibility through sustainable pasture management - Enhance access to food through income generation	- Climate change adaptation through strengthened resilience and adaptive capacity of pastoralist activities - Climate change mitigation through increased carbon sequestration in restored forests	- Farmers - Local communities

*The definition of biodiversity used in this paper was adopted following by the Convention on Biological Diversity (CBD). According to this definition biodiversity "means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (CBD, 2006).

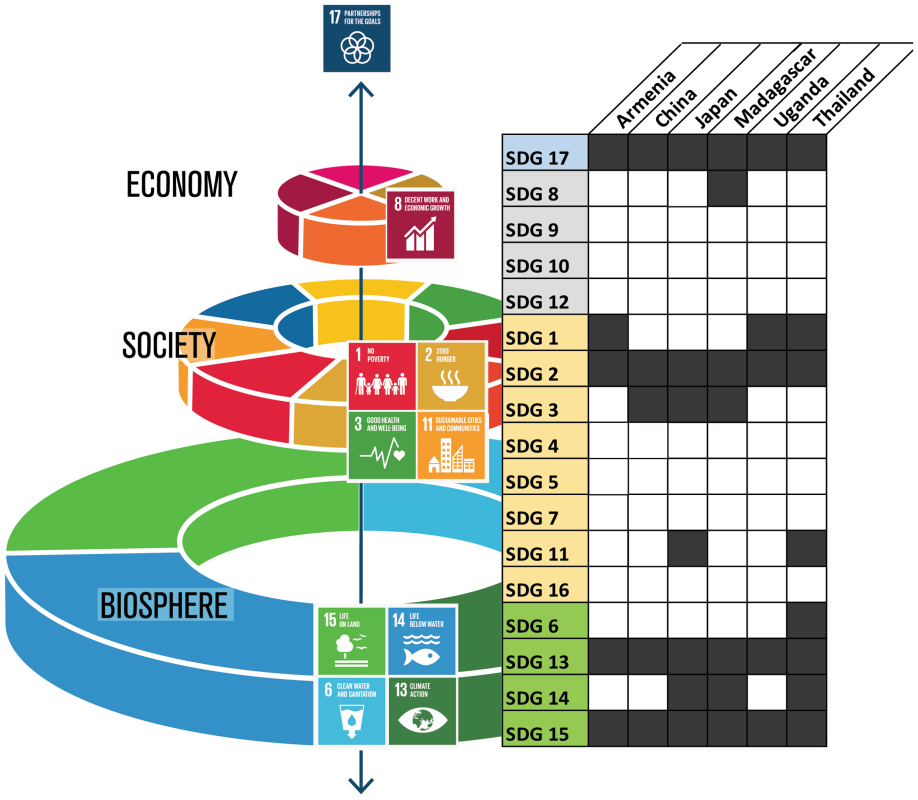

FIGURE 3
Broader sustainability contributions of each SDG-Lab. The division of SDGs across the three thematic categories (i.e., biosphere, society, economy) follows Rockström and Sukhdev (2016).

SDG-Labs contributed substantially to all environment-related SDGs, and especially SDG15 and SDG13.

When it comes to social SDGs, as the focus of the biodiversity-based solutions was to enhance the sustainability of food systems (Table 4), all SDG-Labs contributed to "Zero Hunger" (SDG2). However, all SDG-Labs contributed to at least one more SDG. For example, the China, Japan, and Madagascar SDG-Labs contributes to "Good Health and Well-being" (SDG3). Air pollution in Madagascar could be prevented by the proposed ecotourism-driven forest conservation and restoration. By conserving densely planted Fukugi trees (*Garcinia subelliptica*) around homes and alleys, the SDG-Lab in Japan promotes a solution to heatwaves. Conversely the SDG-Labs in Uganda, Madagascar, and Thailand contributed to "No Poverty" (SDG1). Poverty alleviation effects in the Uganda SDG-Lab were expected through livelihood improvements via improving use of pastoralist knowledge systems on managing and using the diverse vegetation of semi-arid ecosystems. In the Madagascar SDG-Lab, poverty alleviation effects for the local community were expected through income generation via ecotourism, whereas in the Thailand SDG-Lab via the enhanced capacity of local communities for sustainable forest management and biodiversity conservation. Finally, the SDG-Labs in Japan and Thailand are expected to contribute to "Sustainable cities and communities" (SDG11). In Japan, this contribution was expected through building the community value among new residents in the area who do not know the local traditions and have no social network; and among the new generation who had lost the connection with local traditions and biodiversity. The SDG-Lab project provided a space for communal and intergenerational interactions and rediscovery of the use of forementioned Fukugi Tree (*Garcinia subelliptica*), as a natural wind shield and shade, and source of dyeing material and food additive. Conversely, in the SDG-Lab, the contributions to SDG11 were expected through the support to local communities' reliance on sustainable practices such as agroforestry, with engagement in forest rehabilitation.

However, the SDG-Labs had a much lower potential to tackle economy-related SDGs (Figure 3). Only the Madagascar SDG-Lab had such a potential, and only for "Decent work and economic growth" (SDG8). The expected pathway to contribute to SDG8 was via enhancing self-employment in immersive ecotourism, as well as supporting local sustainable tourism-related businesses.

Finally, all projects can contribute to "Partnership for the goals" (SDG17; Figure 3). As outlined in Section 3.2 very diverse stakeholders participated in all six SDG-Lab projects in order to co-design and implement the proposed biodiversity-based solutions for sustainable food systems.

Overall, each SDG-Lab can potentially contribute to multiple SDGs. However, the focus and approaches can vary substantially. This shows the very flexible nature of these transdisciplinary processes in terms of their ability to tackle multiple sustainability challenges through locally-driven solutions.

TABLE 5 Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis for the six SDG-Labs.

Strengths	Weaknesses
Knowledge accumulation about the use of local plants as food resources within local communities Leverage of local biodiversity (crops, animals) for food and income generation Increased farmers' awareness about resource scarcity and environmental degradation Mobilize stakeholders' interest and support for innovative cropping systems and agro-biodiversity for food security Improved local community participation in decision-making processes Recognition of sustainable biodiversity practices as a new potential opportunity for local business development and/or profit generation	Low initiative of local farmers to engage in bottom-up initiatives, as they are used to top-down project implementation Low capacity of farmers to harness modern technologies Lack of knowledge on local farming and ecosystem management practices among the younger generation Lower dependency of local communities on local food, and increased reliance on imported food Low interest on local sustainability transformation among major stakeholders from the private sector (e.g., growing tourism, expanding plantations) Limited capacity of the local government for the effective implementation and monitoring of environmental policies
Opportunities	**Treats**
Rediscovery and preservation of local food and biodiversity from the growing tourism sector Recognition of the value of local agriculture and ecosystems from existing environmental policies and central government initiatives Increasing demand for local and sustainably produced food from national markets Academic research efforts on local food security and biodiversity conservation Interest of other funding agencies to replicate the showcased model(s) for local change	Weak implementation of environmental policies Competition for land and labour with other economic sectors (e.g., mining) Lack of strong policy alignment with the SDGs Lack of policy support for the young generation to stay in the area and/or work on related topics (e.g., sustainable transitions, local food production)

3.5. Strengths and weaknesses of the SDG-Labs

Overall, the SWOT analysis suggests that the methodology and design/implementation of the SDG-Labs had diverse strengths and weaknesses, while the prevailing local and national context offered various opportunities and threats (Table 5). The major identified strengths related to ability of the SDG-Labs to provide a platform for knowledge generation and dissemination for food production and biodiversity conservation, as well as an opportunity to generate income and/or food. Collectively these had several positive ripple effects as outlined in Table 4. In more details, SDG-Labs offered an opportunity to accumulate and disseminate local knowledge about the use of native plants as food sources (in Armenia, Japan, Uganda), and use local biodiversity of plants and animals as food and income sources (in Uganda, Japan, Thailand). In many SDG-Labs the local and national governments, as well as local communities members (especially farmers), showed an active interest in engaging and supporting biodiversity-based solution for food security, new cropping systems, and agrobiodiversity conservation (in SDG-Lab Armenia). Moreover, the SDG-labs in all communities increased the understanding of local communities about resource depletion and environmental deterioration (all SDG-Labs). Furthermore, in many local contexts the businesses and governments recognized the income generation potential of the sustainable practices encapsulated in the SDG-Labs as a big strength of these local transdisciplinary approaches (in SDG-Lab Thailand, SDG-Lab Madagascar, SDG-Lab Armenia, SDG-Lab China).

However, SDG-Labs also demonstrated a number of Weaknesses (Table 5). Although in some SDG-Labs local communities and farmers participated actively in the decision-making process, in other SDG-Labs farmers were less active as they were familiar only to a top-down implementation and were thus less determined to participate in bottom-up initiatives (e.g., in Madagascar). Another weakness of the SDG-Lab model related to the lower capacity of local farmers to harness modern technologies and/or to comprehend that some practices, despite offering higher profits, are essentially not sustainable (in Armenia, China, Thailand). Another weakness of the SDG-Lab model was the inability to engage properly the younger generation that lacked knowledge of local farming and ecosystem management practices (e.g., in Japan), which in the end prevented the revival of some local food production practices. In some cases the SDG-Lab was misaligned with other local interests and priorities, as for example stakeholders from the growing tourism industry and expanding plantations did not have local sustainability transformation high up on their priorities (e.g., in Madagascar). Finally, in some contexts local governments also had a limited capacity for environmental policy enforcement, which generated certain difficulties in the design and implementation of some SDG-Labs, e.g., through ongoing ecosystem degradation in the surrounding areas (in SDG-Lab Madagascar, SDG-Lab Uganda).

The most apparent Opportunities for SDG-Labs were the amenable environment created from some of the main stakeholders (Table 5). For example, the growing tourism sector in some countries/localities encouraged the rediscovery and preservation of local food and biodiversity (in Japan, Thailand, Madagascar, China). Such a case was the SDG-Lab in Madagascar that benefited from (a) the growing demand from the national market for locally and sustainably produced food (which provided a strong incentive for local food production), and (b) the alignment with the interests of other funders (which provided an opportunity to replicate the showcased model for local change in other geographical contexts). In almost all SDG-Labs (with the exception of Madagascar), there was a notion that the SDG-Labs benefited from existing environmental policies and central government initiatives that recognized the value of local agriculture and ecosystems. Finally, in most SDG-Labs the interest of research and

academic organizations in conducting research on food security and biodiversity conservation, was seen major opportunity, benefiting the SDG-Lab implementation teams (in Armenia, China).

Finally, all SDG-Labs encountered a number of negative context-specific circumstances that acted as Treats (Table 5). For example, in SDG-Lab Madagascar, the prevailing policies had an insufficient alignment with the SDGs, which was perceived as hindering the design, implementation and uptake of the SDG-Lab. In SDG-Lab Uganda, despite the reportedly amenable environmental policies that facilitated the groundwork for the implementation of the project, their weak implementation posed certain challenges. Furthermore, the competition for land and labour with other industries such as mining, created a major challenge in acquiring a critical mass of people to enable the sustainability transformation through the SDG-Lab (in Uganda). Similar threats were identified in SDG-Lab Japan, where the lack of effective policies to support the younger generation to stay in the area and work on sustainable transitions (including local food production) was perceived to be a major threat to implementing the biodiversity-based solutions identified through the SDG-Lab.

4. Discussion

4.1. SDG-Labs as transdisciplinary solution spaces

Our SDG-Labs drew upon the concept of Living Labs (Section 1), which have been used for the transdisciplinary design and implementation of sustainable solutions in different thematic and geographical contexts (Lupp et al., 2020). The experiences from the six SDG-Labs reported here demonstrate in practice the application of participatory and multi-stakeholder transition governance models (Nevens et al., 2013; Schäpke et al., 2018), with a particular focus on biodiversity-based solutions for sustainable food systems (Section 3.3). While there is an emerging (but still limited) literature on comparative studies about the performance and effectiveness of Living Labs (see Hossain et al., 2019; Kok et al., 2021), here we elaborate how such transdisciplinary approaches are able to facilitate the creation of models for local seeds of transformation using biodiversity as the "source" of the solution.

Overall, the six SDG-Labs outlined in this study had very diverse thematic foci in terms of the proposed and/or implemented biodiversity-based solution. These ranged from the promotion of traditional food systems that mobilized different components of biodiversity (e.g., Thailand, Japan Uganda) to the development of innovative food systems (e.g., Armenia, China) or ecotourism models (e.g., Madagascar; Section 3.1–3.2). Furthermore, equally wide was the scale within which these biodiversity-based solutions were expected to "operate," that ranged from the level of the agroecosystem (e.g., Armenia, China) to the landscape level (e.g., Japan, Madagascar, Thailand), to the regional scale (e.g., Uganda). It is also interesting to note that all of the SDG-Labs did not only focus on food systems, but other interlinked challenges in the specific local contexts, including biodiversity loss (e.g., China), land use conversion (e.g., Thailand), or climate change (e.g., Uganda). Interlinkages of food systems challenges with other persistent sustainability challenges have been addressed in other Living Labs focusing on for example sustainable food-water-energy innovations (Offermans et al., 2020), wild food for health, food security and livelihoods (Pereira et al., 2022), and organic agriculture for soil health (Hvitsand et al., 2022).

Despite their thematic divergences, when looking at the sub-categorisation of McCrory et al. (2022), all SDG-Labs generally adopted a "make and relate" approach, as they sought to create social innovations, which were constructed and bound at the local level, but were also informal and self-organizing in nature (see Section 1 and Box S3, Supplementary material). Furthermore, they were highly transdisciplinary in the sense that each SDG-Lab during the solution design and implementation phases involved participants from four to five major stakeholder groups, including stakeholders from local communities, private sector, local government, academia, civil society, and other organizations (Section 3.2). On average, each SDG-Lab engaged over 10 stakeholders (Section 3.2), highlighting the ability of these processes to mobilise local interest about the development of sustainable solutions. In addition, the beneficiaries of these six SDG-Labs varied from solely local community beneficiaries (e.g., Thailand) to beneficiaries from a broader industrial sector (e.g., China) and even non-local beneficiaries such as tourists (e.g., Madagascar).

The implementation teams of the SDG-Labs were equally diverse, with some SDG-Labs led by practitioners (i.e., Madagascar and Uganda), others by academic researchers (i.e., Armenia, China and Japan), and some by joint teams (i.e., Thailand; Section 3.1). Transdisciplinarity was further enhanced through the overall design of SDG-Labs that allowed vertical and horizontal information exchange with international researchers in the form of coaching and presentations at international conference venues as well as between SDG-Lab groups (Section 2.1). Similarly, the SDG-Labs used very diverse techniques to design/implement the biodiversity-based solutions and engage with stakeholders (Section 3.2).

The above show clearly how SDG-Labs can follow very divergent approaches anchored on principles of transdisciplinarity (Lawrence et al., 2022). This further reflects the observation there is no universally applied approach for their implementation, but can be rather flexible in terms of methods and approaches, as long as they embrace a participatory and multi-stakeholder mindset to transition governance (Nevens et al., 2013; Schäpke et al., 2018) with a good balance between scientific and societal goals while addressing requirements, interests, and limits of practitioners (Bergmann et al., 2021).

However, we need to also point, although young people can play a critical role for sustainable food transformation and living labs (see Section 1), the six SDG-Labs moderately achieved to include youth as stakeholders. This does not come as a surprise as in many areas youth was simply underrepresented in the general population due to population ageing or migration (Section 3.5). Furthermore, many of the solutions were geared towards agriculture, where younger generations are generally less involved compared to their older cohorts (Christiaensen et al., 2021).

4.2. SDG-Labs as sources of multi-functional solutions

Beyond transdisciplinarity, another common characteristic of all SDG-Labs was the multifunctionality of the proposed biodiversity-based solutions. All six SDG-Labs had strong connections with multiple SDGs (Section 3.4) and potential for climate change adaptation and/or mitigation (Section 3.3).

In terms of SDGs linkages, the biodiversity-based solutions proposed by practically all SDG-Labs did not only contribute to the biosphere-related SDGs, but also to the society-related SDGs (Figure 3). In particular, while SDG15 and 14 (pertaining to life on land and water respectively) were by definition the main SDGs targeted by the proposed solutions, all SDG-Labs also contributed to SDG13 associated with climate change. Similarly, all SDG-Labs contributed to SDG2 on food, and many contributed to SDG3 on health. Finally, the highly transdisciplinary nature of all SDG-Labs (see Section 3.2 and 4.1), implies their possible positive ripple benefits towards the creation of partnership for the SDGs and strengthening locally the means of implementation for sustainable development (SDG17).

A very noteworthy observation was that climate change emerged as a strong cross-cutting theme in all SDG-Labs. This was largely unplanned at the Open Call level (see Section 2.1). In particular climate change featured in two main ways, as discussed below.

On the one hand, in the Armenia, Japan and Uganda SDG-Labs, climate change was perceived as an emerging threat for the food production systems and the wellbeing of the local communities. Therefore, the proposed and implemented biodiversity-based solutions sought to: (a) reduce the impact of climate change and extreme weather events (e.g., conservation of windbreaks: SDG-Lab Japan) or (b) improve the resilience and adaptive capacity of food systems (e.g., innovative cropping system: SDG-Lab Armenia; indigenous pastoralist system: SDG-Lab Uganda) and local communities (i.e., SDG-Lab Japan; Table 4). These actions contributed to enhancing local food availability through higher species diversity (Table 4), which in turn contributed to climate change mitigation via increased carbon sequestration (Section 3.3). Similar efforts to use biodiversity to combat climate change impacts on food production systems have been widely reported in the literature (Duarte et al., 2020; Henry, 2020; Ojea et al., 2020; Tschora and Cherubini, 2020; Dhyani et al., 2021; Miralles-Wilhelm, 2021). Particularly, some of the recent discussions about NbS have encouraged tackling societal challenges not only related to disaster risk reduction and climate change, but also food security and human health (Cohen-Shacham et al., 2016).

On the other hand, in some other SDG-Labs (i.e., China, Madagascar, and Thailand), climate change was not directly mentioned/identified as a major challenge but was inherently interconnected with the proposed and implemented solutions. For instance, the development of forestry-tea gardens in the SDG-Lab China could also help tea trees adapt to the rising temperature. Similarly in the SDG-Lab Thailand, the reforestation targeted native food tree species that have higher tolerance to drought, which could also help the local community and ecosystem adapt better to drought under climate change. The restoration activities in the protected areas of SDG-Lab Madagascar could also contribute to increasing carbon sequestration from restored native biomass (Table 4).

Such types of climate co-benefits are not an uncommon feature of biodiversity-based solutions for food systems. For example, the mobilization of neglected and underutilized crop species (or orphan crops) can enhance local food and nutrition security via agrodiversity conservation, and at the same time help build the resilience of local communities and agricultural systems due to their better adaptation to challenging climatic conditions (Mabhaudhi et al., 2019). Similarly conserving agrobiodiversity for sustainable food systems in the Hindu Kush Himalaya has been argued to provide a good basis for achieving food security and agricultural sustainability, as well as for adapting to climate change (Rasul et al., 2022).

Finally, when looking critically at the biodiversity-based solutions and their design/implementation approaches, beyond their multi-functionality, most SDG-Labs followed multiple pathways to the targeted impact. For example some biodiversity-based solutions aimed at creating societal impact via building individual capacity (e.g., capacity building workshops in SDG-Lab Armenia; re-discovering the value of homestead windbreaks and home gardens in SDG-Lab Japan). Other SDG-Labs sought to create impact via usable products or innovative production models (e.g., tree-garden cultivation systems in SDG-Lab China; mixed-crop cultivation systems and medicinal plants in SDG-Lab Armenia). Other SDG-Labs sought to create impact through novel institutional arrangements (e.g., "immersive tourism model" in SDG-Lab Madagascar). Other SDG-Labs sought to restore traditional systems (e.g., traditional agroforestry farming system for degraded land rehabilitation and management in SDG-Lab Thailand; indigenous pastoralism for ecosystem conservation in SDG-Lab Uganda; homestead windbreaks in SDG-Lab Japan). Finally, practically all SDG-Labs sought to create impact by building networks and relationships considering their highly transdisciplinary nature (Section 3.2).

4.3. Lessons learned and future research directions

When looking critically the SWOT analysis (Section 3.5) and other observations from the design and implementation of the SDG-Labs (both individually and collectively), it is possible to identify some key lessons learned to improve chances of success of future similar initiatives. These lessons relate to the (a) knowledge/capacity/willingness of different stakeholders and community buy-in to engage in transdisciplinary bottom-up processes, (b) productive engagement of the private sector, (c) underlying institutional environment and implementation.

A factor that seemed to benefit greatly the design and implementation of several SDG-Labs was the accumulated body of knowledge in the local communities about the use of local resources and ecosystems. This included for example plant species (SDG-Lab Japan) or livestock and rangelands (SDG-Lab Uganda). It was also encouraging that the participating farmers, local government agencies, and even businesses in most SDG-Lab locations were aware of resource scarcity and environmental degradation, which created a good basis to initiate these activities. Furthermore, many local communities and other stakeholders were already interested in joining forces in actions towards achieving locally important goals such as food security, improved agricultural production, income generation or biodiversity conservation. On many occasions the local residents had some level of capacity and willingness to participate in these bottom-up processes and the overall decision-making process. Conversely, in some SDG-Labs local communities were aware of resource degradation and were willing to participate, but their capacity to initiate/engage in bottom-up initiatives or harness modern technologies were limited, which hindered the implementation of some of the innovations (e.g., SDG-Lab in Armenia). Similarly in some cases local governments also had limited capacity for the

enforcement of sustainability policies due to different context-specific reasons such as the decreasing reliance of local communities on local food compared to imported food (SDG-Lab Japan). This existing knowledge/capacity of local communities and buy in/willingness to participate in local actions has been identified as a major factor of success or failure in other sustainability-oriented labs (Bergmann et al., 2021) and more broadly transdisciplinary research (Lawrence et al., 2022). Awareness of this capacity and buy-in could potentially help to identify promising locations to implement such approaches targeting local sustainability transformation.

A second factor benefiting some SDG-Labs was the productive engagement of local businesses. In particular, some of the proposed sustainable practices were recognized to be new potential opportunities to generate profits, especially in relation to tourism and local food production (e.g., SDG-Labs in Madagascar and China). For example, several of the processes in favor of capitalizing on local actions were driven by the growing tourism sector in Madagascar that seeks the rediscovery and preservation of local food and biodiversity, leading to growing demand from the national market for local and sustainably grown food. Conversely, in some cases the private sector played knowingly or unknowingly an unproductive role for the implementation of some SDG-Labs. For example, the conventional tourism industry, expanding plantations or mining industries operating in the broader areas did not have sustainability on their agenda, and often acted as better income opportunities especially for young people, reducing to some extent local interest for engaging in SDG-Labs (e.g., in Uganda and Madagascar). Many studies have discussed how buy-in from the private sector can be an important factor for facilitating local sustainability transformation, considering its capacity to mobilise funds and political support (Schmidt et al., 2013; Masuda et al., 2022). However, as has been pointed in other sustainability-oriented labs and transdisciplinary processes it is important to ensure that the engagement of the private sector does not trample other local needs and sensibilities, considering the generally high power of such stakeholders (Di Maddaloni and Sabini, 2022).

A third factor that facilitated the design and implementation of some SDG-Labs were the existing environmental policies and the general recognition of national and local governments about the value of local agriculture and ecosystems (e.g., SDG-Labs in Armenia, China, and Thailand). This often helped to promote sustainable farming systems with climate change and biodiversity conservation as the main goal. However, there were also cases where the persistently not firm enforcement of national environmental policies or the lack of policies aligned with the SDGs had a negative impact on the SDG-Labs. For example, this took a toll through continuing deforestation (SDG-Lab Madagascar) and ongoing illegal mining (SDG-Lab Uganda), which threatened biodiversity. Here we need to re-iterate that conducive institutional environments have been identified as an important factor affecting the success or underperformance of sustainability-oriented labs, and transdisciplinary research processes more generally (Bergmann et al., 2021).

In terms of future research, despite their diverse thematic foci on biodiversity-based solutions for food systems, all six SDG-Labs were implemented in rural settings, and mostly revolved around food production. However, there is a growing experience of sustainability-oriented labs in the context of peri-urban areas (Kok et al., 2019) or urban food system transformation (Brons et al., 2022), though few that actually develop biodiversity-based solutions. It is worth noting that biodiversity and other food system components are also closely interlinked, such as food consumption (Crenna et al., 2019) or transportation of agricultural products (Puppim de Oliveira et al., 2011). Future SDG-Labs related to food systems can further explore possible opportunities to develop and leverage biodiversity-based solutions in different component of food systems and urban or peri-urban settings.

Furthermore, species diversity was the main biodiversity component leveraged in practically all SDG-Labs, with other components such as genetic diversity only considered in few cases (Section 3.3; Table 4). Genetic diversity plays a substantial role for ecosystem resilience and maintaining species diversity (Hoban et al., 2020), and although crucial for food security, it is being lost at an alarming rate (Oliver et al., 2015). Even though genetic diversity was a smaller focus among the six SDG-Labs, it can arguably to provide solutions to enhance resilience to climate change and achieve food security goals (Wani et al., 2022), including from crops (Mujeeb-Kazi et al., 2013; Begna, 2021), livestock (Mottet et al., 2018) and aquatic food (Lind et al., 2012). At the same time there have been calls for more attention to genetic diversity (Hoban et al., 2020) including through dedicated goals in the recent post-2020 Global Biodiversity Framework (CBD, 2021). In this respect, future sustainability-oriented labs could develop possible biodiversity-based solution for food systems leveraging on genetic diversity.

5. Conclusion

In this paper we reported the experiences and lessons learned from the implementation of six SDG-Labs that developed biodiversity-based solutions as a means of transforming food systems. The results show that these transdisciplinary and solutions-oriented techniques can follow very diverse approaches and use very different biodiversity components to target equally diverse and context-specific sustainability challenges of local food systems. Furthermore, and depending on the context, all SDG-Labs followed quite different approaches when designing the biodiversity-based solutions and engaging with relevant stakeholders. This suggests that there is no universally applicable approach for the design and implementation of SDG-Labs. Instead, what is important is to embrace actively and unreservedly a solutions-oriented mentality and a willingness to engage meaningfully diverse local stakeholders during the design, implementation and eventual uptake of the solutions.

Through the SWOT analysis we synthesized the experiences and lesson learned from all six SDG-Labs. Some of the Strengths include knowledge accumulation in local communities regarding the use of local plants for food or an increase in farmer awareness about resource scarcity and environmental degradation. Opportunities include broader market developments, for example, on the tourism sector or on alternative food markets for locally and sustainably produced food. Conversely some of the most important Weaknesses include the low initiative of farmers to engage in bottom-up activities (as they are often used to top-down project implementation), the low capacity of local farmers to harness modern technologies, and the lack of knowledge among young generations on local farming and other traditional practices. Commonly mentioned Threats include the weak implementation of environmental policies at different levels, and the fact that many policies are not yet well aligned with SDGs.

Collectively, the synthesis exercise reported in this paper (as well as the broader experience from the entire process of the SDG-Labs) suggests the great promise of this type of transdisciplinary research approach for developing solutions at the biodiversity-food-climate nexus. However, our accumulated experience also points to the very diverse and context-specific challenges that must be overcome to maximize the potential of SDG-Labs to both enable the sustainable transformation of local food systems or be scaled up effectively in other geographical and/or thematic contexts.

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.

Author contributions

MJ: conceptualization, methodology, results, and writing. AG: conceptualization, structuring, discussion, editing, and writing. OS and TE: conceptualization. JS: analysis, writing, and editing. AA, JL, JK, BC, RA, and IO: coordination and results of SDG-Labs. GS and RL: discussion. 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.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1144506/full#supplementary-material

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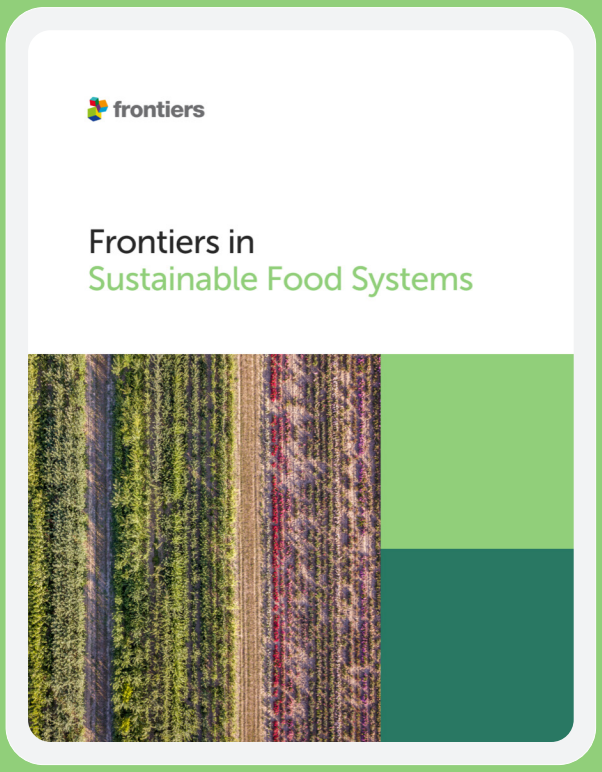

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