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Systems Thinking, Mapping and Change in Food and Agriculture

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Abstract. Societal actors across scales and geographies increasingly demand visual applications of systems thinking – the process of understanding and changing the reality of a system by considering its whole set of interdependencies – to address complex problems affecting food and agriculture. Yet, despite the wide offer of systems mapping tools, there is still little guidance for managers, policy-makers, civil society and changemakers in food and agriculture on how to choose, combine and use these tools on the basis of a sufficiently deep understanding of socio-ecological systems. Unfortunately, actors seeking to address complex problems with inadequate understandings of systems often have limited influence on the socio-ecological systems they inhabit, and sometimes even generate unintended negative consequences. Hence, we first review, discuss and exemplify seven key features of systems that should be – but rarely have been – incorporated in strategic decisions in the agri-food sector: interdependency, level-multiplicity, dynamism, path dependency, self-organization, non-linearity and complex causality. Second, on the basis of these features, we propose a collective process to systems mapping that grounds on the notion that the configuration of problems (i.e., how multiple issues entangle with each other) and the configuration of actors (i.e., how multiple actors relate to each other and share resources) represent two sides of the same coin. Third, we provide implications for societal actors - including decision-makers, trainers and facilitators - using systems mapping to trigger or accelerate systems change in five purposive ways: targeting multiple goals; generating ripple effects; mitigating unintended consequences; tackling systemic constraints, and collaborating with unconventional partners.

Keywords: Systems thinking, Causal loop diagrams, value network analysis, wicked problems, agri-food systems, socio-ecological systems.
Jel Codes: Q10, Q19.

1. INTRODUCTION

Societal actors agree, at least in principle, that the complex nature of social and ecological problems affecting food and agriculture – i.e., food

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insecurity, poverty, biodiversity loss, deforestation, water scarcity and global warming among others (Batie, 2008; Dentoni *et al.,* 2012) – requires cross-scale coordination among private strategies, public policies and civic action (Waddock *et al.,* 2015; Bansal *et al.,* 2021; Williams *et al.,* 2021). For example, the European Union's Farm to Fork Strategy (2021), at the heart of the European Green Deal (2021), conceives public-private partnerships as necessary to support farmer entrepreneurship, climate-smart agriculture, food innovation and, ultimately, the resilience of agri-food systems (Manyise and Dentoni, 2021). The new strategy of the Consultative Group on International Agricultural Research (CGIAR, 2021) recognizes that engagement with local communities and the private sector is vital for agricultural research and development (R&D) to address the problems of food insecurity and climate change effectively. These examples demonstrate the need for coordination among market, societal and political actors to collectively agree – or, at least, agree to disagree – on the depth and breadth of changes needed in socio-ecological systems to address these complex problems (Clarke and Crane, 2018; Dentoni *et al.,* 2018).

Unfortunately, these principles of cross-scale coordination among societal, political, and market actors to address socio-ecological problems are still hardly implemented. Clashes among political and economic actors ramp up on how reducing food insecurity, greenhouse gas emissions, and inequality in revenue distributions in the agricultural and food sector (Leakey, 2018; Sovacool, 2018; van der Ploeg, 2020) across several regions of the world. Geopolitical tensions and wars burst worldwide around a lack of coordination in the use and distribution of water, fertile land, energy, and food commodities (Mergulis, 2014; Scheffran, 2020). These interrelated clashes and tensions demonstrate that current initiatives aspiring to trigger, support or accelerate 'systems change' in food and agriculture fail to address socio-ecological problems at their roots unless actors gain a deeper collective understanding of the issues at stake, and of the systems where they are embedded, and how to address them (Gullino *et al.,* 2018; Orr and Donovan, 2018). This mismatch between the principles and the rhetoric of cross-scale, multi-stakeholder collaboration for agri-food systems change (FAO, 2021) and the current reality of increasing tensions and conflicts among the actors involved is strikingly evident and still poorly understood in food and agriculture studies and, more broadly, in the realm of social sciences.

In this paper, we argue that the current failures in cross-scale collaboration to address urgent socio-ecological problems reveal gaps of competencies and processes necessary for actors – especially to those in power positions – to collectively understand the complex socio-ecological problems (Senge and Sterman, 1992; Senge *et al.,* 2007). Based on this argument, we discuss 1) how approaches of *systems thinking* support (or, when not grounded on sufficient understandings of systems, hamper) the development of competencies and processes of cross-scale coordination in addressing complex problems in food and agriculture; and 2) how processes of *systems mapping* contribute to the collective understanding of these socio-ecological problems, and envisioning how to address them. We refer to *systems thinking* as an approach to understanding reality and enacting change by considering the dynamic interactions among multiple interdependent social and ecological agents (Meadows, 2008; Williams *et al.,* 2017). Furthermore, we define *systems mapping* as a process of co-creating visual depictions – for example, diagrams, maps, or sketched models – of a complex system, including its entangled set of relationships and feedback loops among actors and trends (Sedlacko *et al.,* 2014). Systems mapping is often associated to participatory methods for collectively building systems models in group settings (Király *et al.,* 2016; Barbrook-Johnson and Penn, 2021; Wilkinson *et al.,* 2021). Building upon this literature on participatory systems mapping processes, this study focuses mostly on 'what is mapped' (i.e., the map interfaces) to co-create multiple systems maps which, together, support participants in their collective sense-making and envisioning process. In particular, we provide empirical illustrations of how the purposive combination of systems mapping tools helps developing competencies and understandings that have the potential to support *systems change* – that is, societal changes that are deep enough to challenge power structures and broad enough to cut across multiple markets (Dentoni *et al.,* 2017) – in and around food and agriculture.

By connecting systems thinking and systems mapping to the development of individual competencies and collective processes of addressing socio-ecological problems, this paper aims to speak directly to several actors in food and agriculture. First, this delineation of systems thinking features and systems mapping processes inform public and private decision-makers with the power to address socio-ecological problems at scale (Head and Alford, 2015; Banson *et al.,* 2018). These decision-makers need to be accountable for the way they comprehend complex issues before acting on them too precipitously. Second, these systems thinking features and systems mapping processes offer a strategic toolkit for social entrepreneurs, innovators, changemakers and activists seeking to transform food and agriculture from the bottom up (Dentoni *et al.*, 2019). Third, knowledge brokers such as facilitators, trainers and consultants—in applied research institutes (Posthumus *et al.,* 2021), private companies (Monaghan and Gray, 2021) or non-profit organizations (Systemiq, 2020) would benefit from reflection on connecting systems thinking to systems mapping practices and envisioning systems change with more depth and awareness. Finally, systems thinking and mapping provide an important lens to scholars and educators across disciplines to prepare new generations to address complex problems in novel ways (Savaget *et al.,* 2022; Skoll Centre, 2022). These ways are grounded in practices of active listening, reciprocal empathy (Allievi *et al.,* 2021) and collective experimentation (Ferraro *et al.,* 2015), while less driven by static analyses, linear planning and command-and-control agendas that are inherently detached from everyday perceptions of social reality (Meadows, 2001; Walker *et al.,* 2008). While systems thinking and mapping do not mitigate the risk of detachment from social reality (Seelos and Mair, 2018) per se, they offer a lens for societal actors to build collective understandings that are interdisciplinary and transdisciplinary in the way knowledge from multiple actors is shared and integrated.

2. SYSTEMS THINKING IN FOOD AND AGRICULTURE STUDIES: CURRENT LIMITS AND FEATURES

As an approach to understanding reality and enacting change (Meadows, 2008), systems thinking has been applied in a variety of organizational (Senge and Sterman, 1992) and societal contexts (Stroh, 2015) across disciplines (Williams *et al.,* 2017). Nevertheless, with few exceptions (Banson *et al.,* 2015; Orr *et al.,* 2018; Hansen *et al.,* 2020), the agricultural and food studies field is yet to embrace systems thinking with a sufficiently deep understanding of what systems are and what they do. Lacking to do so, we argue, will lead to the generation of literature that, while influential, risks tackling socio-ecological problems without the necessary depth (e.g., Ruben *et al.,* 2018; van Berkum *et al.,* 2018; Borman *et al.,* 2022). We point out three significant limitations of these applications in the current literature on systems thinking in food and agriculture. These include an excessive focus on the exclusive issues of the food sector, persistent linearity, and the implicit assumption that change can and should be planned.

A first limitation of the current literature on systems thinking in food and agriculture entails its *excessive focus exclusively on issues within the agri-food sector* surrounding value chains (e.g., Ruben *et al.,* 2018), hence setting predetermined boundaries for understanding systems (Borman *et al.,* 2022). This excessive focus contradicts the system thinking principle of *understanding the whole* around the strategic variables of interest (Meadows, 2008; Williams *et al.,* 2017). This literature, in particular, considers socio-ecological interactions beyond food value chains essentially as a given context (Ruben *et al.,* 2018; Borman *et al.,* 2022). In doing so, these approaches implicitly or explicitly choose not to understand and address the broader social, cultural, geopolitical, and ecological issues where the food value chains are embedded (Orr *et al.,* 2019). Systems mapping exercises stemming from this excessive focus on a sector or geography usually pressure their participants to set the boundaries of their system of interest (Woodhill and Millican, 2023). While setting boundaries allows to give a stronger focus to any sensemaking or decision-making initiative, it comes at remarkable cost: encouraging participants to remain blind to the relationships outside the set boundaries. Although not directly related to agri-food, these relationships may influence what occurs within the agri-food system. ‘Elephants in the room’ – such as issues of corruption, socio-political tensions, geopolitical competition for natural resources, energy or water crises – may remain outside these boundaries just because they do not directly relate to agri-food. Hence, this way of setting systems boundaries risks to defy the whole reason for using systems thinking.

A second limitation of recent applications of systems thinking in food and agriculture literature involves *persistent linearity*. Persistent linearity refers to the implicit assumption that actions lead to consequences in the system without recognizing that the system itself also triggers and shapes these actions. The claims that policy, managerial and scientific activities lead linearly to outcomes, goals and problem-solving (e.g., van Berkum *et al.,* 2018) do not take into consideration how these problems affect activities and their outcomes on the ground. This results in an incomplete measurement of the activities’ impact that can go as far as to be misleading relative to the actual effects on socio-ecological systems. Hence, while superficially referring to ‘non-linearity’ (van Berkum *et al.,* 2018: 1), this literature involuntarily retains and perpetuates linear approaches to understanding and changing agri-food systems.

A third and final limitation of this literature is the *assumption that change can be planned*. This literature assumes that food systems could transform through “the design, monitoring and evaluation of multi-annual bilateral programs aimed at different outcomes of sector transformation” (Borman *et al.,* 2022: 100591) rather than through processes of emergence. If we take systems thinking seriously, this assumption is problematic as it fails to recognize that processes of change are spontaneous and continuous, from the interactions between actors in a system to the involvement of those not involved in the design of a system. Yet, research on agricultural systems has pointed out since long time that, at best, change processes can be steered to a limited extent (Klerkx *et al.*, 2010). This limitation leads in practice to planned outcomes that necessarily and systematically differ from those envisioned in multi-annual strategy or program reports, thereby questioning their predictive power and credibility. It would be more helpful to consider how multi-annual plans interact with unplanned but plausibly impactful interactions between social (Jagustović *et al.,* 2019) and ecological agents (Brunton *et al.,* 2019) in changing agri-food systems (Hinrichs, 2014). In other words, less time dedicated to planning and more time dedicated to understanding and fostering complementarity among change agents would better fit with the principles of systems thinking.

To answer these three limitations of current literature on systems thinking applications in food and agriculture, we start by reviewing seven fundamental features of systems (Cilliers, 2002; Williams *et al.,* 2017). We illustrate each feature through an empirical example relevant to food and agriculture. These seven features are interdependency, level-multiplicity, dynamism, path dependency, self-organization, non-linearity and complex causality (see Table 1, first column). We argue that taken together, these features provide sufficiently deep underpinnings for mapping systems in ways that support participants to address socio-ecological problems in food and agriculture. On the basis of these features, we encourage actors seeking to address complex socio-ecological issues in and around food and agriculture to take the time and effort to *zoom out, zoom in, zoom up, zoom down, zoom forward, zoom backwards, zoom around and zoom aside agri-food systems* (see Table 1, third column). By doing so, actors seeking systemic change will commit their resources to understanding 'the whole' in a way that looks beyond what is seemingly relevant in the short term. The question that remains to be addressed is: how can these seven principles of systems thinking help actors to collectively understand systems and enact systems change without getting lost in complexity? In what follows, we propose a systems mapping process that takes these principles into account to collectively building a shared understanding and vision of socio-ecological systems change.

3. UNDERSTANDING AND ADDRESSING COMPLEX PROBLEMS THROUGH SYSTEMS MAPPING

Systems thinking begins with the idea of general systems theory, by Ludwig von Bertalanffy (1968), defining systems as foundational models of organization between parts that form a cohesive and relational whole. Considering socio-ecological problems in food and agriculture as an interconnected set of multiple issues and actors helps societal actors seeking to address these problems to understand, harness and tackle their complexity (Dentoni *et al.,* 2018; 2021). It does so because, fundamentally, problems and systems are two sides of the same coin (Senge *et al.,* 2007). If we map a complex system both in terms of the interconnected set of issues and actors that it entails, then we can then understand and envision – at least in principle – how a reconfiguration of these actors could address the complex problems entrenched in that system. By disentangling and making sense of these entanglements between actors and issues, then, we are then better equipped to address these complex problems. For example, problems of food insecurity in a city neighborhood or rural area can be described as a large set of interdependent issues causally connected with each other (a *system of issues*). These would be, for example, extreme heat, drought, inflation, poverty, social exclusion or traffic. The problem of food insecurity may indeed be described through this system of issues. On the other side of the coin, these problems can also be described as a large set of interdependent actors connected (or disconnected) and providing (or failing to provide) valuable resources to each other (a *system of actors).* These would be, for example, consumers, retail shops, food transporters, peri-urban farmers, neighborhood associations, the municipality or the local church. Altogether, this system of actors plays a role in the food insecurity problem, either influencing it or being affected by it. Therefore, *understanding and mapping systems of issues and of actors as two sides of the same coin provide a grounded view of a complex problem, that is, an approach that connects the multiple issues with the multiple actors that experience them.*

Understanding the intertwining of systems of issues and systems of actors provides a starting point for envisioning a collective process of systems mapping meant to collectively address a complex problem. Through systems mapping, envisioning the process of systems change becomes concrete as we realize that *we are part of the system of actors entangled with the systems of issues we are tackling.* By purposively changing our actions and interactions alongside others in our system, we change the system of actors that we are part of (see table 1, 'self-organization' principle). In turn, *by purposively altering our system of actors, we also meaningfully shift the system of issues (or complex problems) we seek to address.*

While each actor could individually make sense of and envision a change in their systems of actors and

Table 1. Seven fundamental features of systems: implications for food and agriculture.

Key systems feature	Example in agri-food context	Implication for systems mapping and change in food and agriculture
Interdependency Agents in a system are independent from, yet indirectly connected with, each other. Systems themselves are also independent from, yet indirectly connected with, each other.	Consumers, value chain actors, policy-makers, farmers, plants, animals are all agents in a food system. Within it, they all indirectly relate and influence each other. Furthermore, the food system relates, influences and is influenced by other systems, such as ecological, energy, political, cultural, financial, technological, and education systems.	To understand the present and envision the future of agri-food systems, we must purposively **<u>zoom out</u> beyond food and agricultural issues** and also consider social problems (such as war and conflict, socio-economic inequality gender discrimination, or ethnic biases from) and ecological problems (such as deforestation, greenhouse gas emissions, land, water and energy use and distribution). We cannot comprehend the issues facing food and agriculture, nor elaborate collective strategies to address these issues, without taking into account the other systems that influence or are influenced by them.
Multi-level Agents are hierarchically configured in sub-systems (e.g., organizations, networks, states) and spatially embedded within geographical systems (e.g., landscapes, basins, natural regions).	A head of state might impose an export ban on a food community, or an agribusiness company board of directors might disinvest in a country, with trickle-down effects on its food system. At the same time, each consumer and farmer make choices that, although at small-scale, influence the same food system from the bottom up, starting from their family, community, farm and landscape.	To understand the present and envision the future of agri-food systems, we must purposively **<u>zoom up</u> to understand power dynamics that hierarchically and spatially shape the issues**. Furthermore, we must purposively **<u>zoom down</u> to understand how agents 'on the ground'** (that is, within the smaller sub-systems, for example households, farms, teams, networks) **are influenced by these issues and, to the extent they can, seek to address them**. We cannot comprehend the issues facing food and agriculture, nor elaborate collective strategies to address these issues, without asking ourselves key questions about both power dynamics and everyday practices taking place 'on the ground'.
Dynamism Systems that they constitute are in a constant state of flow, as they react to triggers and stimuli from agents within or outside their boundaries.	War between two countries may accelerate an energy crisis that, in turn, accelerates inflation and magnifies food insecurity issues. Increasing droughts in a region may decrease water use in agriculture, hence reducing agricultural productivity and raising food prices.	To understand the present and envision the future of agri-food systems, we must purposively **<u>zoom forward</u> to foresee how agents or sub-systems that currently do not seem to influence food and agricultural issues in the present time may do so, in interaction with other agents and sub-systems, in the future**. We cannot comprehend the issues facing food and agriculture without asking ourselves what are the key factors that might come into play and shape future scenarios.
Path-dependency Agents act and interact, hence (re)configure sub-systems, also on the basis of their past actions and interactions.	Farmers and value chain actors operating in landscapes that experienced past floods, volcano eruptions or pandemics, in conscious or unconscious memory of their lived experience, organize differently than others. Global value chain may reproduce, consciously or unconsciously, dependency and inequality patterns in their socio-economic relationships.	To understand the present and envision the future of agri-food systems, we must purposively **<u>zoom backward</u> to make sense of why some patterns of action and interaction reproduce themselves over time**, and how they evolve in relation to epochal systems changes. We cannot comprehend the issues facing food and agriculture, nor elaborate collective strategies to address these issues, without understanding the historical factors that reproduce and maintain the configuration of existing systems.
Self-organization As they act and interact, agents constantly change and adapt systems from within.	Grassroots initiatives (such as alternative food networks or local currency communities) often emerge from relationships between farmers and their communities, or between neighbors. Within food companies, intrapreneurs seek to build relationships within and outside their firm boundaries to influence their corporate strategies, hence the system that they perpetuate. Entrepreneurs seek to build networks and develop new markets that disrupt current systems.	To understand the present and envision the future of agri-food systems, we must purposively **<u>zoom in</u> on-going processes of interaction between agents in a system**, even and especially when these take place at a micro- or small-scale. The emergence of these interactions signals that energy is high enough for some agents to start acting in notably different ways than others constituting it. Therefore, focusing on these processes allows to understand the key factors that justify their emergence in the system, and to anticipate the barriers to change or pathways of change that these processes may trigger. We cannot comprehend the issues facing food and agriculture, nor elaborate collective strategies to address these issues, without monitoring processes of emergence, what moves them, and what constrains them.

Key systems feature	Example in agri-food context	Implication for systems mapping and change in food and agriculture
Non-linearity Agents reciprocally influence each other in a system, so that causes, effects and boundaries of issues cannot be unilaterally identified.	Companies and citizens seeking to reduce food waste in supermarkets, restaurants and households face legislative. logistic and financial constraints in some countries. This generates vicious circles, because legislation, logistics and financial institutions do not adapt to the demands of actors seeking to reduce food waste unless these reach a critical mass. It might take the reaching of a tipping point, for example a legislative reform or a financial agreement made with a company seeking to reduce food waste, to invert this trend from a vicious to a virtuous system.	To understand the present and envision the future of agri-food systems, we must purposively **zoom around the issues that affect them, that is, exploring its causes, manifestations and consequences, as well as their interdependent relationships** (that is, how consequences become reinforcing causes, and vice versa). This implies that 'looking for the root causes' (a label often used by some consultancies, companies or public agencies suffering of short-termism) of complex issues is not just useless, but even counter-productive; if we take non-linearity seriously, then issues affecting food and agriculture do not look like trees (with no 'root causes', nor 'branch consequences'), but they rather look like spiny, climbing bushes. We cannot comprehend the issues facing food and agriculture, nor elaborate collective strategies to address these issues, without asking ourselves how agents and issues in a system are together entangled in vicious or virtuous circles.
Complex causality Multiple agents influence others in a system, so responsibilities of issues cannot be unambiguously attributed.	Multiple causes and agents influence the phenomenon of illegal forms of agricultural labor: farmers' little power in food value chains, the presence of criminal organizations, cultural factors in a community, lack of employment alternatives for the marginalized individuals in a society, and/or the lack of a clear legislation. None of these causes alone explains this phenomenon, nor an agent alone can be pointed as its sole responsible.	To understand the present and envision the future of agri-food systems, we must purposively **zoom aside from just one specific agent or cause that may determine an issue, and identify the other multiple agents and causes that may simultaneously drive the same issue.** It might be simpler to blame just one reason, person or organization for an issue, but complex issues just call for a much deeper investigation of its multiple causes. We cannot comprehend the issues facing food and agriculture, nor elaborate collective strategies to address these issues, without striving to understand the multiplicity of factors that simultaneously shape the issue at hand.

issues to address a complex problem that they are facing, this paper focuses on *collective processes of mapping systems and envisioning systems change*. Firstly, because complexity theory (Cilliers *et al.,* 2002; Waddock *et al.,* 2015; Hubeau *et al.,* 2017), underlines that knowledge co-creation and visualization are necessary to understand a complex problem through its multiple facets. Secondly, because systems thinking focuses on understanding both the dynamics between elements of the system as it does on understanding the functioning of the elements themselves (Levy *et al*., 2018). Knowledge co-creation refers to complementing the experiences, viewpoints, and information available to multiple stakeholders influenced by (or influencing) the problem at hand (Pohl *et al.,* 2010). Knowledge co-visualization involves using tangible interfaces – for example, diagrams, tables, puzzles or models – to envisage how different information and viewpoints might complement each other or clash with each other (Jean *et al.,* 2018). In the context of collectively understanding complex problems, knowledge co-creation and co-visualization systems have been commonly referred to as systems mapping (Sedlacko *et al.,* 2014).

As a way of knowledge co-creation and co-visualization among multiple actors in a system, systems mapping facilitates collectively understanding complex problems and envisioning changes that will address them over time. Systems mapping consists of creating visual, simplified depictions of a system of issues, such as the relationships and feedback loops, actors, and trends. Collective processes of systems mapping, that is, the action of collectively drawing a systems map integrating the knowledge and perspectives of diverse actors, is commonly referred to as group model building (Vennix *et al.,* 1992; Vennix, 1995; Andersen *et al.,* 2007; Rouwette *et al.,* 2002). Hence, while systems mapping could a priori be done individually by just one actor, group model building represents a group-based way of conveying perspectives from multiple participants' perspectives to generate a simplified understanding of a system. On the basis of how participants are recruited and facilitated (see, for example Király *et al.,* 2016, Wilkinson *et al.,* 2021, Barbrook-Johnson and Penn, 2021 and 2022), group model building conveys the multiple participants' views and values in relation to the complex problem that they seek to collectively address (Videira *et al*., 2009, Videira *et al*., 2012). Hence, with effective facilitation, group model building provides a collective understanding of a complex problem by the involved participants, including a clear understanding on what they may agree to disagree. This collective understanding, in turn, helps decision-makers to develop and choose pathways that address this complex problem over time.

While this group model building literature (Vennix *et al.* 1992; Vennix 1996) provides insights on why and how to collectively engage diverse actors in systems to understand a complex problem (Videira *et al*., 2009, Videira *et al*., 2012), this paper departs from (and hopefully contribute to) it in two directions. First, we see systems mapping not only as a process of collectively understanding a complex problem but also as a process of collectively realizing how a system of issues and a system of actors reflect two sides of the same coin. This process gives participants a concrete understanding of how they, individually and collectively, relate to the problem. Second, we see systems mapping not only as a process of collectively understanding a complex problem but also as a process of collectively envisioning how to address it. In our view and experience, expanding this group dynamic from a straightforward collective understanding of a system to a collective envisioning of a systems change provides participants with more opportunities to develop their own competencies and appropriate the feeling of empowerment concerning their role within the system. Instead of just providing their knowledge and delegating the envisioning of systems change to analysts and decision-makers, group participants have the chance to reflect and discuss how to intervene in a system collectively and how to do so collaboratively by pooling resources and sharing resources and tasks. Hence, in the next section, we discuss how our specific approach to systems mapping contributes to applications of systems thinking in these two directions.

4. SYSTEMS MAPPING: VISUALIZING COMPLEX PROBLEMS AND SYSTEMS AT THE SAME TIME

We hereby propose a systems mapping process that, in our view and experience (Table 2), helps addressing the discussed limitations of systems thinking applications in current agri-food studies and of group model building approaches to collectively envision changes in a system. We discuss the principles and stages of this proposed process as follows.

4.1. Systems of issues and systems of actors as two sides of the same coin

To apply systems mapping as a way to collectively understand *how problems (as a system of issues) and social systems (as a system of actors) relate to each other*, and to collectively envision *how to address these problems through systemic change*, we propose a process that combines the use of two maps. These are causal loop diagrams and value network maps (Figure 1). These two maps are complementary and can be used iteratively. Causal loop diagrams help to describe and envision how to address complex problems collectively; value network maps help to collectively describe and alter complex social systems in ways that address these problems. Their use reflects, in this practice, the assumption that systems of issues and systems of actors are two sides of the same coin (Senge *et al.,* 2007; Waddock *et al.,* 2015).

This systems mapping process entails that participants collectively and iteratively draw and visualize these two maps to tackle four sets of questions. Specifically, with causal loop diagrams, participants can tackle the following two sets of questions:

1. What are the specific issues that constitute our problem? And how are these specific issues causally related to each other? (*To collectively understand and visualise a complex problem*)
2. What are the specific issues where we, as participants, could intervene? Which activities or interventions could we envision to address our problem? (*To collectively envision how to address the complex problem*)

Iteratively, with value network maps, participants tackle other two sets of questions:

1. Who are the specific actors that are somehow related to our problem, either because they are affected by it, or because they can influence it? How are these actors connected (or perhaps disconnected) to each other in a social system? And which resources do they share (or perhaps do *not* share) through their relationships? (*To collectively understand and visualize the social systems entrenched in the complex problem*)
2. How can we, as participants, contribute to reconfiguring the social system in ways that address our problem? Specifically, how can we build new relationships (or break old relationships) among actors, and with which resources, to do so? *(To collectively envision how to trigger or support systemic change in ways that address the complex problem*).

The iteration between these two maps, and between the sensemaking and the envisioning phases, allows the participants to go back and forth between making sense of the problem; suggesting how to address it; describing the networks of actors involved in the problem; and considering how to reconfigure the network to address it. Of course, participants may not agree on the answers of these questions, hence on the way that systems maps

Table 2. Empirical evidence in testing and adapting systems mapping approaches.

Title (and year)	Participants	Session length	Country (institutions)
Global Center for Food Systems Innovation (2013-2018)	80 policy-makers, development agency officers and researchers	4 hours (causal loop diagrams + value network maps)	Malawi, Southern and Eastern Africa, United States (USAID)
Putting Big Ideas into Practice: Developing Soft Skills for Large Systems Change (2015)	60 junior scholars across life and social sciences	30 hours across five days (causal loop diagrams + value network maps)	Poland, The Netherlands (Pro-Akademia, European Regional Funds)
Nudge Global Impact Challenge on Global Peace, SDGs and Circular Economy (2016-2021)	90 social entrepreneurs, managers, Master students and activists below 30 years old	2-3 hours (causal loop diagrams + value network maps)	The Netherlands (Nudge B-Corporation and Wageningen University)
Entrepreneurship and Innovation in Emerging Economies (2017-2020)	75 Master students in 3 years	30 hours across 10 workshops (causal loop diagrams + value network maps)	Global, The Netherlands (Wageningen University and EU's Comenius program)
Organizing business models for SMAllholder REsilience (OSMARE) project (2017-2020)	120 dairy farmers, seed growers, value chain actors, policy-makers, and researchers.	5 workshops ranging between 2-4 hours (causal loop diagrams + value network maps)	Malawi, Zimbabwe (NWO/WOTRO and CGIAR/CCAFS)
Beyond Fair Trade: Transnational entrepreneurship and partnerships with African Diaspora (2019)	15 researchers, entrepreneurs in the cacao sector, civil society organizations and Master students.	2 hours (causal loop diagrams + value network maps)	Ghana, The Netherlands (Science Shop, Wageningen University)
Food Design and Innovation (2018-2022)	80 Master students	4 hours (causal loop diagrams + value network maps)	Global, Italy (Polytechnic School of Design)
Changing Socio-Ecological Systems at the Theory-Practice Nexus (2021)	75 management researchers, junior scholars, and management practitioners	3 hours of preparation (causal loop diagrams + value network maps) + 1,5 hours of pitch and reflection	Academy of Management (AoM), Organization & Natural Environment (ONE) and Social Issues in Management (SIM) Divisions
Capacity Development for Agricultural Innovation Systems (CDAIS) (2019)	70 life scientists, research managers, facilitators, consultants, value chain actors and entrepreneurs in the fish sector	16 hours across 2 workshops (causal loop diagrams + value network maps)	Ethiopia with the Feed the Future (FtF) Livestock Innovation Lab, Nigeria with the FtF Fish Innovation Lab (USAID)
Entrepreneurship for systems change (2021-) and Organizational behavior and systems change (2021-)	300 Master students (Program Grandes Écoles, PGE + Master of Science) in 1 year	18 hours across 6 workshops (causal loop diagrams + value network maps)	Global, France (Montpellier Business School)
Comprendre et confronter problèmes socio-écologiques complexes (2022-)	25 company managers, entrepreneurs and Master students	6 hours (causal loop diagrams + value network maps)	Global, France (Montpellier Business School in collaboration with Veolia France)
ENcouraging Farmers towards sustainable agri-food SYStems (ENFASYS) project (2022-2026)	25 applied researchers, research managers, consultants, civil society organizations and junior scholars	1,5 hours (causal loop diagrams + value network maps)	Europe, Belgium (European Commission's Horizon 2020 and Farm to Fork Strategy)

should be drawn. They may for example perceive different relationships between issues and actors, give different value to the addressing of different issues, or have different opinions on pathways to address these issues. In any case, mapping their viewpoints helps them to build a clear understanding of their visions, including their complementarities and their possible antagonisms. Hence, as follows, we briefly describe what causal loop diagrams and value network maps are, and how they can be used meaningfully as part of this systems mapping process.

4.2. Mapping systems of issues through causal loop diagrams

Causal loop diagrams graphical representations of assumed interactions between causes and effects of the multiple elements of a complex problem (Sterman 2000). The set of elements of the complex problems are specific issues which, interrelated to each other, form a system of issues. These causal relationships between elements are simply represented on a map with arrows accompanied by a plus sign (+) or a minus sign (-). The plus sign (+) indicates a positive or direct relationship between two elements, i.e., the 'more of this → the more of that'.

Figure 1. Leaflet of systems mapping workshop at Academy of Management 2021.

For example, if participants note that increasing temperatures cause a rise in water demand, they will connect 'temperatures' and 'water demand' with an arrow accompanied by a plus sign (+). Conversely, the minus sign (-) indicates a negative or inverse relationship between two elements, i.e., the 'more of this → the less of that'. For example, an arrow accompanied by a minus sign (-) could indicate the relationship between 'pollution' and 'quality of life'.

Causal loop diagrams serve two main functions in systems mapping. First, by causally connecting multiple pieces of the problem to each other, causal loop diagrams provide an easy way to *identify feedback loops*. Feedback loops are important to understand the patterns that constitute problems. They can be of three types. First, self-balancing feedback loops reinstate stability in a system: for example, heat → (+) → humidity → (-) → rain → (-) → heat means that, in ecological systems, the patterns linking heat, humidity and rain usually help maintaining a state of equilibrium. Second, vicious circles may cause instability in a system: for example, greenhouse gas emissions → (+) → temperatures → (+) → use of air conditioning → (+) → greenhouse gas emissions constitute a pattern that provokes and accelerates disequilibrium in a system (here, please mind that the plus sign does not indicate anything desirable, but simply a direct relationship between two variables!). These vicious circles are often referred to also as 'lock-ins' in a system, because their non-linearity make it difficult to disentangle and address them (Vanloqueren and Baret, 2008; De Herde *et al.,* 2022). Third, virtuous circles may promulgate desirable changes in a system: for example, investment in renewable energies → (+) → renewable energy stocks → (+) → energy savings → (+) → investment in renewable energies. Independently from the desirability of these patterns, both vicious and virtuous circles represent reinforcing mechanisms (Sterman, 2018).

As a second key function, causal loop diagrams also allow participants to collectively identify the underlying factors that perpetuate the occurrence of vicious circles or impede the generation of virtuous circles. These are often called systemic constraints, barriers or bottlenecks that prevent lock-ins from being addressed. Typical examples of barriers emerging from participants in causal loop diagrams involve institutional issues (such as heavy bureaucracy, incoherent public policies, inadequate market regulation, or corruption), cultural issues (such as conservativism or top-down 'command and control' attitudes in organizations), or ecological issues (such as natural disaster risks preventing social agents to invest on a territory). Importantly, these barriers should not be seen as 'root causes' (see Table 1, non-linearity property of systems) because they themselves may be influenced by other factors in the system. Identifying these barriers, as well as the specific lock-ins that they are perpetuating, are important as possible leverage points, that is, 'places to intervene in a system' (Meadows, 1999: 1). This means that places within a complex system where a small shift of one element within the system can produce significant changes within the overall system (Stroh 2015). Participants can collectively assess if and how to remove these barriers to trigger, support or accelerate systemic change processes (e.g., Abson *et al.,* 2017; Dorninger *et al.,* 2020).

Therefore, relative to more sophisticated systems dynamics, causal loop diagrams have the advantage of being '*rich enough* to capture underlying mechanisms, *precise enough* to spot leverage, but also *simple enough* so that most important dynamics clearly stand out' (Vermaak, 2011: 4). While systems dynamics might be challenging when involving participants outside academic contexts (e.g., farmers, policy-makers, managers, or other civil society representatives) because of its use of stocks, flows, internal feedback loops, and time delays (Lie and Rich, 2016), causal loop diagrams allow participants to visualize, discuss and compare their own understandings of the problem rather than just talking about it (Nicolini *et al.,* 2011). This visualization helps participants to express how they understand the complex problem beyond words, and recognize that they may have talked to each other before but not understood each other's views the with the same level of precision and depth.

However, there are two limitations of causal loop diagrams to be aware of: their inherent reductionism and subjectivism. First, while causal loop diagrams take all seven principles of systems (Table 1) into account, all representations of systems (or systems maps) necessarily reduce the complexity of problems relative to the social reality that it seeks to reflect (Seelos and Mair 2018). To address this limitation, the process of developing causal loop diagrams requires a deep understanding of participatory processes such as the involvement of stakeholders holding different positions and viewpoints on the problem and the creation of space and time for their voices to listened, understood, and acted upon (Király *et al.*, 2016; Barbrook-Johnson and Penn, 2021 and 2022). Hence, depending on the heterogeneous values and frames carried and represented by these stakeholders, the causal loop diagrams will evolve on where the mapping of the issues begins (which usually starts from the question: *what is the aspect of the problem that bothers or hurts you the most?*); for example, for some stakeholders, the starting issue might be 'farmers' household livelihoods' or 'rural communities' exposure to drought'; for other, it might be 'industry profitability' or, for others again, it might be 'corruption' or 'limited policy implementation'. In these processes, of course, participants may strategically emphasize some issues more than others, or manipulate the relationships between issues, to steer the debate towards where their vested interests lay. The same holds for how much to zoom in or zoom out on the problem or, in other words, on how broad or specific the causal loop diagram should become. During a systems mapping workshop with multiple stakeholders in the Malawian dairy industry, one representative of a dairy farmers' association sighed loudly and stated: *"We could continue mapping the problems even until tomorrow!"* To address this limitation, the use of causal loop diagrams requires systems mapping facilitation with a deep understanding of participatory processes (Király *et al.*, 2016; Barbrook-Johnson and Penn, 2021). In particular, participants naturally tend to focus on what they value and already know, and to be reluctant to map what they value less or are less familiar with. From our experience, finding this balance between zooming in/zooming out on the basis of participants' values and viewpoints is more challenging, but also more generative, than forcing participants to set systems boundaries (as we already discussed in section 2).

A second limitation of causal loop diagrams as systems mapping tools involve their subjectivism. All representations of systems, including causal loop diagrams, represent social constructions: depending on the role, status, and viewpoint of the participants in the system they seek to understand, their view on the problems at hand will be different, as well as the envisioned future ways to address them (Seelos and Mair, 2018). To address these limitations, it is important for facilitators of systems mapping sessions using causal loop diagrams to make participants aware of them. The key is that participants focus on their own process of learning – in terms of knowledge integration and/or juxtaposition as their different viewpoints get visualized on the causal loop diagrams. For example, in our meeting with the Malawian dairy industry, participants mentioned that they started to see how someone's problem (e.g., access to medicine of a dairy farmer) ultimately became a problem for another in their system (e.g., the dairy processer lacking milk supply and government extension workers being warned after problems have emerged). In other words, it is the visualization of mental representations of the complex problems that triggers further thinking. In this Malawian case, for example, we started out with mapping challenges experienced by smallholder farmers (Lubberink and Dentoni, 2019), and then complemented with experiences of the other industry stakeholders (the milk company Lilongwe Dairy, ministries, farmers associations and research institutes). The causal loop diagram showed how the issues highlighted by the different stakeholders were interrelated, and not solely 'owned' by any of them. The leader of a farmers' association shared that *"it was helpful to open your mind and thinking process to see the bigger picture and systematically narrow down the problems"*, and *"it actually is a great method I can replicate in future projects and bring back to my organization and share with others. I also think that it is especially valid in the area of sustainability since everything is so interconnected […], so being able to identify those connections is vital"*. Hence, causal loop diagrams allowed farmers and stakeholders from different villages and viewpoints to share, compare, integrate and sometimes juxtapose their views on their challenges concerning the bigger problem they are collectively seeking to tackle. In doing so, they need to remain aware that, rather than an objective representation of social reality, they are 'just' generating a useful and functional collective framing of how they see the problems they seek to address.

4.3. Mapping systems of actors through value network maps

We consider value network maps not as a helpful, but as a necessary complement to causal loop diagrams. As systems of issues and systems of actors are two sides of the same coin (see section 4.1). the process of systems mapping that we propose here has the key advantage of linking representations of interconnected issues, represented by causal loop diagrams, with representations of interconnected actors composing a system, which represent value network maps. By definition, value networks encompass webs of relationships between several actors *together with* the resources transferred, exchanged, shared or co-created among them (Allee, 2008); these resources have a subjective value for the related actors, hence the value of those resources may determine the establishment, evolution or ending of a relationship (Allee, 2008). Valuable resources are not only tangible, such as natural resources, commodities or finance, as commonly depicted in traditional supply chain management, but also intangible such as information, knowledge, training, legitimacy, reputation, rules/hierarchy, or rule enforcement.

Hence, by identifying how actors are connected or disconnected in a system, and resources flow or do not flow among them, value network maps provide a graphical representation of the same problems as causal loop diagrams, albeit in terms of the actors that are involved in a problem or affected by its symptoms (Dentoni and Krussmann, 2015; Barzola *et al.,* 2019), thereby supporting actors to intervene in the system. By drawing and interpreting value network maps collectively, participants are called to reflect upon which actors hold responsibility for the problems at hand and how the re-configuring of their relationships and associated resources may generate the systems change necessary to address these problems (Dentoni *et al.*, 2020; Dentoni *et al.*, 2021). Hence, in value network mapping, participants describe and visualize the involved actors based on the issues identified (Figures 1 and 2). Like in causal loop diagrams, they can zoom into specific issues and actors or zoom out to understand more macro-level patterns depending on how they visually integrate or juxtapose their viewpoints. Participants may agree or not with each other on how they perceive actors in value networks to be connected or disconnected, the resources they share, and the implications of their responsibilities on the problem. Hence facilitation according to participatory principles is again recommended (Király *et al.*, 2016; Barbrook-Johnson and Penn, 2021)

However, to see complex problems reflected in value network maps, participants must first draw them and then interpret them. For example, by looking at the map that they draw, participants should ask themselves: *which actors within the system are tightly interconnected with each other, and which resources do they share?* By answering these questions, participants may recognize *power structures* (Battilana and Casciaro, 2021) that may constitute barriers to address the current problems (Dentoni *et al.*, 2020). Depending on the case, these power structures may revolve around information sharing (Vurro *et al.*, 2009), as dominant actors in global commodity supply chains tend to have at the expense of farmers and farmer organizations (Quarmine *et al.,* 2012); or around rules and rules enforcement, as many small producers of Geographical Indications in Europe (Meloni *et al.,* 2019). A second point participants should reflect upon revolves around the question: *which actors within the system are receiving more resources than what they give, and why?* This may reveal *patterns of dependency* within the system. For example, some actors may appear to need to rely upon most of the resources, while providing to others only one or few; for example, consumers may appear as 'givers' of funding in exchange for all other resources; while farmers may appear of 'givers' of natural capital (and/or commodities, as fruits of their land), while 'receivers' of all other resources (Barzola *et al.,* 2019). A final question to address is: *which actors are disconnected from others, and why?* Reflecting on the *modularity* of the system is crucial, in particular, to understand why resources in a system are unequally distributed, and how a reconfiguration of the system may favor more equal distributions (Dentoni *et al.,* 2020). While the assessment of power structures, dependency patterns and resource distributions from value network maps is inherently subjective, participants should ground their interpretations on the visual observation of actor centrality in the networks and on the directionality of the resource flows.

After reflecting upon power, dependence, and modularity issues in the system, participants would benefit from positioning themselves within the value network map they drew. Starting from the premise that – on the basis of the self-organizing principle of systems (Table 1) – all of us are part of a system and constantly molding it with our actions and interactions (Dentoni *et al.,* 2021), participants should add a supplementary question to complete their value network map before envisioning what should be changed in the future: *where are we, as individuals and organizations, in the map?* Picturing ourselves in the value network map incites us to take responsibility (Jones Christensen *et al.,* 2014) for the current status of the system, as we are also giving and receiving valuable resources with others, hence potentially constitute power structures, perpetuate dependency issues, and reinforce modularity. The habit of thinking of ourselves as part of the system, and constantly shaping it, also triggers action competencies (Olsson *et al.,* 2020), that is, the awareness and drive of being personally involved in processes of social-ecological systems change, through interconnected mechanisms of intrapersonal, interpersonal and organizational change.

The experience built during the USAID Feed the Future program supporting the Ethiopian livestock innovation lab (IFPRI, 2019) provides an example of how this reflection took place (Figure 3). The interpretation of the value network maps, associated with the causal loop diagrams, led the participants (local and international animal scientists, veterinarians, local policymakers, and farmer association representatives) to identify the following barriers to systems change: (1) a tightly interrelated network of policy-makers at the national level that do not prioritize investments in livestock/dairy value chains in agricultural and food policies; (2) modularity in value chains between farmers, farmers' associations, agricultural input providers and agricultural investors, which hampers the widespread adoption of new agricultural technologies; and (3) the financial dependency of academic institutions, seeking to support the livestock policy, from hierarchy and funding from the national government. These interpretations would not have been reached if the focus of the systems mapping without

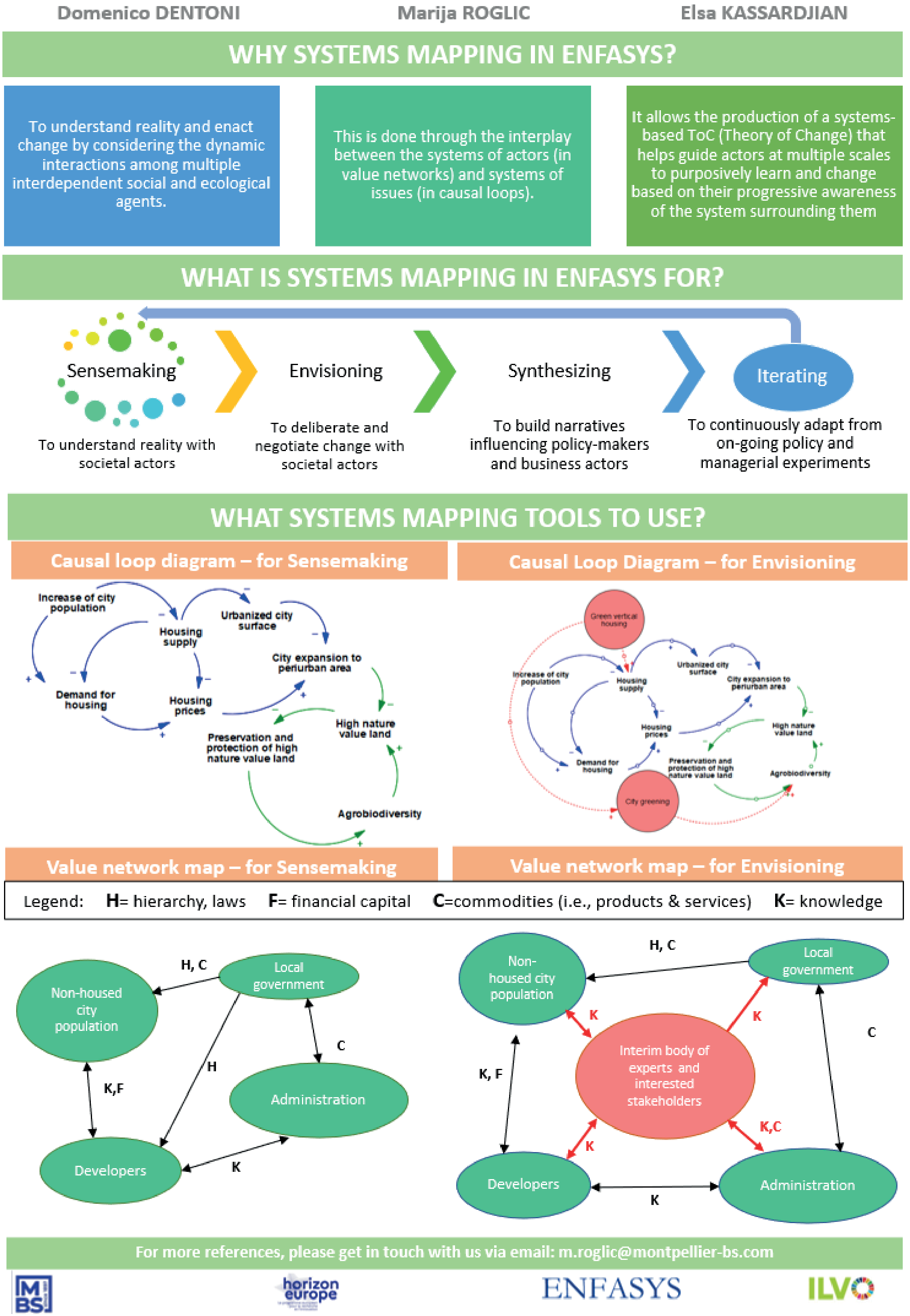


Figure 2. Leaflet of systems mapping approach for ENFASYS project kick-off meeting.

(a) Life scientists, research managers and consultants envision interventions on causal loop diagrams and value network maps during systems mapping workshop in Addis Abeba (2019), as part of the FtF's Livestock Innovation Lab activities funded by USAID. Photo credits: Domenico Dentoni (2019).

(b) Smallholder farmer, ministry of agriculture, dairy processor and health scientist map the complex problems in the dairy industry in Malawi. This was part of the NWO-WOTRO funded OSMARE project. Photo credits: Rob Lubberink (2019).

Figure 3. Participants' groupwork on causal loop diagrams and value network maps.

associating the value network maps to the causal loop diagrams.

This collective process of interpreting value network maps to understand how power structures, patterns of dependence, and modularity in the system reflect and perpetuate complex problems is essential for the next step: envisioning systemic change. As they prepare to move from interpreting of the current system to envisioning a reconfigured system, it is important for participants to consider how to leverage the resources and relationships already in place. This requires a remarkable act of balancing: on the one hand, addressing complex problems may require a comprehensive reconfiguration of the system (which is often referred to as systems transformation, in terms of depth and breadth of systems change; Dentoni *et al.,* 2017); on the other hand, to make the change pragmatically feasible and sensitive to the local context, participants need to also build upon the resources and relationships already in place. This necessary act of balancing is entrepreneurial (Cucchi *et al.,* 2022) in two ways. First, it provides participants with a lens to see complex issues as opportunities to make valuable structural changes to the system they are embedded (Dorado and Ventresca, 2013). Second, this logic of addressing problems by leveraging the relationships and the resources already at hand is inherently effectual (Sarasvathy, 2001). For example, in the Ethiopian livestock innovation lab (IFPRI, 2019), the value network maps helped participants to start thinking about how to change capacity development practices in the livestock industry. This helped them to envision change from short-term trainings and physical infrastructure investments to curriculum development for students in Technical and Vocational Education and Training institutions, in ways that built competencies and incentives to collaborate and create local impact (IFPRI, 2019).

4.4. Envisioning systems change to address complex problems

As participants become aware of their reciprocal views of the system and roles in it, and of the problems entrenched in them, they can envision and map action intervention points that collectively address their problems. This collective envisioning process revolves around two iterative stages: First, *envisioning interventions that address the issues using causal loop diagrams*; and, second, *envisioning interventions that alter relationships and distribution of resources among actors in the system using value network maps*. Participants reflect on how to formulate and prioritize interventions that will address prioritized issues by identifying leverage points. Of course, they may also disagree (or agree to disagree) on where and how to intervene; hence facilitation needs to orchestrate this envisioning stage in awareness of participatory principles (Wilkinson *et al.,* 2021). Iteratively, participants deliberate which configurations among actors in the system, connected in new ways or by sharing new resources, will enact the envisioned interventions. Finally, to complete the process, they describe their systems-based theory of change (Wilkinson *et al.,* 2021), that is, how these interventions, enacted through envisioned reconfigurations of their value networks, tackle the complex problems that they seek to address.

The following example from a peri-urban area in southern France (Chaigneau, 2021) illustrates how participants could move from collectively making sense of their system to envisioning its change (Figure 2). Suppose an urban center, facing increased demand for housing, changes its spatial planning to meet the needs of the incoming population and the construction industry, hence spreading the construction zones around the city. This will reduce the peri-urban agricultural land, its agrobiodiversity, and, in the long term, its local agri-food value chain development and resilience to heat waves (Figure 2, upper left quadrant). While citizens exert pressure on the construction industry, the latter sees this as a market opportunity that requires them to collaborate with the municipal administration in charge of spatial planning (Jaroniak, 2022). The municipality is responsible for conveying citizens' demands, setting regulatory constraints and opportunities, and promoting economic opportunities. The central government has the authority and resources to meet the needs of the city population needing housing and regulate the construction industry (Figure 2, bottom left quadrant). To confront these entangled issues of demand for housing, urbanization, agrobiodiversity loss, and climate reduced resilience, participants could envision spatial reconfigurations in their municipal area. This spatial plan would densify the existing residential construction zones by opting for vertical constructions, for instance, residential buildings instead of detached houses, while investing in public infrastructures that support the newly developed areas (Figure 2, upper right quadrant). To enact these spatial planning changes in ways that effectively foster resilience, the municipality will need to align the knowledge from the growing city population councils and representatives of the construction industry, with the regulatory and political constraints posed by the central government. For example, the creation of an interim body of experts and interested stakeholders may be essential to catalyze the existing resources to meet the heterogeneous stakeholder demands and latent needs (Figure 2, bottom right quadrant).

However, the process of moving from systems mapping to envisioning systems change is highly context-specific, hence it may unfold in a vast array of ways. For instance, reconfiguring value networks may require not only envisioning new actions or partnerships but also building coherence between the already existing ones to better complement their efforts in addressing their commonly addressed problems. For example, participants of the workshop in Ethiopia recognized that the day-to-day challenges they face often are characterized by perpetuating vicious circles. The inability of university researchers to organize and advocate for their own needs in an appropriate manner and at the appropriate level. A proposed solution was to strengthen the capacity of the Ethiopian Agricultural Research Council on the livestock research-policy-practice interface (IFPRI, 2019). The council could be capacitated to provide an overview of research demands and research findings in the livestock sector (so as to align research priorities). It also could support livestock researchers in the communication of their research findings for a different audience that can enable or trigger change (e.g., policy influence). Another suggested solution was building researchers' capacity to find their voice and agency, to express their needs appropriately, and to connect them with actors who can play as bridging institutions to create a more comprehensive network (Figures 4 and 5).

Reconfiguring value networks may also imply bringing into the system new actors that before did not have a role and that yet could potentially curb the challenge at hand and support the envisioned intervention. For instance, during the professional development workshop at the Academy of Management conference in 2021 (Figure 1), participants explored a case around food safety

(a) Senior animal scientist from Hawassa University pitches the outcome of his group's causal loop diagrams and value network maps during systems mapping workshop in Addis Abeba (2019), as part of the FtF's Livestock Innovation Lab activities funded by USAID. Photo credits: Domenico Dentoni (2019).

(b) One of the participants in a multi-stakeholder workshop on the dairy industry in Malawi shares the insights retrieved by value network mapping during the systems mapping workshop in Lilongwe, Malawi. This was part of the NWO-WOTRO funded OSMARE project. Photo credits: Rob Lubberink (2019).

Figure 4. Participants' pitches of causal loop diagrams and value network maps.

(a) Seeking to understand lock-ins to systems change in the Ethiopian livestock sector, this group of professionals found a disconnect between skilled lab technicians, vocational education institutes and universities as a leverage point. Hence, they envisioned the constitution of living labs, with the support of international universities and research centers, to address this gap. Photo credits: Domenico Dentoni (2019).

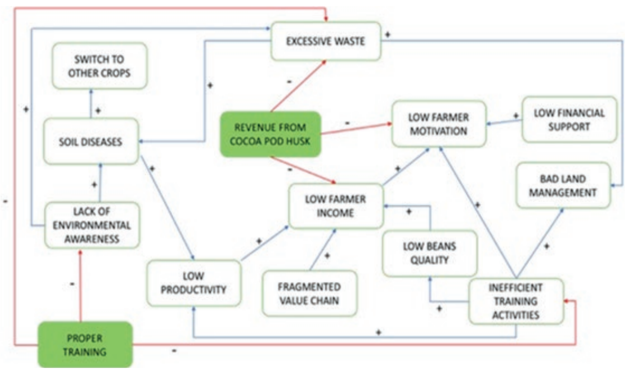
(b) Seeking to understand lock-ins to systems change in the Ethiopian livestock sector, this other group of professionals described how university structures do not provide career incentives for making societal impact. Hence, they envisioned the creation of an Ethiopian Research Council with tasks of coordination and constitution of a 'challenge fund' to change these structures. Photo credits: Domenico Dentoni (2019).

Figure 5. Output of causal loop diagrams and value network maps in workshop.

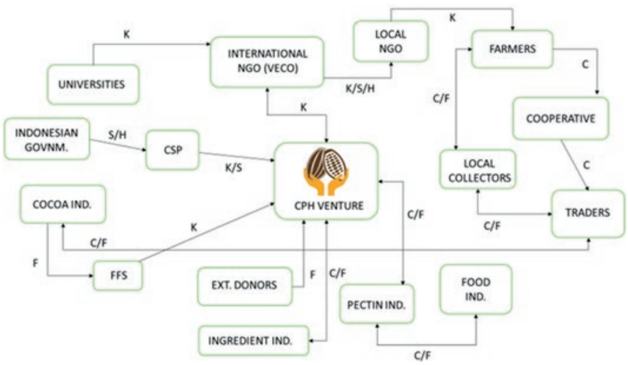
issues in meat markets in Nigeria. After identifying the vicious circles that reproduce food-borne illnesses, participants concluded that informal meat markets' food safety could be improved by enhancing the outreach of training and technology, and accessibility to disinfectant to street vendors. Participants envisioned ministries, businesses, universities, media, and civic associations should complement each other in improving knowledge on healthy handling of vendors and strengthening consumer awareness. Hence, the team envisioned pathways to overcome the current modularity between the health and food subsystems, which are segmented in silos between private and public actors specialized either in food or health; but rarely at their vital nexus. Furthermore, participants envisioned leveraging the role of market associations as a helpful bridge between informal vendors and government agencies, while consumer associations could act as triggers for initiating this change process.

Envisioning change by reconfiguring value networks may also take place in classroom settings for pure competence development purposes. For instance, Master of Science students explored a case around the waste of cocoa pod husks (Figure 6). Based on the local knowledge of one member of the team, triangulated with secondary data collection, students identified the key constraints in the form of causes and consequences of dumping the cocoa pod husks (a waste by-product obtained after the removal of the cocoa beans from the fruit) by smallholder cocoa producers in the Indonesian island of Sulawesi. The group envisioned the creation of a new business venture that, in collaboration with local stakeholders, would support smallholder producers to process the cocoa by-product and convert it into a valuable pectin fiber. Ultimately the pectin material extracted will be sold nationally and internationally. By leveraging the role of unconventional partners, such as local NGOs participants envisioned a pathway that overcomes current power and information asymmetries in the system. In the new set up, the network of local and international NGOs would support smallholder farmers with appropriate training in high-quality pectin extraction processing, activities supervised by local universities specialized in food technology. The business venture value proposition would be therefore intrinsically linked to the farmer's activities through a partnership which reconfigures the network of actors and their associated resources (i.e intellectual property, equipment, expert knowledge) in ways tackle both environmental problems and secure an alternative source of income for smallholder farmers (Figure 6). As a note of caution, this envisioning exercise in the classroom is often detached and sometimes distant from the reality of what is mapped (Seelos and Mair 2018). Hence, trainers and facilitators need to be careful to encourage systems thinking without encouraging 'magical thinking,' that is, the development of unrealistic ideas that are utterly detached from social reality that is mapped (Burton and Muñoz, 2023). To prevent so, they should encourage participants to iterate their idea development with rapid cycles of feedback and experimentation with a variety of locally involved actors.

To sum up, envisioning systems change provides systems mapping participants with concrete strategies and narratives that influence policymakers, business actors and civil society. By continuously adapting the systems maps on the basis of ongoing policy and



(a) This group of Master students at Wageningen University, including one Indonesian student with local networks in this domain, focused on socio-ecological issues in and around the Indonesian cocoa sector. They found that low farmer income and little environmental awareness were critical lock-ins in addressing these issues of rural poverty and environmental degradation. Photo credits: Carlo Cucchi (2017).



(b) Having understood these issues, this group of Master students at Wageningen University, envisioned the creation of a self-sustaining venture to use farmers' cocoa pod husks (otherwise becoming waste) as a source of pectin extraction for the food ingredient industry, with support from the Indonesian government, external donors and international NGOs. Photo credits: Carlo Cucchi (2017).

Figure 6. Example of causal loop diagram (a) and value network map (b) in Master course.

managerial experiments, participants can enact systems change over time. Such an iteration between systems mapping and experimentation on the ground is essential to understand how the participants' understandings and expectations translate in tangible effects when applied in reality. In turn, the experiments implemented on the ground would help participants to adapt and update their systems maps to come up with more grounded ways of envisioning systems change. Hence, this iteration between systems mapping and on-the-ground experimentation will be essential to refine and update (and, if needed, even wholly re-envisioning) the systems-based theory of change that helps guide actors at multiple scales to purposively learn and change based on their progressive awareness of the system surrounding them.

5. TAKING SYSTEMS THINKING SERIOUSLY: IMPLICATIONS FOR AGRI-FOOD SYSTEMS CHANGE

By grounding systems mapping processes, such as those discussed in sections 3 and 4, into a sufficient understanding of systems (articulated in section 2), we argue that societal actors can more effectively trigger and support systems change in directions that address complex socio-ecological problems in food and agriculture. After participating in these systems mapping stages, both public, private and civil society actors can engage in five practices that coherently direct their joint efforts towards envisioning systems change. These are discussed as follows.

5.1. Targeting multiple goals

First of all, we argue that systems mapping processes that combine causal loop diagrams and value network maps support societal actors in collectively envisioning how to address socio-ecological problems while, at the same time, pursuing also their strategic and personal goals. Traditionally, food and agriculture studies have framed the multiple goals of societal actors either as in competition with each other (Grafton *et al.*, 2018) or easy to align under superficial definitions of the triple-bottom line (Detre and Gunderson, 2011). Yet, in food and agriculture studies, we know little how about collaborative practices meant to purposively find a balance between these multiple goals (van Paassen *et al.*, 2022). Our view of systems mapping suggest that societal actors can purposively identify and experiment actions that, through envisioned chains of effects, seek to simultaneously achieve these goals. To target these multiple goals purposively, societal actors need awareness of the multiple cause-effect relationships that constitute the problems they seek to tackle; and the multiple actors that may coherently contribute in addressing these problems. For example, under certain conditions, circular economy solutions for the product of a large multi-national company may simultaneously address climate change, social justice, and the supply chain issues (Black, 2013). Or, conservation agriculture may support farmers and their local stakeholders to target multiple biophysical and socio-economic goals (Lalani *et al.*, 2021). At a planetary scale, systems mapping approaches can support identifying practices that simultaneously pursue goals of global food security and climate mitigation and adaptation goals (Vermeulen *et al.*, 2012; WEF, 2021). Hence, these systems mapping processes help societal actors to visualize and choose between multiple pathways towards agri-food systems change (Horton *et al.*, 2016; Dentoni *et al.,* 2017). Furthermore, targeting multiple goals provides avenues for a visually tangible discussion on how to achieve multiple and plausibly conflicting objectives, such as the pursuit of economic versus environmental benefits. Altogether, these systems mapping processes support changes in "the system by improving the relationships among its parts, not optimizing each part separately" (Stroh, 2015: 28).

5.2. Generating ripple effects

The second implication of the described systems mapping processes is that participants, when underpinned with sufficient understanding of systems, will become more purposive in how they generate ripple effects. As systems are interdependent, path-dependent, and self-organizing, our actions and interactions trigger, support or shape chains of causally connected events in our environment; of course, not only in desirable ways. For example, human-caused climate change "has dramatically altered the hydrologic cycle of the western United States, which in turn has influenced the economics of irrigation for farmers and has consequences in farm labour dynamics, hydroelectric energy supply and freshwater ecology" (Levy *et al*., 2018: 413). The described systems mapping processes make societal actors more aware of these ripple effects and how they can together enact systems change in desirable directions. In particular, the purposive generation of ripple effects via systems mapping can support the scaling of transformative actions (Kerton and Sinclair, 2010; Tobias *et al.,* 2013) also to novel contexts, provided that participants with deep understanding of those contexts are engaged in the mapping processes. For example, public agencies and local incubators could strategize how to support entrepreneurial behaviors and identities in rural post-conflict areas, such as Rwanda in the 2000s, in ways that reduces poverty and attenuates social tensions (Tobias *et al.,* 2013). In doing so, farmer field schools could play an important role to trigger ripple effects in food and agriculture through processes of learning (Duveskog *et al.,* 2011). Or, community-supported agriculture initiatives could involve municipalities to expand their food production and civic outreach in ways that, in turn, engage their neighbors in processes of food lifestyle change (Kerton and Sinclair, 2010). This purposive way of strategizing how to trigger or support ripple effects through systems mapping would be important for several ongoing institutional attempts of supporting agri-food systems transformation (EU Environment Agency, 2022; Environmental Initiative, 2022).

5.3. Mitigating unintended consequences

As a third implication, we argue that systems mapping supports anticipating and reducing the risk of negative consequences of their envisioned actions. From the extant literature, we know that actions meant to address socio-ecological problems in food and agriculture may often have unpredicted and undesirable side effects (Stroh, 2015), as often "today's problems come from yesterday's solutions" (Kofman and Senge, 1993: 5). For example, fertilizer subsidies – while meant to increase food productivity and reduce food insecurity – reduce farmers' incentives for crop diversification, hence reducing their soil fertility over time (Theriault and Smale, 2021). Or, climate change mitigation policies related to land-use change emissions can have negative side effects on local water demands (Giuliani *et al.,* 2022). What we know less is how we can purposively and systematically consider them and mitigate their undesirable effects (Martí, 2018; Dentoni *et al.,* 2021), especially in the domain of food and agriculture. Systems mapping processes that take sufficiently into account these nonlinear, complex and multi-level dynamics (such as the one hereby described in section 4) addresses this limitation. By collectively discussing the possible side effects, participants of systems mapping workshops can identify the possible unintended consequences and the actions to undertake in case that these occur. This collective discussion prepares societal actors to reflect upon plausible unintended effects of their actions and be accountable to each other in mitigating these effects, when negative. For example, the European Commission and its stakeholders could use systems mapping to make sense and respond to negative claims on their Farm to Fork strategy by some of their detractors (European Scientist, 2021; Farm Europe, 2021). These include, for example, the claimed negative side effects of investing on organic and regenerative agriculture policies and regulating biotechnology on farms' food production and revenues, ultimately with consequences on European food security. Considering these claims on negative consequences of the Farm to Fork strategies may help European policy-makers and their stakeholders to develop actions that mitigate these risks, and narratives that counter these claims.

5.4. Tackling systemic constraints

As a fourth implication, systems mapping approaches (when grounded with sufficiently deep understanding of systems) help societal actors to identify and address systemic constraints that prevent lock-ins to be addressed (see details in section 4.2). Systemic constraints risk to turn interventions in a system into 'fixes that backfire' (see Stroh, 2015: 54). These fixes are relatively quick, short-term, apparently clever actions (sometimes not-so-cleverly labeled as 'low-hanging fruit' interventions) that do not produce desirable long-term impacts because their causal mechanisms have not been addressed in sufficient depth. For example, direct subsidies of local agriculture (in terms of farm size or production) may have short-term desirable effects on food security and rural development, yet may not tackle systemic constraints of agricultural adaptation to climate change, for example in terms of water and energy efficiency (WRI, 2021). Through systems mapping, instead, societal actors can strategize how to combine 'quick fixes' with more fundamental work that addresses systemic constraints. For example, the Consultative Group for International Agricultural Research (CGIAR) noted that farmers' adoption of climate mitigation and adaptation practice also grounded into a limited organizational capacity of researchers to work across disciplinary and sectoral silos to support agri-food systems transformation (ISDC, 2021). On the basis of this realization, the organization reformed its internal structure and its relationships with public agencies and private foundations to foster inter-and trans-disciplinary research and innovation which, ultimately, could create more favorable systemic conditions for farmers' adoption. Hence, in engaging in these deeper change processes, we recommend societal actors like the CGIAR to make use of sufficiently deep systems mapping approaches.

5.5. Collaborating with unconventional partners

As fifth and final implication, when they sufficiently consider the features of systems, systems mapping approaches help participants to set up very much needed collaboration with unconventional partners. We already know from the agri-food systems literature that building weak ties (that is, relationships with actors across circles that are other otherwise very disconnected) may help societal actors to support sustainable transformations (Nelson *et al.,* 2014; Dentoni *et al.,* 2020). For example, building structural relationships between life scientists and social scientists, or between higher education institutes, policy-makers and communities, or between vocational trainings, tech companies and farmers may foster agri-food systems adaptation to and mitigation of socio-ecological challenges (Dentoni *et al.,* 2020; Rosenstock *et al.,* 2020). Yet, current food and agricultural studies do not yet inform how to prioritize and set up these much-needed forms of unconventional collaboration. Appropriate systems mapping processes, such as an iterative combination of causal loop diagrams and value network maps, contribute understanding how to do so. Through causal loop diagrams, participants can visualize how to prioritize unusual collaborations to act upon leverage points in the system. For example, having identified farmer business trainings as a critical lever to empower rural communities in linking them to legume and maize markets, the Malawian Agricultural Commodity Exchange (ACE) developed rural incubators with local farmer field schools and higher education institutions (Dentoni *et al.,* 2020). Complementarily, through value network maps describing current and potential resource flows among actors in a system, participants can visualize how to distribute appropriate incentives for unconventional partnerships to work in practice. For example, the Malawian Agricultural Commodity Exchange engaged farmer field schools and training organizations through international and national funding, while developed incentives for farmers and agricultural commodity storage operators to collaborate through warehouse receipt systems financed by national banks (Dentoni *et al.,* 2020). For the Malawian agri-food context and beyond, these partnerships were novel and contributed to change the system towards more interconnected, resilient and food secure rural areas. Finally, as systems mapping involves collective creation and visualization of resources and incentives potentially available among actors in a system, it encourages participants to the same session to brainstorm and negotiate concrete possibilities of collaboration, partnership, and collective action in a multilateral setting. Hence, by inviting mutually disconnected actors, but accessing potentially complementary resources, facilitators of systems mapping workshops may purposively steer the opportunities of building these unconventional partnerships.

6. CONCLUSION

The scale, persistence and aggravating nature of the socio-ecological problems that we face in and around the food and agricultural sector force us to undertake novel, bold, and interdisciplinary endeavors to address them. Widely applied in other social and ecological contexts, the use of systems thinking processes has rapidly expanded also in food and agriculture in the last decade, yet still lacking the depth sufficient to address the complexity of the problems at hand. As a result, narratives around 'food systems approaches', 'systems change' and 'food systems transformation' are dangerously becoming meaningless buzzwords. These worrying trends and scientific limitations urgently call scholars to propose systems mapping processes for societal actors - including us as researchers and educators - to better comprehend and address complex social and ecological issues in collective settings, while grounding them approaches in sufficiently deep understandings of what systems really mean.

Based on a review of the agri-food literature applying systems thinking in contrast with the key features of systems, we first argued that the food and agriculture literature has so far struggled to reach sufficient depth to support societal actors and researchers in addressing the complex socio-ecological problems at hand. Second, to overcome this limitation, we proposed a systems mapping processes that – through the use of causal loop diagrams and value network maps – iteratively combines the collective visualization of systems of issues and systems of actors in collective settings. Finally, we demonstrated how combining the mapping of systems of issues and systems of actors provides a powerful way to understand, in practice, how complex problems and complex systems are two sides of the same coin. When undertaken with adequate participatory processes (Király *et al.,* 2016; Wilkinson *et al.,* 2021), these systems mapping processes help develop individual competencies and collective understandings for participants to purposively target multiple goals, generate ripple effects, mitigate unintended consequences, tackle systemic constraints and build collaborations with unconventional partners. Hence, by making sense of systems and envisioning how to change them, these systems mapping processes can equip participants with different roles and viewpoints in societal to become better equipped to address socio-ecological problems confronting them.

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