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Research

Building food system resilience: insights from Finland using causal loop diagrams

Pasi Rikkonen [1], *Kalle Aro* [1], *Linda Rosengren* [1] and *Karoliina Rimhanen* [1]

ABSTRACT. The resilience of European food systems is being put to the test by complex and unexpected shocks, disruptions, and discontinuities, recent examples of which include COVID-19 and the Russian invasion of Ukraine. Owing to the complexity of the food system and the high degree of interdependence within it, the impacts of disruptions reverberate throughout the system, exposing vulnerabilities that were poorly recognized before the crisis. These cascading effects highlight the need to understand system-wide interconnections and to develop adaptive capacities that strengthen resilience under conditions of uncertainty. This study identifies the key variables that affect the ability of the Finnish food system to secure desired outcomes, as well as the key measures that can enhance its resilience. To achieve this, we interviewed nine experts on the Finnish food system and conducted a qualitative analysis to construct causal loop diagrams that visualize the system's dynamic interactions. These diagrams were further refined and validated during a researcher workshop. Building on this process, we identified four interlinked sub-systems, i.e., systems thinking and cooperation, flourishing rural areas, profitable and sustainable primary production, and diversified input and food markets, which shape resilience through distinct feedback mechanisms. Six key measures emerged as central to strengthening resilience: improved supply pool coordination, resilience-inspired policymaking, revitalization of rural areas, improved profitability, increased crop diversity, and reduced reliance on imported inputs. Together, these findings underscore the importance of systemic, cross-sectoral approaches that go beyond static indicators and address the dynamic nature of food system resilience.

Key Words: *causal loop diagrams (CLD); Finland; food systems; resilience*

INTRODUCTION

The resilience of European food systems is being put to the test because of complex and unexpected changes including COVID-19, the Russian invasion of Ukraine, and record-high temperatures and droughts during the summers of 2023 and 2024. Although disruptions are challenging for any system, they also reveal the system's strengths and weaknesses and provide an opportunity to identify areas for improvement (Engle 2011, Laborde et al. 2020). There is scientific evidence that various shocks and crises (e.g., financial crises, COVID-19, tsunamis) have, in the past, led to improvements in governance and management systems as well as to the development of new technologies (Suppasri et al. 2015, Anginer et al. 2019, Atkinson et al. 2021). Besides these sudden shocks, food systems face long-term changes, some of which can be predictable, such as demographic changes, the development of the farm structure in Europe guided by the Common Agriculture Policy by the EU (European Commission 2024), changes in consumption habits toward more sustainable options (Saarinen et al. 2019), or the lengthening of the growing season due to climate change (Peltonen-Sainio et al. 2018). In summary, there is a need to gain a better understanding of how the resilience of the European food systems can be further improved.

Tendall et al. (2015) have defined food system resilience as

> *the capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances.*

Several past studies have analyzed different methods and approaches to strengthening this capacity (Tendall et al. 2015, Himanen et al. 2016, Bullock et al. 2017, Béné 2020, Kuhmonen 2020, Rimhanen et al. 2023). Food systems are social-ecological systems, shaped by dynamic interactions between ecological processes and human activities. These systems comprise deeply intertwined environmental, economic, and social dimensions that are imperative to acknowledge and understand to manage the system (Ericksen 2008). Therefore, to remain functional in the face of both slow, predictable changes and sudden, unexpected shocks, food systems require resilience to increase their capacity to cope, adapt, and transform to intertwine economic, natural, or social disturbances (Folke et al. 2010).

In previous research, resilience has often been approached through abstract concepts, indicators, or survey-based methods, typically focusing on specific actor levels within the food system, such as households, farms, or producer groups. In their study, Tendall et al. (2015) conceptualized resilience holistically, viewing it as the capacity of the entire food system to maintain food security over time in the face of disturbances. In contrast, Béné (2020) emphasized resilience primarily at the level of households and communities, defining it as their capacity to absorb shocks without experiencing long-term adverse effects. Furthermore, renewal, innovation, and reorganization are central components of resilience in food systems (Gunderson and Holling 2002, Meuwissen et al. 2019). While Bullock et al. (2017) adopted an ecological and production-oriented perspective, framing resilience as the ability to sustain adequate and nutritious food production, Himanen et al. (2016), through a participatory Delphi study, identified key factors that enhance the adaptive capacity of the food system. Elsewhere, Kuhmonen (2020) approached resilience in a manner aligned with Holling's (1973) theoretical framing, highlighting the system's ability to absorb disturbances while maintaining both its economic and ecological core functions. Taken together, this body of literature

[1]Natural Resources Institute Finland, Helsinki, Finland

conceptualizes resilience both as a structural property of the food system and as the adaptive capacity of its actors, that is, their ability to adjust to and learn from change.

Resilience in food systems emerges from complex interactions across social, ecological, and economic dimensions, which means that disturbances can propagate in non-linear and often unexpected ways (Liu et al. 2015). As a result, the impacts of shocks are difficult to predict and may trigger cascading effects throughout the system. At the farm level, multiple disruptions may accumulate on the farmer's shoulders, and even a small additional disturbance, on top of ongoing shocks, can push the system beyond critical thresholds, resulting in declining performance or even collapse. Because these interactions shape how management options play out, the consequences of different interventions can be equally difficult to foresee. In the Finnish context, recent assessments identified infectious animal diseases, climate-related impacts, market disruptions, and energy-supply disturbances as key threats to food supply (Rimhanen et al. 2023). These threats are often driven by external factors outside farmers' control, which further complicate efforts to anticipate or mitigate their impacts. Past studies have shown that scarcity factors play an important role in determining the long-term trajectory of agriculture (Harner 1975). In Finland, vulnerability is further heightened by the high dependency on imported inputs, which amplifies exposure to external shocks (Knuuttila and Vatanen 2021, Rimhanen et al. 2023).

Despite growing interest in food system resilience, there remains a critical need to better understand the interdependencies among drivers and system characteristics that either hinder or support efforts to enhance resilience. Existing studies have often relied on static frameworks, indicator-based assessments, or case-based approaches. Alternative approaches, such as quantitative system dynamic modeling, network analysis, scenario analysis, or indicator-based frameworks have been considered. Although these approaches provide valuable insights, they may be less suited to capturing feedback mechanisms and cross-scale interactions within complex social-ecological systems (Liu et al. 2015).

To address this gap, the present study investigates the social, ecological, and economic variables shaping the dynamics of the Finnish food system. We contextualize system interactions and feedback through causal-loop diagrams (CLDs), which are widely used and offer a systems-based method to analyze complexity, revealing how interdependent factors and feedback mechanisms influence system behavior. Guariguata et al. (2023) stated that causal diagrams help to understand complexity, support interdisciplinary co-planning, and reduce the risk of undesired consequences. By using a system-level analytical tool that reveals the interventions to strengthen resilience, our analysis enriches the research literature on food system resilience. The present study poses the following research questions:

1. Which social, ecological, and economic drivers and interactions shape the dynamics and functions of resilience in the Finnish food system?
2. Consequently, what are the key measures to improve food system resilience?

METHODS

Data collection

To gather insights into the functioning of the Finnish food system under disturbances, we conducted interviews with nine experts, focusing on security of food supply, with the interviews conducted as semi-structured expert interviews. To ensure thematic consistency across interviews, an interview guide was used. The nine experts brought together both scientific and practical knowledge and had educational and professional backgrounds of primary production, food processing, trade, and public administration (see also Rikkonen et al. 2023, Rimhanen et al. 2023). Their perspectives reflected different levels of food system operations, from local to global scales. Professionally, the interviewees were affiliated with diverse institutional sectors, including research and development (n = 2), national emergency supply organizations (n = 3), interest groups (n = 2), government administration (n = 1), and the food industry and trade sector (n = 1). This multidisciplinary and cross-sectoral composition of expertise provided a comprehensive understanding of food system resilience and facilitated a nuanced exploration of systemic vulnerabilities, adaptive capacities, and preparedness strategies.

The interviews comprised three sections. First, the respondents were asked to assess the severity of different disturbances and their consequences for the food system functions and food security. These disturbances included several shocks such as climate change hampering agriculture; infectious animal diseases; trade wars and market disruptions; scarcity of resources; disruptions in energy supply, such as prolonged power outages, cybersecurity, bioterrorism, contaminated foods; and other unexpected shocks that can be considered surprise events with major impacts in society. Second, the respondents selected one to three disturbances to focus on in a more nuanced and careful manner. Here, the respondents reflected on multiple sides of the effects of the chosen shocks within the food system to uncover linkages between different actors and processes. Third, the respondents were asked to describe how to prepare for the disturbance, what promotes preparedness and what makes preparedness difficult. The interviews, which were recorded and transcribed, were held as remote online meetings in November-December 2021, lasting about one and a half hours each.

Data analysis

The qualitative analysis followed a primarily inductive approach. Themes, system variables, and causal relationships were identified from the interview transcripts through thematic coding. Although analysis was data-driven, it was informed by existing resilience literature. Thus, the analytical process combined inductive identification of system dynamics with theory-informed structuring.

The principles of causal loop diagram (CLD)

To map the drivers of change in the Finnish food system and to understand their interactions and interdependencies in the context of resilience, we used qualitative systems mapping, which consists of variables, cycles, and feedback within a system that can be used to analyze direct and in-direct system causalities (Oliva 2004). A widespread tool for analyzing and visualizing relationships between variables in a system is a causal loop diagram (CLD; Williams and Hummelbrunner 2010). Causal loop diagrams have been used in a large range of applications ranging from public health studies (Waterlander et al. 2021) to analyzing the environmental impacts of bioenergy supply chains (Groundstroem and Juhola 2021) and learning the effects in an organizational environment (Haghighat and Hosseinichimeh 2021).

A causal loop diagram is intended to portray a selected system as a group of interlinked variables that affect each other through positive and negative causal links (Williams and Hummelbrunner 2010), where a positive causal link (+) implies a positive correlation, and where an increase in variable A leads to an increase in variable B. Similarly, a negative causal link (-) does the opposite, i.e., an increase in variable A leads to a decrease in variable B. One major analytical strength of CLDs comes from the possibility of identifying feedback loops by following the causal link patterns. When a group of variables respond in the same direction in a cyclical pattern, a reinforcing feedback loop (R) forms. If considered isolated, reinforcing loops thus generate exponential growth or decline. A balancing feedback loop (B) comprises a group of variables in which at least one variable responds to opposite direction compared to others. Therefore, balancing loops portray hindering and balancing effects that resist and limit the otherwise exponential growth (Williams and Hummelbrunner 2010). The number of negative causal links determines whether a loop is a reinforcing or balancing one. If the sum of negative causal links is an even number or zero, the loop is a reinforcing one. In the case of an odd number, the variables form a balancing feedback loop. In practice, variables are usually connected in a web-like manner and may be part of multiple reinforcing and balancing loops (Williams and Hummelbrunner 2010). Consequently, analyzing variables as part of a larger interconnected system helps to understand the systemic forces strengthening and reducing a single variable; something that is easy to overlook with a narrower perspective.

As emphasized by Williams and Hummelbrunner (2010), CLDs are best suited for visualizing complexity and exploring interdependencies, rather than predicting long-term system behavior because the temporal dimension of system behavior is not explicitly modeled. Indeed, the arrows between variables in the CLDs do not reflect equal speed, strength, or rate of change, and time lags, delays, and the sequencing of effects are only partially captured, limiting the ability to assess how quickly or slowly resilience measures might take effect. As a result, the diagrams should be interpreted as qualitative heuristics rather than precise models of system behavior.

Building causal loop diagrams from interviews

The present study applied the systematic approach by Kim and Anderssen (2012), which sets out to create causal loop diagrams based on qualitative data in five methodological steps. Based on the similarity of qualitative data sources, we considered this a relevant reference point to our analysis. We adopted a slightly different approach by validating the CLDs in an expert workshop because multidisciplinary perspectives were considered important for refining the final versions. The steps in the Finnish case are described in detail below. To visualize the data and to analyze the resulting causal loop diagrams throughout the process, we used Vensim computer software (Ventana Systems, Inc. 2023).

1. Discovering themes and variables in the data

We started by conducting a thematic analysis of the transcribed recordings of the interviews using the NVivo program (Lumivero 2023) to uncover the main themes emerging from the qualitative data. Coding was conducted in an inductive and iterative manner, in which the transcripts were reviewed for food system variables. Transcripts were then segmented into excerpts, containing information of relationship between two or more variables. Variables from the excerpts were identified and sorted into corresponding codes with shared meaning. The coding resulted in a list of key food system variables mentioned in the interviews, as well as their relationship with other variables.

2. Identifying causal relationships between variables:

Next, we took a closer look into interactions between coded variables by moving all the variables identified from the coding data into a table. Each variable was then paired with the coded variable(s) it interacts with based on the segmented excerpts. Additionally, rereading the plain transcripts was also necessary to review any additional interactions that had been potentially lost due to segmentation. The associations were reduced into a simple form featuring one association per table row, consisting of only two variables and a single-headed arrow indicating the directionality of the association and the characteristic of the association as either positive or negative. We also identified elements that supported the resilience of the Finnish food system. To guide our analysis, we searched for variables that aligned with four main elements of food system resilience based on Rimhanen et al. (2023). The four elements are: (1) system thinking through science and communication; (2) redundancy of activities and networks; (3) diversity of production and partners; and (4) buffering strategies. These elements were marked in orange in the causal loop diagrams.

3. Transforming text into words-and-arrow diagrams:

We then created a large, integrated causal loop diagram portraying the Finnish food system with all the variables and causal links identified during steps 1 and 2. At this stage, the causal loop consisted of 109 unique variables and 243 causal links between them.

4. Generalizing structural representations:

Following the previous three steps, we condensed the diagram into a simpler form to make it more practical for our analysis. A reduction was made by identifying overlaps in the codes and condensing them together. We also aimed to set the variables on a similar analytical level while simultaneously portraying the content of the preceding variables as accurately as possible. This step was iteratively conducted multiple times in pursuit of a compact yet descriptive model that would help us to understand the central dynamics within the food system.

5. Zooming in on subsystems:

To enable a more detailed, focused and nuanced analysis, the large single causal loop diagram of the Finnish food system (Appendix 1) was broken up into smaller subsystems. The division of the subsystems was based on identifying

Table 1. Summary of the improvement measures identified in the subsystems.

Key measures for resilience enhancement	Type of system element	Justification
Improved supply pool coordination	Reinforcing feedback loop (R1)	Supply pool coordination acts as an independent, self-reinforcing feedback loop, which enables other desired developments in the system.
Integration of resilience-inspired policymaking	System variable	Required for generating momentum toward resilience in the food system and wider society.
Revitalizing rural areas	Reinforcing feedback loop (R4)	Required for driving the rural subsystem because the system cannot function without it. Includes many interconnected functions enabling viability such as investments in rural areas, functioning infrastructure, availability of services, attractiveness of rural areas.
Improving profitability	System variable	Profitability (and the lack of it in the current case) is central to driving two feedback loops. The posture of this variable greatly affects the function of the overall subsystem. Some effect may be triggered via targeted interventions, yet the system design may act as a significant counterbalance.
Increasing crop diversity	System variable	Crop diversity enables two central feedback loops that drive the system, i.e., regenerative farming and climate-smart farming.
Reducing the reliance on imported inputs	Reinforcing feedback loop (R8)	The strength of this reinforcing loop greatly determines the overall system function. When the feedback loop is strong, the system steers toward self-sufficiency. When the feedback is weak, the system is oriented towards diversification of imports.

clusters of variables that exhibited strong internal causal linkages. Although the CLDs of the subsystems primarily portray the current structure of the Finnish food system, they also include potential places for improvements that support system resilience. In line with resilience thinking, we conceptualized resilience not as an external layer, but as an emergent property of the system. Therefore, the same components may reflect both existing structures and resilience-building potential, depending on their position within the feedback loops. This integrative approach allows us to identify how present elements can be reinforced or reoriented to strengthen system resilience.

The validation of the CLD results

To strengthen the validity of our diagrams, we conducted a workshop including a total of 11 researchers who had not initially been interviewed during the data collection. These 11 researchers covered an array of expertise including economics, natural sciences, sustainability, and social sciences related to the Finnish food system. In the workshop, the researchers discussed the four CLDs featuring the four subsystems that were sent to the workshop participants in advance. The 11 researchers evaluated the accuracy, functionality, and explanatory power of the diagrams considering their internal dynamic as well as potential interactions between the subsystems. Then, the subsystem diagrams were further developed based on the comments received while ensuring that the logic of the diagrams drawn based on the original interviews could be maintained. In addition to the four updated subsystem CLDs, the large single CLD was updated to reflect the most important interactions within and between the four subsystems (Appendix 1).

RESULTS

Below, we present the findings of our analysis to respond to our two research questions. First, the four emergent subsystems were: (1) systems thinking and collaboration; (2) flourishing rural areas; (3) profitable and sustainable primary production; and (4) diversified input for food inputs. These subsystems functionally covered the majority of the initial large-scale causal loop diagram of the Finnish food system. Second, we identified six measures to improve food system resilience across the subsystems (see also Table 1).

Subsystem 1: resilience through system thinking and cooperation

Key variables and system dynamics

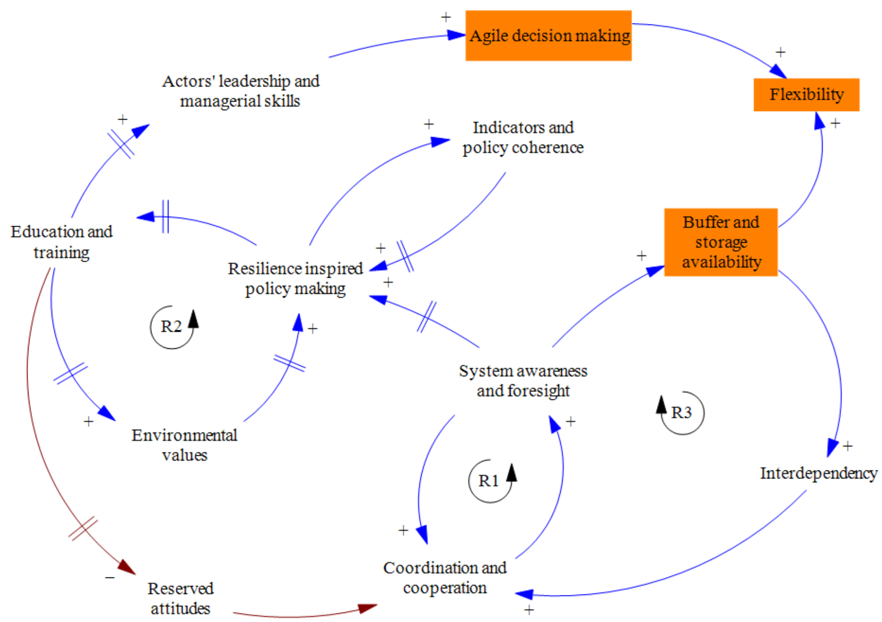
The causal loop diagram "Systems thinking and cooperation" (Fig. 1) visualizes those variables building an improved understanding of system characteristics and their interdependencies, and how cooperation can contribute to the enhanced resilience of the Finnish food system. In the causal loop diagram, system thinking, and cooperation, the focus is on two reinforcing feedback loops: (1) supply pool coordination (R1), and (2) environmental value change among stakeholders (R2). Supply pool coordination brings a wide range of food system stakeholders together, including farmers, processors, advisors, retailers, consumers, scientists, and policymakers, and promotes systematic assessment of the food system dynamics, thus allowing forward-looking planning and policymaking. The reinforcing nature of R1 becomes visible in how improved coordination enhances shared situational awareness and forward-looking planning.

As one interviewee emphasized, preparedness work moved beyond sectoral silos:

> *Previously, preparedness work was pretty much just something to be done within one's own field of responsibility, but that has changed quite quickly in that quite a lot is done outside of that sector.*

Systems thinking knits resilience more strongly together with policymaking and mainstreams resilience thinking to society broadly via education. It does this by acting as a connector and aligning resilience goals with policymaking and embedding them into societal consciousness through education. Moreover, systems thinking equips both leaders and citizens to think beyond short-term fixes, fostering a culture that values sustainability, adaptability, and collective well-being.

Fig. 1. Causal loop diagram of subsystem 1: resilience through system thinking and cooperation.



Interviewees noted that such thinking is still relatively rare in practice:

> *I think there's too little of that kind of systems-level thinking. I think we still see a lot of that kind of narrow-minded approach to solving these damn problems, like this food system issue.*

Although learning effects accumulated through reinforcing loops help to overcome reserved attitudes held by some food system actors, this effect occurs with a delay. Many actors in the food system have commercial connections, being either sellers or buyers relative to one another and hold varying degrees of reserved attitudes toward new kinds of vertical cooperation. Though the effectiveness of the policies should be evaluated and refined through cross-sectoral indicators set for resilience, this development is likely to be time-consuming due to the novelty of the resilience-centered approach and the large number of policy domains involved. Because flexibility in the food system increasingly depends on a combination of material buffers and the knowledge required to coordinate and deploy them, interdependence within the food system is likely to increase, driven both by deeper trust among actors and by the practical necessity for a more systematic collaboration on resilience-centered questions (R3).

- R1 = supply pool coordination,
- R2 = environmental value change in society,
- R3 = interconnectedness increases between food system actors.

Measures to improve food system resilience

Within the first subsystem, we identified two measures for strengthening the resilience of the Finnish food system: (1) supply pool coordination and (2) resilience-inspired policymaking.

Interpretation of results

Supply pool coordination: based on the causal-loop diagram of the first subsystem "systems thinking and cooperation," supply pool coordination appears to be the most feasible point for enabling and strengthening the desired effects in the subsystem. Coordination and cooperation and system awareness and foresight variables create a tight reinforcing causal loop, which acts as a primary motor for this subsystem. The loop directly strengthens buffer and storage availability while simultaneously strengthening agile decision making and flexibility through indirect effects. An existing example of this type of coordination between supply pool actors appears in the context of the Finnish National Emergency Supply Agency, whose task is to increase risk awareness, preparedness, and cooperation between public and private actors within Finnish society (NESA 2025). Building upon the existing actor infrastructure, the strength of supply pool coordination may be accelerated, which in turn may widen the range of coordination and cooperation outside the sole activities of official organizations. Moreover, supply pool coordination improves information exchange among food system actors and may even generate informal coordination among food system actors.

In their response, one interviewee noted:

> *And to mention the authorities and the business community separately, so that the authorities know the activities of the business community and the food chain, what is being done. Not only from their own perspective, but also from how those companies operate, what the boundary conditions are for their operations and the operating conditions that they need.*

This highlights the need for institutional structures that enable mutual understanding across actor groups, particularly between public authorities and private sector actors, as a basis for more adaptive and coordinated responses.

Resilience-inspired policymaking: in terms of the subsystem diagram, resilience-inspired policymaking is reliant on successful supply pool coordination (R1) and is a vital variable in distributing this positive momentum onto the larger system. Resilience-inspired policymaking can thus be understood as an independently important variable, but also as a policy extension to the supply pool coordination loop that could modify rules of the food system structure. Finnish food policy can be regarded as highly self-sufficiency oriented (Jansik et al. 2021), focusing mainly on the tangible availability of agricultural inputs and food products.

As one interviewee noted:

> *It has been a kind of policy background that self-sufficiency is maintained or attempted to be maintained at a certain level, because then if problems arise, imports are not a given.*

Subsystem 2: resilience through flourishing rural areas

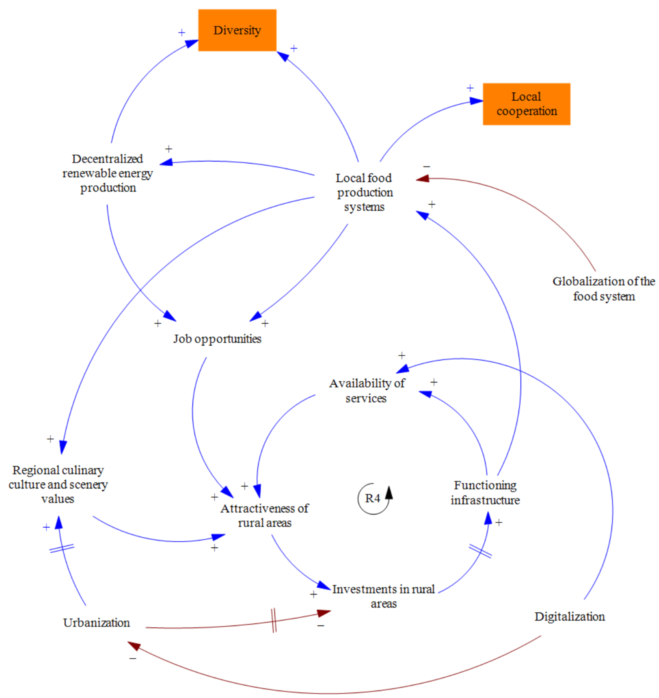
Key variables and system dynamics
This subsystem visualizes structural developments in rural areas, focusing on revitalizing a more diversified and spatially dispersed food system. By taking care of the local infrastructure of information technology, transportation, and local services, rural areas become more attractive for farmers and the food industry. Moreover, local companies in the food, energy, and other industries create job opportunities that add to the attractiveness and liveliness of rural areas.

Nonetheless, one interviewee was hesitant to express any enthusiasm about this type of development:

> *I don't see the possibility of ever larger, ever more specialized facilities in an increasingly deserted countryside. No people, no one wants to do anything there anymore.*

As agriculture, food industry, and energy industry collaborate at the local level, they strengthen the cooperation and self-sufficiency of the region. Indeed, a spatially dispersed food system increases diversity and healthy redundancy in the overall food system. Unfortunately, two major trends hinder development: urbanization and globalization of the food system. Urbanization reduces investments in rural development, which has far-reaching effects on the subsystem as a whole. However, urbanization creates increased interest in rural attractions such as traditional rural cultural landscapes and regional culinary culture, though only after a prolonged period. As well as urbanization, globalization of the food system counterbalances local cooperation, indirectly reducing job opportunities, local cooperation and diversification, and decentralization in the Finnish food system. Because urbanization and the globalization of the food system are major balancing factors that originate mainly from global developments, they are largely beyond the influence of developments within the subsystem itself, which highlights the need to address the interconnectedness of the subsystems. Moreover, actions must be undertaken on multiple system levels simultaneously if the vitality of rural areas is to be enhanced (Fig. 2).

Fig. 2. Causal loop diagram of subsystem 2: resilience through flourishing rural areas.



- R4 = revitalizing rural areas

Measures to improve food system resilience
Within subsystem 2, we identified one key measure for strengthening the resilience, revitalizing rural areas.

Interpretation of results
Revitalizing rural areas is a positive feedback loop, found in the middle of the subsystem. Interviewees also described how functioning local infrastructure creates cumulative advantages for rural communities:

> *...they have an interaction, and it therefore forms such a whole...*

This reflects the reinforcing structure of R4 in which investments, infrastructure, services, and attractiveness interact dynamically. Improvements in one element strengthen the others, enabling the loop to generate sustained regional resilience. Attention is given to local food production systems, especially to preconditions and infrastructure that are vital for the rural area to attract actors and businesses. Although not directly linked with resilience-oriented variables in the causal-loop diagram, i.e., "local cooperation, diversification," and "decentralization," the role of the revitalization loop in strengthening intermediate variables including "local food production systems" and "decentralized renewable energy production" is evident. As visualized in Figure 2, the measure is a reinforcing feedback loop comprising four variables: (1) investment in rural areas, (2) functioning infrastructure, (3) availability of services, and (4) attractiveness of rural areas. Functioning infrastructure serves as the main variable through which the positive inertia of R4 is distributed into the food system. That being said, its strength is highly dependent on the influence of the other variables in the reinforcing loop. When the variables contributing to revitalizing rural areas (R4) are strong, their combined effect may generate a self-reinforcing effect that distributes positive gains to the whole subsystem. At the same time, actions from national-level actors are likely to be needed to jumpstart the positive development.

Subsystem 3: resilience through profitable and sustainable primary production

Key variables and system dynamics

This subsystem focuses especially on the adaptability of the Finnish primary production. Ongoing structural change toward growing unit size acts to tackle low profitability; this is portrayed in the balancing loop B1. This trend appears to directly reduce resilience via centralization and specialization into certain crops and products. However, on a macro level, centralization and specialization generate up-to-date professionalism and practical management skills in the primary production, which creates more willingness and capabilities to invest in resilience-oriented solutions. Although the investments come with a cost in the short term, their value in ensuring long-term stability might prove invaluable in times of shocks and disturbances. On the other hand, centralization and growing unit sizes seem to act against a more diversified farming system, which in turn enables other reinforcing loops. In the regenerative farming loop (R5), nutrient cycling and crop diversity coupled with domestic protein production generate both environmental benefits and self-sufficiency in the form of domestic inputs. Steady income for the agricultural sector could be generated directly from the improved yields (R6) and protein crops, as well as indirectly from the reduced dependency on foreign inputs.

In their response, one interviewee noted:

> *On average, you can't make a living from actual agriculture, so it has changed this structure a lot. Increasing average yields is not something that would be very profitable on a grain farm, for example, through soil structure and land improvement.*

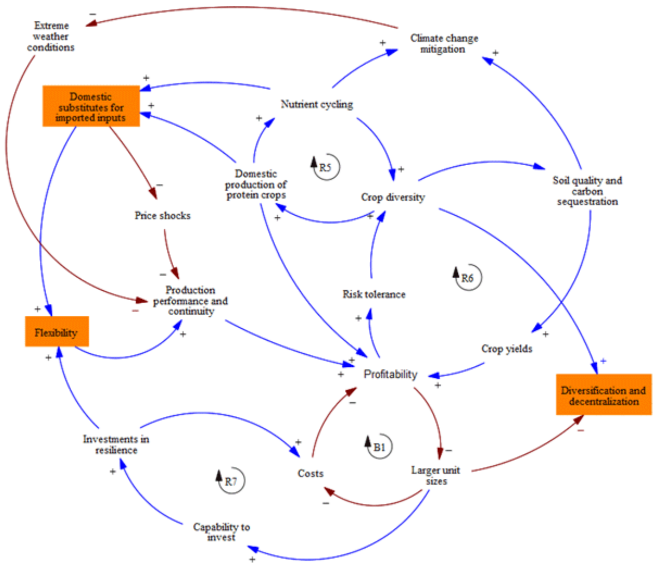
Such a response reflects how economic pressures have influenced structural change in primary production, driving farm expansion and specialization as necessary strategies for survival. At the same time, it underlines the challenge of justifying long-term resilience investments when short-term profitability remains low (Fig. 3).

- R5 = regenerative farming,
- R6 = climate-smart farming,
- R7 = large units tend to invest in resilience,
- B1 = structural development in primary production.

Measures to improve food system resilience

Within subsystem 3, profitability and crop diversity were identified as two key measures for strengthening the resilience.

Fig. 3. Causal loop diagram of subsystem 3: resilience through profitable and sustainable primary production



Interpretation of results

The profitability of primary production emerges as the central variable of the subsystem. It directly affects the economic and mental well-being of farmers and drives the trend toward larger farm unit sizes. Profitability and continuity of production are identified as key variables around which nearly all other elements of the subsystem revolve. Nevertheless, one major constraint for resilience-enhancing actions is the cost of investments, either directly or indirectly, with one interviewee stating:

> *This system prioritizes things other than the profitability of agriculture.*

As shocks in the system reduce profitability, the financial capability to invest is lower, with one expert explaining how limited financial capacity directly constrains adaptive action:

> *When there is no opportunity to invest, it naturally affects the prioritization of those actions.*

This captures the reinforcing dynamic between profitability, investment capacity, and long-term resilience. When financial margins narrow, the ability to implement resilience-enhancing measures declines, potentially amplifying vulnerability to future shocks. However, when there have been no shocks negatively affecting profitability, the willingness to invest in resilience may also be low. As investments in resilience generate costs in the short term but allow for more stable and predictable revenue in the long term, it is easy to disregard the upfront costs of the resilience investments in the absence of acute or foreseeable threats. Moreover, the requirement for capital investments may deepen the divide between highly profitable and poorly profitable farms. Highly profitable farms may further increase their profitability through resilience measures such as diversifying crop rotations, investing in soil health improvements, or adopting water-saving irrigation technologies. In contrast, farms that are unable to invest may experience significant financial impacts in the event of shocks.

Crop diversity is situated at the intersection of two reinforcing loops: regenerative farming (R5) and climate-smart farming (R6). Positive impacts on farmers' profitability and environment, as well as national production in agricultural inputs, can be accelerated through both loops, implying that they can coexist and reinforce each other. Though regenerative farming would possibly generate profitability through increased crop yields and reduced reliance on imported farming inputs, this comes with increased short-term costs. These initial investment costs are likely to hinder the more widespread introduction of crop diversity and new farming methods. However, if this loop gains momentum, the positive effects on resilience can be generated directly by enabling diversification and decentralization, and indirectly through R5, which strengthens the production of domestic substitutes for imported inputs, which in turn increases flexibility in the food system.

Subsystem 4: resilience through diversified input and food markets

Key variables and system dynamics
This subsystem addresses the trade of inputs and food products. The starting point for the analysis is the globalization of food trade, which generates interdependency between national food systems via trade routes and encourages centralization and specialization across regions. As production and processing become concentrated, market functioning becomes increasingly dependent on a limited number of actors and infrastructures. These interdependencies are not limited to trade flows but extend to critical infrastructures that enable processing and distribution. When input provision, industrial processing, and retail logistics are tightly coupled, disruptions in one infrastructural node can cascade rapidly across the food chain. As one interviewee described:

> *If the electrical system is disrupted, it will primarily affect the functionality of industrial, but even more strongly commercial, distribution systems.*

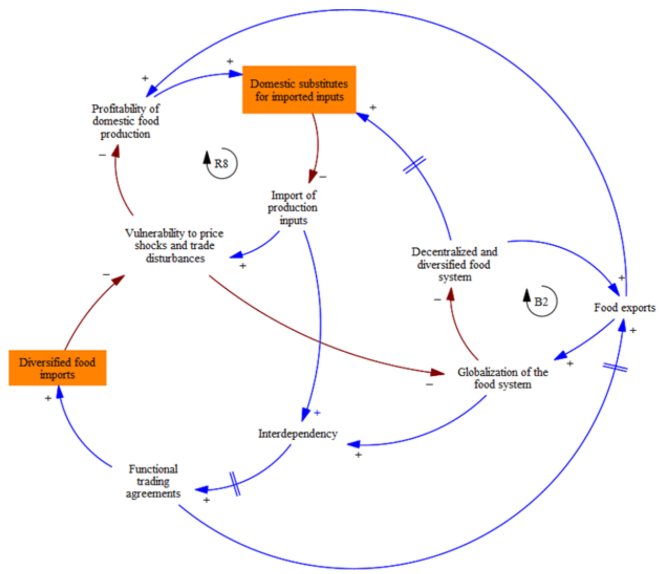
This observation illustrates how market concentration and infrastructural dependency interact. In a centralized system, disturbances in energy supply or logistics may directly constrain both domestic market availability and import-based supply chains. Such cascading dynamics underscore the vulnerability associated with highly integrated and specialized trade structures.

In contrast, decentralized and diversified agricultural production can reduce reliance on imports by enabling domestic substitutes, with one interviewee stating:

> *I personally believe that this highly concentrated processing industry should be dismantled into a more decentralized model for its resilience. Which would then be connected to this diversified agricultural production throughout the country.*

This perspective reflects the reinforcing loop (R8), in which reduced reliance on imported inputs strengthens domestic production capacity and buffers the system against external

Fig. 4. Subsystem 4: resilience through diversifying input and food markets.



shocks. Each time the global food system is perceived as vulnerable, incentives for domestic substitution increase, further reinforcing this dynamic. At the same time, growing exports may deepen integration into the global markets and encourage the specialization in the most competitive products, thereby reducing overall system diversity. This balancing dynamic is represented in B2: although specialization and export orientation may enhance efficiency and economic performance, they may simultaneously increase exposure to global volatility and reduce structural redundancy. The main challenge is finding a balance between strong domestic production and participation in global markets in a way that maintains both flexibility and resilience (Fig. 4).

- R8 = reducing the reliance on imported inputs,
- B2 = specialized food exports, to a limit.

Measures to improve food system resilience
Within subsystem 4, reducing the reliance on imported inputs was identified as one key measure for strengthening the resilience.

Interpretation of results
Due to the duality of this subsystem, there are two resilience-oriented variables present: "domestic substitutes for imported inputs" and "diversified food imports," which are situated as partly exclusive. Domestic substitutes for imported inputs are included in reinforcing loops depicted in subsystem 3 (Fig. 3). In this loop, they function as the central variable within the subsystem dynamics. Moreover, it appears that the strength of this loop affects the dynamic of domestic production and imports more than any other force in the system. Beyond containing resilience-oriented variables, other variables in the loop can be regarded as vital: profitability of domestic food production is directly linked to "profitability" as presented in subsystem 3; vulnerability to shocks and disturbances feeds into the reinforcing

loop B2; and import of production inputs is indirectly linked to the other resilience-centric variable "diversified food imports," strongly affecting its intensity within this subsystem. Due to this central role within subsystem 4 and linkages to other resilience-oriented variables, we position "reducing reliance on imported inputs" in the realm of feedback because its strength greatly determines the overall system function.

Summary of the results

The analysis from the four subsystems to enhance resilience highlights six key measures that enhance the resilience of the Finnish food system across its subsystems. The justification of these six improvement measures is presented in Table 1.

DISCUSSION

This study examines the resilience of the Finnish food system by explicitly addressing two central research questions: (1) Which social, ecological, and economic drivers and interactions shape resilience dynamics in the Finnish food system? and (2) What are the key measures for improving food system resilience?

Through a systems-based analysis using causal loop diagrams (CLDs), we identified how resilience emerges from the interplay of four interconnected subsystems. Each subsystem contains reinforcing feedback loops and critical system variables that influence the system's capacity to absorb shocks, adapt, and transform. Six key measures were identified as central to enhancing resilience across these subsystems: an improved supply pool coordination, an integration of resilience-inspired policymaking, a revitalization of rural areas, an improved profitability of primary production, increased crop diversity, and a reduced reliance on imported inputs. These key resilience measures function as pivotal system variables that shape the direction and strength of system dynamics. Notably, the CLDs revealed how trade-offs, such as those between centralization and diversity, or short-term profitability and long-term adaptability, must be carefully navigated to avoid undermining resilience.

The findings of this study reinforce and extend existing conceptualizations of food system resilience by emphasizing its emergent, systemic nature. In line with Tendall et al. (2015), resilience is not confined to individual actors or sectors but is a property of the entire food system, shaped by dynamic interactions across social, ecological, and economic domains. In this study, the causal loop diagrams (CLDs) developed provide a visual and analytical bridge between abstract resilience concepts and the concrete realities of the Finnish food system.

Unlike many previous studies that rely on static indicators or actor-specific assessments (e.g., Bullock et al. 2017, Béné 2020), the present study highlights the importance of feedback loops and interdependencies. For example, the reinforcing loop around supply pool coordination illustrates how trust, cooperation, and shared foresight can amplify system-wide adaptability. Similarly, the profitability loop in primary production reveals how economic viability is both a prerequisite and a constraint for resilience-enhancing investments; an insight that aligns with Kuhmonen's (2020) emphasis on the interplay between structure and agency in Finnish agriculture. Moreover, the present study contributes to the growing body of work that applies systems thinking and qualitative modeling to food systems (e.g., Glenn et al. 2020, Guariguata et al. 2023). Not only does the use of CLDs uncover leverage points but it also brings to the surface trade-offs and tensions, such as those between centralization and diversity, or between short-term efficiency and long-term adaptability, which are often overlooked in a more linear analysis.

By offering a systems-based, qualitative analysis of the Finnish food system using causal loop diagrams (CLDs), the present study contributes to the growing literature on food system resilience. The findings reinforce the view that resilience is an emergent property of complex systems, shaped by feedback, interdependencies, and structural conditions (Folke et al. 2010, Tendall et al. 2015). As stated, food systems are notoriously complex and path-dependent, which makes them resistant to transformation through both internal and external interventions. Although shocks such as pandemics, geopolitical conflicts, or energy disruptions are often described as windows of opportunity for transformation, resilience theory cautions that disturbances do not automatically lead to systemic change. In the Panarchy framework, release dynamics (Ω) may be followed either by reorganization into a novel configuration or by a "remember" dynamic, in which the system reorganizes into a structure closely resembling its prior state (Gunderson and Holling 2002). Biggs et al. (2010) emphasized that navigating the back loop of the adaptive cycle requires deliberate social innovation and institutional change; otherwise, systems may revert to dominant structures and practices. In the Finnish food system, reinforcing feedback related to profitability pressures, centralization, specialization, and global trade integration suggests strong structural tendencies toward stabilization. This feedback may enable the system to absorb shocks while simultaneously reinforcing pre-existing patterns, particularly under broader political-economic pressures that prioritize efficiency and competitiveness. In this sense, shocks can both expose vulnerabilities and strengthen regime persistence rather than induce transformation.

Interpreted through this lens, the reinforcing loops identified in our CLDs can be understood as contributing to the maintenance of particular attractors or basins of attraction within the food system (Holling 1973, Walker and Salt 2006). Feedback linking structural change, profitability constraints, and specialization may stabilize a centralized production model, potentially generating rigidity traps that limit diversification and adaptive capacity (Gunderson and Holling 2002). Conversely, loops centered on crop diversity, rural revitalization, and supply pool coordination represent structural conditions that could weaken existing attractors and enable reorganization toward alternative configurations. Rather than positioning the Finnish food system within a single phase of an adaptive cycle, our findings suggest that different subsystems simultaneously exhibit dynamics of consolidation and renewal, reflecting the multi-level and asynchronous character of complex social-ecological systems (Olsson et al. 2006).

External drivers, such as agricultural policy reforms or EU-level initiatives like the Critical Entities Resilience Directive (EU 2022), have aimed to strengthen resilience, particularly in response to recent disruptions like the COVID-19 pandemic and the war in Ukraine. However, the tangible impacts of these efforts on the Finnish food system remain limited. In contrast, internal drivers, such as improved cooperation among actors, increased crop diversity, and more effective local coordination may offer more direct and context-sensitive pathways for change. These internal dynamics are embedded in the everyday functioning of the food system and can influence how actors respond to shocks and adapt over time. Nevertheless, they are not without constraints: persistent challenges such as low profitability, sectoral centralization, and limited flexibility in national agri-food policy continue to hinder the system's capacity to evolve (Kuokkanen et al. 2017).

Our analysis highlights that some resilience-enhancing measures, such as supply pool coordination and crop diversity, can be activated largely through internal system dynamics. Others, like revitalizing rural areas or improving farm profitability, are more dependent on external policy support and global economic trends. This distinction is crucial for designing interventions that are both feasible and impactful.

The present study also confirms the central role of diversity in promoting resilience, a theme widely supported in the literature (Darnhofer et al. 2010, Cabell and Oelofse 2012, Carpenter et al. 2012, Hodbod and Eakin 2015, Hertel et al. 2023). In our findings, diversity manifests across multiple dimensions: biological (e.g., crop species), operational (e.g., farming practices), economic (e.g., market channels), and institutional (e.g., actor knowledge and roles). As Kahiluoto et al. (2014) and Altieri et al. (2015) have shown, such diversity enhances adaptive capacity by enabling differentiated responses to shocks, whether climatic, economic, or social. For example, diversified farms may better withstand droughts, while varied market channels can buffer against trade disruptions. Because processors often define the quality standards that shape production decisions, communication between producers and processors is also essential.

Finally, the study identifies trade-offs and alternative development paths within the food system. In primary production, resilience may be pursued either through larger, more capable farms with the resources to invest in resilience, or through a more spatially dispersed and diverse network of smaller farms. Both paths have merits and limitations, and in practice, elements of both are likely to coexist. Similarly, in input and food markets, resilience can be enhanced either by diversifying imports or by reducing import dependency through domestic production. These strategies are not mutually exclusive but require careful balancing to avoid over-reliance on either global interdependence or national self-sufficiency.

Together, these insights underscore the need for context-sensitive, multi-level strategies that align internal system dynamics with external policy frameworks. In this study, the CLDs developed offer a practical tool for identifying leverage points, navigating trade-offs, and guiding interventions that support long-term resilience.

CONCLUSION

This study contributes to the growing body of research on food system resilience by offering a systems-based, qualitative analysis of the Finnish food system through causal loop diagrams. By identifying six key measures ranging from supply pool coordination to crop diversity and reduced import dependency, we demonstrate how resilience is not a static attribute, but an emergent property shaped by feedback, interdependencies, and structural conditions. The findings underscore the importance of integrated, cross-sectoral approaches that align policy, practice, and local development with long-term resilience goals. Although the study is grounded in the Finnish context, the methodological approach and insights offer broader relevance for other food systems facing similar challenges of complexity, uncertainty, and transformation. Strengthening resilience requires not only technical solutions but also institutional learning, inclusive governance, and a willingness to reimagine the food system as a dynamic, adaptive whole.

Author Contributions:

CRediT author statement: Conceptualization: all authors; Methodology: K. A., P. R., K. R.; Formal analysis: K. A.; Investigation: K. R., P. R.; Writing - Original Draft: all authors; Writing - Review and Editing: all authors; Visualization: K. A., L. R.; Funding acquisition: P R, L. R.

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Data Availability:

Anonymized data will be made available on request.

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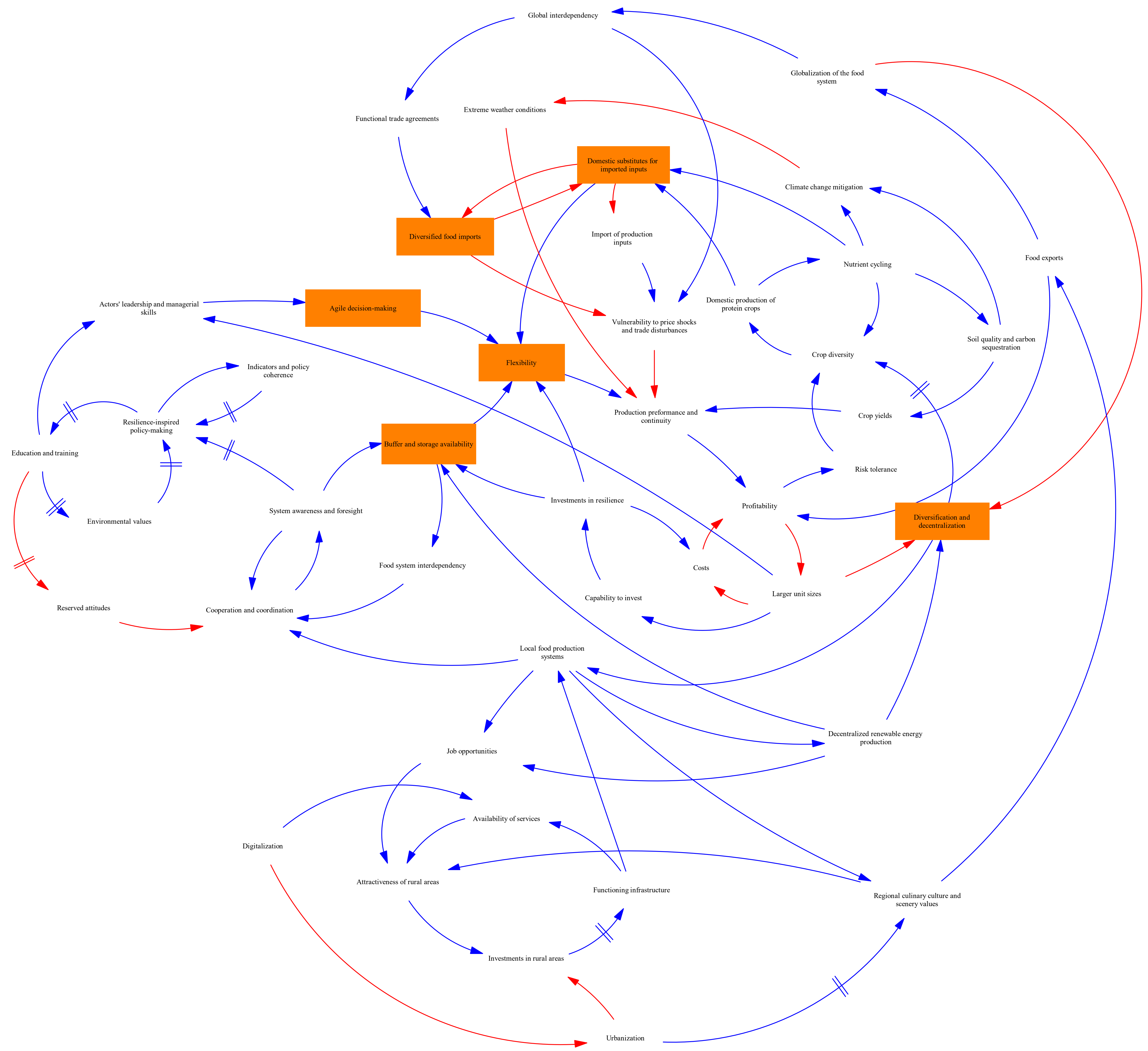
Global interdependency
Globalization of the food system
Functional trade agreements
Extreme weather conditions
Domestic substitutes for imported inputs
Climate change mitigation
Diversified food imports
Import of production inputs
Nutrient cycling
Food exports
Actors' leadership and managerial skills
Agile decision-making
Domestic production of protein crops
Vulnerability to price shocks and trade disturbances
Soil quality and carbon sequestration
Flexibility
Crop diversity
Indicators and policy coherence
Production preformance and continuity
Crop yields
Resilience-inspired policy-making
Buffer and storage availability
Education and training
Risk tolerance
Investments in resilience
Profitability
System awareness and foresight
Diversification and decentralization
Environmental values
Food system interdependency
Costs
Capability to invest
Larger unit sizes
Reserved attitudes
Cooperation and coordination
Local food production systems
Decentralized renewable energy production
Job opportunities
Availability of services
Digitalization
Attractiveness of rural areas
Functioning infrastructure
Regional culinary culture and scenery values
Investments in rural areas
Urbanization