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RESEARCH BRIEF

RESILIENCE AND SUSTAINABILITY IN FOOD SYSTEMS RESEARCH: A REVIEW OF THE MAIN ISSUES AND KNOWLEDGE GAPS

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The European Sustainable Agriculture Dialogue (ESAD) is a multi-stakeholder platform created in 2019 that brings together key actors from across society – including industry, civil society, universities, and research centres – to discuss key topics, exchange our views and standpoints, and ultimately shape decisions towards sustainable agriculture. The brief was developed in consultation with ESAD members and the authors took their inputs into account in the drafting process. The paper does not reflect the views and opinions of single ESAD members. As such, their contribution is not to be interpreted as an endorsement of the final paper.

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EXECUTIVE SUMMARY

Food systems play a central role in our societies, operating across multiple spatial and temporal scales. However, food systems are under pressure from climate change and simultaneous challenges related to environmental, social and economic dimensions of sustainability.

The concept of resilience can help build food systems' capacities to ensure continuous delivery of outcomes in the face of predictable and unpredictable disturbances, which are projected to increase in the future.

This brief explains the concept of resilience, along with the approaches used for its study and its links to sustainability. It argues that identifying the factors that contribute to food and farming system resilience can guide decision-making processes that lead to food system transformation towards increased sustainability. However, the observation is made that sustainability norms should be the framework under which resilience operates. Leaving out the sustainability framework can lead to situations in which system resilience is increased (in the short term) at the cost of sustainability, and resilience capacities become lock-ins and barriers to food system transformations.

This brief places the focus on farming systems, which in the EU have evolved towards efficiency and simplicity over time, leading to a reduction in environmental and social resilience. This has been accompanied by a reductionist view of resilience as economic robustness in farming policies, further limiting farmers' capacity to invest in adaptability and transformability measures that allow for longer-term responses to perturbations. Strategies to increase the resilience of food and farming systems should focus on environmental, economic, and social aspects to identify trade-offs and synergies at different temporal and spatial scales. As the brief highlights, resilience, as an intrinsic factor of the transition towards sustainable food systems, can be a powerful tool to help identify transformative pathways for various stakeholders operating at various levels and at multiple scales.

EU and global food systems could also benefit from additional research on the resilience concept, its applicability to different contexts and links to sustainability. Four main areas for further research are identified in the brief:

- **Improving current definitions of concepts and system boundaries**, in relation to resilience and its links to sustainability.

- **Better characterisation of shocks and stresses** that might affect food systems directly and indirectly (both at present and in the future) and establishing metrics and indicators to measure resilience.

- **Increasing the understanding of the stakeholders' perceptions** of resilience and the interdependence between resilience capacities.

- **Exploring and testing measures and interventions that can strengthen the resilience** of food systems, from knowledge exchange to nature-based and technological solutions, following bottom-up and "learning from the future" approaches.

- **Shaping the governance processes that can build or hamper food system resilience at different scales**, from the farm to the international dimension.

Guiding the food system towards increased sustainability and resilience is a necessary endeavour that will require the engagement of all actors within the food system. Research and innovation funding should ensure that the researched solutions encompass the broadest range of contexts, scales and actors and that today's responses to increase the resilience of food systems do not compromise their future delivery of desired outcomes.

INTRODUCTION

Food systems are complex socio-ecological systems that operate across multiple spatial and temporal scales and play a central role in our societies. Globally, food systems are under pressure from climate change and environmental, social, economic and political pressures Tendall et al (2015). The EU is not exempt from these challenges and pressure mounts to ensure that our food systems can continue to deliver desired outcomes, do so in a sustainable way, and in a context of increasing extreme weather events and perturbations.

The study of system resilience can provide a better understanding of the functioning of food systems and a reflection on the outcomes that these are expected to deliver. The term offers the opportunity to incorporate food security into a more complex and systematic approach (Lindgren and Lang, 2023). Unsurprisingly, the impacts of climate change on agricultural production, the COVID-19 pandemic and the war in Ukraine have led to a rapid and greater interest in the concept as it applies to food systems. Multiple calls have been made to enhance food system resilience since the outbreak of the pandemic, rapidly making it a political priority in Europe and globally, quickly taken up by policymakers and stakeholders (European Commission, 2022; Hiller, Bas-Defossez and Baldock, 2021). However, applying resilience concepts to food systems remains relatively new, and efforts are still being made to conceptualise the terminology and how it can translate into action, especially about sustainability and the transition towards sustainable food systems. Transforming resilience into a new buzzword without delving into the concept and its implications risks diluting the term’s potential to help shape future policies and assess current ones.

The purpose of this brief is to explore the concept of resilience and its links to sustainability. Some of the questions raised in the literature related to the objective of resilience (what is resilience wanted for?) and whether the focus should be placed on maintaining the current system versus maintaining the system functions (Zurek et al, 2022). Several approaches have been proposed over the past years to study food system resilience. Chapter 2 provides an overview of these and discusses the links between resilience and sustainability for food systems. In Chapter 3, the discussion focuses on resilience in the farming sector, looking into the challenges and building resilience capacities. Chapter 4 overviews policy support and research needs to guide the transition towards sustainable and resilient food and farming systems.

DEFINING RESILIENCE AND SUSTAINABILITY

This section defines resilience and sustainability and discusses the links between the two.

2.1 Resilience

As a concept, resilience has its roots in ecology (Holling, 1973) and was subsequently taken up by physical sciences and behavioural science (Roosevelt, Raile and Anderson, 2023). Every discipline has contributed to defining the concept and adapting it to different scientific contexts (Tendall et al, 2015). However, most of the literature converges on a common definition of resilience as the capacity of a system to maintain its structure and functions following stresses and shocks and to adapt and reorganise when necessary (Bullock et al, 2017; Hoddinott, 2014; Meuwissen et al, 2019; Rimhanen, Aro and Rikkonen, 2023; Tendall et al, 2015; Walker et al, 2004b). Resilience capacity can be assessed against targeted and (to some extent) predictable shocks and disturbances, as well as against unknown and unforeseen events (Hoddinott, 2014; Meuwissen et al, 2019). Applied to food systems, resilience can be defined 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 unpredictable biophysical, social, or economic disturbances (Miles and Hoy, 2023; Tendall et al, 2015).

The acceleration of the effects of climate change and, more recently, the outbreak of the COVID-19 pandemic and the war in Ukraine have led to a resurgence of the concept. These events and phenomena have demonstrated the potential to expose food systems, among others, to shocks and stresses to levels at which they might cease to maintain their functions (Rimhanen, Aro and Rikkonen, 2023; Roosevelt, Raile and Anderson, 2023), pushing researchers and practitioners to look more deeply into the concept (see for example Chandler, Grove and Wakefield (2020)). As a result, the literature provides multiple ways of conceptualising resilience depending on the areas of research and the scientific discipline. For this paper, the discussion is limited to those elements of the debate that are considered the most relevant for the discussion on the resilience of food systems, particularly farming systems.

The first step is to identify the framework around which an assessment of resilience can be built and its implications. Consider here the concept of socio-ecological systems (SES), which are often described as a "system of people and nature" or, in more complex terms, as an integrated system in which human society and its multiple expressions interact with ecosystems, identifying a close relationship between social and ecological systems (Lyndsay Bott, 2022; McGinnis and Ostrom, 2014; Ostrom, 2010). SESs are, therefore, made of different parts that interact to build a more complex unit than the individual components (Alliance for Resilience, 2010). Setting the spatial and temporal boundaries of the SES will be a critical (but still reversible) step in assessing the resilience of a system, as it will define its components and impact the relevant external and internal factors over a given period. However, no matter the scale, this approach is generally considered holistic due to the focus on the dynamics of the interactions between the parts of the system rather than on understanding how each piece functions in isolation (Lyndsay Bott, 2022). Food systems are generally considered social-ecological systems and analysed as such (Allen and Prosperi, 2016; Duncan, Carolan and Wiskerke, 2020; Golden et al, 2021; Rimhanen, Aro and Rikkonen, 2023).

In complex socio-ecological systems, resilience can rarely be measured as an aggregate of individual resilience capacities, even though each component's resilience capacity may affect a system's overall capacity to continue delivering (Roosevelt, Raile and Anderson, 2023). This is because risks and vulnerabilities are not equally distributed within a system, and they may also affect the various components of a complex system differently. This aspect emerges quite clearly from the five generic principles of resilience proposed by the Alliance for Resilience (Alliance for Resilience, 2010):

1. diversity, which refers both to functional diversity and response diversity to disturbances;
2. modularity, implying that systems are divided into connected but independent modules having different functions;
3. openness, as the external connections with other systems;
4. tightness of feedback, understood as the way parts of the system respond to changes in other parts of the systems, also depending on the internal flow of information;
5. system reserves, to which a system has access when reacting from stresses and shocks, which could compensate for failures in some parts (and functions) of the system.

The holistic approach to resilience and its five generic principles capture the complexity of the multiple processes and actors and the different individual and collective characteristics of food and farming systems (e.g. farming practices governance) (Meuwissen et al, 2019). It also allows other elements of resilience to be investigated, as identified by Rimhanen, Aro and Rikkonen (2023), such as science and communication, redundancy of activities and networks, diversity of production and partners, and buffering strategies.

Another essential element of the debate is the dynamic character of resilience. The capacity of a system to "bounce back", preserving its structure, its function and even its identity (Walker et al, 2006; Walker et al, 2004a) can be accompanied by dynamic processes leading to changes and improvements in the functioning of the systems, using shocks and stresses as an opportunity to reach a more "desirable state", as Norris puts it (Norris et al, 2008). The acknowledgement and growing consensus on the many societal challenges lying ahead has favoured this dynamic understanding of resilience, which promises more than dealing with disturbances in the short term and introduces hopes for resilience as a framework for adapting and even transforming systems to face contemporary social challenges (Roosevelt, Raile and Anderson, 2023).

To better frame these evolutions, several authors have pointed towards three main capacities indicating how a system can adapt to the shocks and stresses and providing an initial framework for assessing resilience. These are robustness, adaptability and transformation (Meuwissen et al, 2019; Tendall et al, 2015; Walker et al, 2006; Zurek et al, 2022). Robustness is the ability of the system to maintain its functions while resisting the stresses and shocks, adapting its activities in a way that resists disruption in the expected outcomes. Adaptability (sometimes referred to as recovery) takes it a step further and is the ability to bounce back once the system has been disrupted and continue to deliver the expected outcomes or make small changes in the inputs without significant changes in structures and functions to deliver the outcomes. And finally, the resilience of food systems can also be measured by their ability to transform or reorient their internal structure when disruption hits and the existing system cannot continue performing its functions (Tendall et al, 2015).

Improving resilience around and for these three capacities could lead to trade-offs, especially in the case of transformation, which might require political and financial investment and societal acceptance. (Zurek et al, 2022). The same synergies and trade-offs can also exist between the three measures themselves. In the case of food systems, diversifying supply chains or increasing soil health can benefit the three elements. In contrast, a narrow focus on increasing the robustness of a particular component (e.g. investing in the development of specific genome traits) can result in a loss of adaptability and transformability of the system by reducing its ability to reorient itself in case of failure (Buitenhuis et al, 2022; Zurek et al, 2022). In the SESs framework, these dynamics are well captured by specified and general resilience. Specified resilience refers to the resilience of a specified part of the system to identified disruptions, whereas general resilience refers to the capacity of a system to withstand all hazards, including novel and unforeseen ones, while continuing to provide essential functions (Walker et al, 2009). Resilience theorists often stress the importance of combining both types of resilience (Anderies et al, 2013).

Finally, another essential element to consider in assessing and framing resilience is the question of scales, both in terms of space and time and their range (Alliance for Resilience, 2010; Anderies et al, 2013). This aspect was briefly touched upon at the beginning when discussing the importance of setting the boundaries of a system to be able to assess its resilience. However, multiple temporal and spatial scales can interact simultaneously and affect the system's resilience. For example, increases in temperatures and localised tornados affect agricultural production differently in different parts of the globe and have other social, economic and environmental impacts depending on the spatial and temporal scale (Rimhanen, Aro and Rikkonen, 2023; Wood et al, 2023).

This cross-scale element is essential when looking at the resilience of complex SESs. The notions of specified and general resilience can help identify the spatial scale. When system boundaries are well defined, it is possible to refer to specified resilience, while general resilience is often used in literature to discuss broader scales. Moreover, what is perceived as general resilience for one system boundary can become specified resilience for another (Anderies et al, 2013).

The temporal dimension is associated with the capacities of the systems to withstand (or not) stresses and shocks, from its capacity to maintain the system functioning in the short term (robustness) to responses that incrementally adapt in the medium to long term (adaptation) and finally, transformations (either very long or rapid) when the conditions of the socio-economical systems are untenable (Anderies et al, 2013). The complex interactions between the local and global dimensions and the short- and long-term impact of stresses and shocks make them very relevant to the debate on the resilience of food systems.

2.2 Sustainability

The United Nations Bruntland Commission described sustainability in 1987 as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This broad definition is still relevant, and it has been applied to various systems, including food systems (Allen and Prosperi, 2016; Roosevelt, Raile and Anderson, 2023; Tendall et al, 2015). As such, sustainability has no time boundaries, reflecting potentially never-ending processes as long as they can sustain themselves both as a whole and at each systemic level. Sustainability is global in scope, and even if the concept is rooted in the environmental movement, it encompasses three interdependent and widely accepted dimensions: environmental, social and economic (Allen and Prosperi, 2016; Brown et al, 1987).

Sustainability embeds a moral responsibility for equity and justice between generations through its long-term characterisation. Sustainability is therefore usually considered a normative concept (Schmieg et al, 2018): it refers to how things (a system in this case) should be and what should be done to achieve it. The answers to these questions are based on a set of values and objectives on which the stakeholders that are part of the system must agree (Norton et al, 2016; Roosevelt, Raile and Anderson, 2023). The main question is: *what* should the present generation leave to the next generation?

To this extent, sustainability can be seen as a skeleton supporting a narrative about the interaction between human societies and the environment and based on the recognition that a functioning biosphere is necessary for economic and social development (Anderies et al, 2013; Folke et al, 2010). The way sustainability performance is measured is the result of deliberative decision-making processes (Anderies et al, 2013).

Today's understanding of sustainability is reflected in and by its three dimensions, and it is well represented by fundamental political texts of our time, such as the Agenda 2030 for Sustainable Development, leading to the adoption of Sustainable Development Goals (SDGs) and replacing the old Millenium Development Goals, and the Paris Agreement, the negotiated outcome of COP21, setting long-term goals to limit the global temperature increase in this century to 2 degrees Celsius. However, despite this general agreement on the ultimate goals of sustainability, it is essential to note that there are still conflicting and, at times, mutually excluding perspectives concerning the most appropriate pathways to reach them.

2.3 Sustainability and Resilience

Sustainability and resilience are often seen as two sides of the same coin, especially in food system studies (Roosevelt, Raile and Anderson, 2023). Sustainability is often considered a normative concept, while resilience is more descriptive (Anderies et al, 2013; Roosevelt, Raile and Anderson, 2023). According to Tendall et al (2015), the different temporality between the two explains their complementarity. By preserving the capacity of a system to function and deliver in the wake of disturbances as they happen, resilience enables the sustainability of a system in the future. Such complementarity should also align both concepts in terms of functions and outcomes. If a system is described as unsustainable, it should not be possible to give a positive assessment of its resilience capacity (Meuwissen et al, 2019).

However, the existence of trade-offs between resilience capacities is also a reminder that resilience alone is not always a positive attribute, despite being often described as such. Some authors have analysed cases of “resilience traps” when, for example, an agroecosystem can successfully retain the same function and structure following a disturbance, but it delivers poor ecosystem services (Davis, Huggins and Reganold, 2023). This implies that in a transition towards more sustainability, some elements of adaptive resilience and robustness could also be seen as lock-ins, posing barriers for alternative dynamics even though they effectively maintain the current system function. At the same time, a system's transformation can effectively increase its resilience by accepting structural changes.

Consequently, the transition towards both, increased system resilience and sustainability, might not be fully aligned. Rather, the complementarity between resilience and sustainability cannot always be taken as a given. Their alignment will depend on the objectives, motives and worldviews of those actors involved.

SUSTAINABLE AND RESILIENT FOOD AND FARMING SYSTEMS

This section defines food systems and then proceeds to identify the main challenges that these systems face. It then provides a more detailed look at what resilience means for the farming sector about environmental stresses and shocks. It ends with discussing some issues to be considered when increasing system resilience, including potential trade-offs.

3.1 Defining Sustainable Food Systems

Food systems include the range of actors and their interlinked activities related to producing, processing, distributing, retailing, preparing, consuming and disposing of food products, as well as the environments in which these activities take place (von Braun et al, 2021; Zurek et al, 2022). These multiple interactions between human and natural components make food systems very complex socio-ecological systems, influenced by a large number of social, political, technological, environmental and economic factors, among which stresses and shocks also figure (Allen and Prosperi, 2016; Zurek et al, 2022). One of the desired outcomes of a food system is food security, which is determined by the availability, accessibility, safety, quality and nutritional adequacy of food (Roosevelt, Raile and Anderson, 2023; Stefanovic, Freytag-Leyer and Kahl, 2020). However, the activities of each of the actors involved in food systems may produce other social, economic and environmental outcomes, with trade-offs at multiple scales simultaneously.

Sustainability introduces goals concerning "what" is produced and "how" in a way that actors should align with outcomes that are considered socially, economically, environmentally sustainable and just. According to SAPEA, a sustainable food system can be defined as one that "*provides and promotes safe, nutritious and healthy food of low environmental impact for all current and future EU citizens in a manner that itself also protects and restores the natural environment and its ecosystem services, is robust and resilient, economically dynamic, just and fair, and socially acceptable and inclusive. It does so without compromising the availability of nutritious and healthy food for people living outside the EU, nor impairing their natural environment*" (SAPEA, 2020).

This umbrella definition of a sustainable food system, patching together a web of existing definitions, clearly includes a social, environmental and economic dimension, as well as a global perspective, and it sets out a series of principles. Resilience is also part of this definition and can be understood as the capacity to produce food and contribute to addressing the challenges of climate change and biodiversity loss, as well as the sustainable management of other vital resources and components of the biosphere, such as water, soil and air while being able to respond to additional economic, social and institutional stress and shocks such as price shocks, changes in consumer preferences and so on (Baldock and Hart, 2021).

Because of the unsustainability of most of today's food systems, including the EU's (SAPEA, 2020), the concept of sustainable food systems conveys the sense of a change towards greater sustainability compared to the current situation, and it is, therefore, a transformative concept in many ways (von Braun et al, 2021). Consequently, resilience capacities should not become barriers to system transformation despite their effectiveness in preserving current functions. Resilience for sustainable food systems should, therefore, be aligned with the same outcomes and objectives of sustainable food systems. As suggested by (Caron, Daguet and Dury, 2023), resilience becomes a property of system transformation and stops being presented as an attribute.

3.2 Challenges for the EU food system and resilience responses

EU food systems face multiple challenges in the form of (long-term) stresses and shocks threatening their sustainability pathway. These multi-dimensional challenges encompass environmental, economic, social and political/institutional perturbations (Table 1). There are choices to be made when addressing these challenges, which determine the actions to be taken and the resulting outcomes. First, is the objective to build general system resilience or resilience to specific challenges? As briefly mentioned in section 2 concerning the SES approach, general resilience does not discriminate against the type of stresses or shocks, nor does it look at specific parts of the system, while specified resilience is directly applied to a part of the system facing very concrete stress or shock (Cabell and Oelofse, 2012; Darnhofer et al, 2010)., Second, what resilience capacities should be favoured (robustness, adaptability, transformability) to achieve a long-term transition towards sustainability?

The diversity and specificity of the contexts in which food system actors operate will determine their response to opportunities or threats. Each actor may prioritise different goals, which can lead to increased or reduced sustainability in the system (Zurek et al, 2022). Decisions to increase resilience by one actor can potentially result in uncertain feedbacks and trade-offs inside the food system with differing outcomes. Some of the stresses and shocks may derive from, or are exacerbated by, unsustainable practices in current food systems but would not be there in sustainable food systems.

Table 1: Examples of stresses and shocks affecting different dimensions of food systems (Accatino et al, 2022; FAO, 2021; Meuwissen et al, 2019)

Environmental	Economic	Social	Political /Institutional
Climate change *Soil erosion* *Extreme weather events (droughts, floods, frosts, storms, fires)* *Changes in water availability* *Extreme temperatures* *Pest, weed or disease outbreaks* *Decline of pollinators* *Biodiversity loss* *Antimicrobial resistance*	*Reduced access to credit* *Food or feed safety crisis* *Increased competition in globalised markets* *Unbalanced value chain* *Increase in labour costs* *Low prices and price fluctuation* *Rising input costs*	*Land access* *Poor infrastructure* *Changes in consumer preferences and diets* *Lack of generational renewal* *Rural depopulation* *Labour shortage*	*Changes in agricultural policies and support* *Changes in environmental policies* *Changes in IP rules* *Wars and conflicts* *Product bans* *Trade barriers*

The specific case of farming systems is discussed below to exemplify some of the potential responses and links between resilience and sustainability.

3.3 Case study – building resilience in farming systems

Farming systems are socio-ecological systems (where nature and humans interact) that produce environmental, economic and social outputs (Renting et al, 2009). Farming systems are subject to most of the challenges outlined for food systems (Table 1), and their dependence on natural factors makes them particularly vulnerable to environmental shocks and stresses. Farming systems can range from high-(chemical)-input ones to nature-based (Therond et al, 2017). At the extreme, the first has a strong reliance on external inputs, often grow a limited number of crops and focus on efficiency. The second aim to reduce their dependency on external inputs, have higher crop diversity and often integrate crop and livestock systems.

Assessing the resilience of farming systems is not an exact process (Van Apeldoorn et al, 2011), and most studies on farming resilience so far have focused on the capacity of the systems to reduce their vulnerability to perturbations (van der Lee et al, 2022). This coincides with the view that EU farmers tend to look at robustness and short-term economic viability rather than focus on adaptability and transformability, which require longer-term thinking (Reidsma et al, 2020). While there is a constant and gradual adaptation process to disturbance in farming systems, periods of shocks can lead to major changes in the way they operate (Darnhofer et al, 2010). A list of indicators revised by Cabell and Oelofse (2012) allows some of the elements that can contribute to resilient farming systems to be distilled, e.g. a degree of ecological self-regulation, diversity to buffer against perturbations, responsible use of local resources, shared learning, spatial and temporal heterogeneity.

One of the frameworks proposed to study the resilience of farming systems was developed by Helfgott (2018) and reformulated by Zurek et al (2022). It involves examining the answer to the following questions: i) *Resilience of what?; ii) Resilience to what?; iii) Resilience from whose perspective; and iv) resilience for how long?* A similar framework was discussed by Meuwissen et al (2019) with slightly different questions: i) *resilience of what*?; ii) *resilience to what?;* iii) *resilience for what purpose*?; iv) *what resilience capacities*?; and v) *what enhances resilience*? Both Zurek et al (2022) and Meuwissen et al (2019) propose looking into the three resilience capacities (robustness, adaptability and transformability) as defined in section 2.1 of this brief when addressing these questions.

The discussion below focuses on building resilience in farming systems ('*resilience of what*') in relation to environmental stresses and shocks ('*resilience to what*'), with the objective of increasing the sustainability of farming systems with a focus on natural resources and biodiversity ('*resilience for what purpose*') and highlighting practical applications/implementations where possible ('*what enhances resilience*'). The discussion is organised around the three capacities ('*what resilience capacities*'). In addition, the distinction is made on whether the resilience built is 'general resilience' or 'specified resilience'.

What resilience capacities?

Robustness in farming systems is understood as the ability to maintain the expected outputs (i.e. consistency) regardless of the impact of perturbations (Urruty, Tailliez-Lefebvre and Huyghe, 2016). It can be broken down into three elements: avoiding exposure, withstanding exposure, and recovering from exposure (de Goede, Gremmen and Blom-Zandstra, 2013). While robustness in farming systems has been mostly looked at from an economic or social perspective, the robustness of natural or ecological resources (soil, nutrients, water) is essential for farming operations (Meuwissen et al, 2019).

The state in which these natural resources are found will have a large impact on the robustness of farming systems. As such, systems with low environmental sustainability will have a lower robustness to stresses and shocks. To bring it down to a concrete example, a healthy soil will be able to withstand and recover from exposure to a perturbation more successfully than a degraded soil (Neher et al, 2022). However, determining the robustness threshold, in the case of soils, is difficult given soils' heterogeneity and multi-functionality (Ludwig, Wilmes and Schrader, 2018).

Several strategies can be followed to increase the robustness of natural resources used in agriculture. General system robustness can be increased by reducing soil exposure through permanent soil cover or cover crops and protecting the soil against erosion processes. Enhancing the capacity of soils to retain water can also help crops withstand droughts, floods and maintain soil health in adverse weather conditions. Increased plant diversity, both temporally and spatially can contribute to robustness in several ways. In the case of crop failure, it can act as an economic buffer (Shroff and Ramos Cortés, 2020) and it can reduce pest and disease outbreaks (exposure) by promoting natural predators and overall disease risk by interrupting disease cycles through crop rotations (Lin et al, 2011). At the crop level, specified robustness can be achieved by increasing the plant’s inherent resistance to a particular stress (e.g. drought resistant or pest-resistant crops). In relation to drought, a specific combination of crops in a rotation can also lead to overall reductions in water consumption (Watson, 2019). Other practices, such as agroforestry, can reduce exposure to meteorological events, therefore making the system more generally robust (Li et al, 2019; Lin et al, 2011).

When it comes to **adaptability**, the attributes sought are a capacity to adjust the response to the perturbations (e.g. changing the composition of inputs) while maintaining key system functionalities (Darnhofer et al, 2010; Folke et al, 2010). Darnhofer et al (2010) identify three strategies focusing on learning and experimenting, flexibility in the farm (business) organisation, and diversification to spread risks and create buffers on the farm (including income diversification). These strategies allow the perception of change to shift from a disturbance to an opportunity but require farmers to invest time and financial resources into acquiring new skills (Manevska-Tasevska et al, 2021).

In terms of agricultural practices, those that increase the adaptive capacity of farming systems from a natural resources point of view include those that generally contribute to soil health and the building up of organic matter to increase the soil's buffering capacity and ability to sustain a diversity of crops under changing environmental conditions. This is the case of nature-based solutions which are acknowledged to play an important role in increasing system resilience and adaptability to climate change (EEA, 2023). More specifically, crop diversification appears as an important element. Intercropping, for instance, can reduce the risk of total yield failure (Raseduzzaman and Steen Jensen, 2017). Monitoring and digitalisation can play an important role in increasing the adaptability of farming systems. Precision agriculture and remote sensing allow for a reduced and more tailored use of inputs (nitrogen, pesticides, water), thereby allowing for an adjustment of inputs under changing conditions. In addition, digitalisation tools (including artificial intelligence) are also increasingly used to improve forecast systems and provide decision support tools for management, increasing the capacity of systems to change and respond to the identified stresses and shocks (e.g. pest outbreaks) (Finger, 2023).

Transformability is 'the capacity to create a new system when ecological, economic, or social structures make the existing system untenable" (Walker et al, 2004a). The attributes associated with transformability are related to general resilience rather than specified resilience (Folke et al, 2010), and changes are often implemented at multiple scales (both temporal and spatial) and dimensions. Transformability can take place following the collapse of the previous system, but it can also be the result of planned incremental changes (Meuwissen et al, 2019). Transformability requires changes in production methods to be possible or high levels of diversity, which enable the reorientation of the system. This could be the case of switching from one agricultural system (conventional farming) to another (i.e. organic agriculture). The biophysical environment in which farming takes place is important in enabling transformability, for instance, avoiding practices that impede the ability to reverse land use changes (e.g. soil sealing) or contaminate soil. As such, allowing for change at smaller scales will make it possible to enable resilience at larger scales (Folke et al, 2010). Also, avoiding farmer lock-ins into specific production methods or technologies is crucial to ensure the transformability of farming systems. Digitalisation can also play a role in enabling transformability, for instance, at an institutional level by providing data to guide decision-making processes to tailor the needs of specific farm types (Ehlers et al, 2022).

While this section has focused mostly on the environmental aspect of resilience, it is important to note that there are economic and social barriers and challenges to the uptake of some of these practices. For example, in the case of crop diversification, a key component of resilient systems, farmers implementing longer crop rotations are often faced with the difficulty of finding market support to sell the minority crops (Meynard et al, 2013). Although not addressed in detail in this research brief, it is crucial to identify and address the barriers that are blocking the transition towards sustainable and resilient food and farming systems.

Finally, going back to the links between sustainability and resilience. It is imperative to ask about the sustainability of the farming system for which resilience is being enhanced, as increasing the resilience of an unsustainable system will only perpetuate current problems. In this sense, a starting point for addressing system resilience in the farming sector could be asking what transformations are required to make these systems both resilient and sustainable?

3.4 Assessing the trade-offs

General versus specified resilience

Assessing the resilience of farming systems is a complex task that cannot be undertaken from a single perspective or a unique resilience capacity. Responses to disturbance will sometimes require robustness, adaptation, complete transformation or a combination of the three. Given the speed at which climate change perturbations are impacting the agricultural sector and the unpredictability of future political or economic developments, it is crucial that the overall transformability of the system is not compromised when building robustness and adaptation against current and future stresses and shocks, particularly where the current system is not sustainable.

Choices made by farmers and other actors will inevitably lead to trade-offs. Intensification processes, leading to specialisation, can increase production outputs and, to a certain extent, the robustness of farming systems. However, specialisation reduces their ability to adapt and transform (Hoekstra, Bredenhoff-Bijlsma and Krol, 2018). The current focus on production efficiency has eliminated system redundancies, leading to an overall loss of system resilience and causing unsustainability (Walker, Salt and Reid, 2012). Diversification (e.g. from crop diversity to business diversification) appears to be key to increasing the resilience of farming systems. While diversification may remove the focus from exploiting the current system's strengths (e.g. in terms of efficiency economies of scale) (Darnhofer et al, 2010), looking only at profitability from a yield perspective can be limiting when increasing resilience, as diversification can open new income streams that compensate for (initial) yield losses (Pappo et al, 2023). At a broader food system level, dietary shifts towards an increased share of plant-based foods and reductions in food waste would allow for a de-intensification of food production without compromising food security (Poux and Aubert, 2018).

Increasing general resilience capacities can provide benefits over focusing on increasing specified resilience. On the one hand, this is because isolating the resilience needed to address a specific disturbance for assessment is difficult due to the temporal overlap between long-term stresses and short-term shocks (Roosevelt, Raile and Anderson, 2023). On the other hand, because stresses and shocks can also evolve over time, making specified resilience obsolete if no longer adapted to currently unforeseen and unpredictable perturbations. This question is of particular importance in the case of technological solutions targeting specific stresses and can take a few years to develop and reach the market in comparison to the speed at which the effects of climate change are impacting agriculture and changing the environment in which farmers operate (Lin et al, 2011). Awareness that increasing specified resilience can reduce the capacity of the system to respond to other disturbances is needed when considering solutions to increase the resilience of the system (Folke et al, 2010).

Pursuing general resilience over specified resilience is more likely to also support system transformation, given that robustness and adaptability tend to contribute to enhancing the resilience of the current system, as opposed to building a different one. It is therefore vital to understand that that the path to system transformation will lead to trade-offs, not only between different resilience capacities, but also more generally among stakeholders and economic activities (Ingram et al, 2023). This raises the need for discussions on the desired sustainable food system outcomes as well as the acceptable level of trade-offs for the wide range of stakeholders involved in food systems transformations.

Table 2: Examples of practices and actions that enhance resilience capacities of farms in general and specified ways, in relation to biophysical stresses (Cabell and Oelofse, 2012; Darnhofer et al, 2010; de Goede, Gremmen and Blom-Zandstra, 2013)

	General resilience	Specified resilience
Robustness	*Improving soil health* *Crop diversification* *Agroforestry* *On-farm biodiversity*	*Sustainable irrigation systems* *Animal breeding* *Early-warning systems*
Adaptability	*Learning and experimenting* *Diversification of practices (contrary to specialisation)* *Access to knowledge and finance* *Digitalisation*	*Precision agriculture* *Gene editing* *Temperature control systems in animal housing*

	Diversity and redundancy	
Transformability	*Avoiding lock-ins* *Nature-based solutions* *Crop diversification* *Landscape-scale approaches*	*Reduction of chemical inputs*

Local versus global

Since the COVID-19 pandemic, growing attention has been given to the spatial scale at which agricultural production takes place, leading to polarised debates over locally-centred food systems vs globally coordinated ones, large vs small-scale farming systems, increasing self-sufficiency vs more involvement in global markets through trade, prioritising local or larger communities and so on (Ben Hassen and El Bilali, 2022; Hiller, Bas-Defossez and Baldock, 2021; Wood et al, 2023). Depending on the chosen interpretation of the scale at which sustainability challenges should be addressed, different approaches to resilience can emerge, with differing outcomes. If we take the example of food insecurity and trade, trade can be seen both as increasing resilience since it diversifies food supply routes (Janssens et al, 2020) but also reducing resilience as export-reliant countries risk losing food sovereignty (Alandia et al, 2020).

Table 3: Examples of arguments in relation to food insecurity and trade and proposed strategies to reframe those arguments through a resilience lens, from Wood et al (2023).

Archetypal "local arguments"	**Archetypal "global" arguments**	**Resilience-based transformative pathways**
- Global food systems can drive food insecurity by, for example, leaving import-reliant countries vulnerable to the disruptions and volatility of the global market - Export-reliant countries often lose food	- Global trade is a critical tool to ensure the availability, affordability, and stability of food supply - Global trade helps provide more equitable access to food - Global trade (and thus diversified sources of food supply) provides a	- Sufficiently yet not overly connected food systems enhance resilience in the face of either local or global disturbances - Trade structures need to allow for and incentivise connection to markets at different scales

sovereignty as they integrate into the global market	buffer against local disturbances to the food supply	- Alternative trade structures, for example, dormant links, could ensure food security during disturbance

Resilience thinking requires looking at the complex dynamics that arise from interactions between human and ecological systems at different spatial and temporal scales while moving towards a more desirable development. Table 3 shows that by shifting the focus from the scale element to the resilience capacity to be enhanced, the study of resilience can contribute to shedding some light on some of the local versus global pathways to sustainability.

If fully aligned with the overall goals of a transition towards more sustainable food systems, the study of resilience and its capacities can contribute to making links between decision-making processes at multiple scales and help define tools to operationalise sustainability when moving across scales from specified to general resilience, or across timelines from robustness to transformational capacities. Resilience, therefore, can be a powerful tool to identify transformative pathways for a wide range of different stakeholders operating at different levels and at multiple scales. This will require continuous negotiations to align different views and agree on common resilience frameworks, as well as having governance structures in place that create trust and enable action.

ROLE OF POLICY, RESEARCH AND INNOVATION

As crucial as the study of the resilience of food and farming systems is when facing the challenges posed by climate change and other long-term and short-term stresses and disturbances, many knowledge gaps remain to move from a conceptual approach to one that is implementable so that solutions can be put into action on the ground. This section discusses the role of policies and innovation in enabling the resilience capacities as outlined in section 2.1 and presents areas on which future research could focus to move forward.

4.1 Policy support for resilience

How can policies support food system resilience and, more specifically, the three resilience capacities in the farming sector? According to Buitenhuis et al (2020), robustness-enabling policies in the farming sector are those characterised by '*a short-term focus on recovery of existing functions of the system, protecting the status quo, providing buffer resources and government-supported modes of risk management*'. Adaptability-enabling policies are described '*by a focus on the medium term (one to five years) and flexibility that allows for tailor-made responses, they enable variety between and within farming systems, and support social learning*'. Finally, they define transformability-enabling policies as those that have a long-term focus, remove incentives that support the status quo (to encourage change) and support learning and innovation.

The Farm to Fork Strategy (European Commission, 2020), one of the EU Green Deal's flagship initiatives, paved the way for more sustainable and resilient food and farming systems, including a proposal for a legislative framework for sustainable food systems[1] (FSFS). While several of the components of the Strategy have been watered down over the past years, and the FSFS proposal itself has been repeatedly postponed, its aim to help the EU transition towards a resilient EU food system provided some pathways towards reducing environmental and climate impacts of agriculture and increase its resilience to climate change. Since the Common Agricultural Policy (CAP) shapes the EU agricultural sector, achieving the goals of the Farm to Fork Strategy will largely depend on how the CAP aligns with its objectives and how sustainability and resilience are supported therein.

A close look at policy support for resilience in the farming sector has generally been limited to one resilience capacity, robustness, and narrowly understood

[1] This was announced as part of the European Commission's work programme for 2023

from a risk management and economic perspective[2]. This is well exemplified by the EU's CAP. While the CAP does not have resilience as one of its key goals, it mentions the term under the objectives of 'ensuring a viable farm income' and 'climate change action'. In practice, however, the support for resilience within the CAP is directed towards increasing robustness, and economic robustness in particular (Žičkienė et al, 2022). Buitenhuis et al (2022) identified the main interventions in the CAP that enhance the three resilience capacities. They identified robustness-oriented interventions as direct payments, market safety net instruments, crisis reserves and support for insurance schemes. Adaptability interventions, with a lower share of the budget, were mostly rural development measures, including agri-environmental measures, investment support for sustainable farming practices and the LEADER programme. They found the CAP limited transformability, with its focus placed on maintaining the status quo and little support offered for long-term system changes. Exceptions to this were support for organic farming, new rural value chains and the EIP-Agri, with its focus on innovation and knowledge exchange. Finally, the new eco-schemes could enhance the three resilience capacities by shifting farming practices towards e.g. improved soil management and introduction of biodiversity features. However, the level of ambition of some of the eco-schemes remains low (Midler et al, 2023).

The observation that the CAP may be limiting the transformability of the farming sector is important here. Other studies have observed that by supporting a specified resilience capacity, policy instruments can constrain the support for others (Ashkenazy et al, 2018). Using a bottom-up approach, Buitenhuis et al (2022) explored whether and how policies enabled or constrained the resilience of farming systems from a farm system-level perspective in several EU Member States. They observed that a robustness measure like direct payments constrained the adaptability of farming systems by allowing unsustainable farming models to continue operating. They also discouraged the search for innovative opportunities which would enhance business adaptability. Research has shown that similar conclusions can also be drawn with regard to risk management tools such as risk insurance payments, especially if subsidised, leading to maladaptation practices both in high-income and low and medium-income countries (Müller, Johnson and Kreuer, 2017; Santeramo and Ford Ramsey, 2017).

Mathijs et al (2022) identified six principles to create a resilient-enabling environment for farming systems, which could be used to guide policy

[2] See for instance the recent draft opinion by the Natural Resources commission in the Committee of the Regions on strengthening the sustainability and resilience of EU agriculture https://cor.europa.eu/en/news/Pages/Regions-and-cities-want-new-criteria-and-rules-to-support-farmers-hit-by-natural-disasters-and-crises.aspx

development. These are: (i) help the system cope first in the face of stress or a shock, but with temporal relief measures; (ii) build anticipatory and responsive capacities before shocks take place; (iii) assess the long-term trends and challenges (to build for the three capacities); (iv) encourage a diversity of responses, rather than focusing on a limited set of actions; (v) balance support between short-term vs. long-term challenges; and finally, (vi) analyse the root causes of the challenges, to ensure the real problem is fixed. Following these guiding principles should allow for the provision of the immediate support that farmers need to respond to shocks while at the same time keeping the focus on long-term solutions that build adaptability and transformability capacities for farming systems.

Enlarging the scope beyond the current focus on robustness, and specifically on coping, is therefore crucial for the long-term sustainability and resilience of farming systems (Finger, 2023). This requires an in-depth understanding of how to enable system resilience in front of the multi-dimensional challenges and applied to the different EU contexts. In the next section, we explore the role of research and innovation in contributing to filling current knowledge gaps.

4.2 EU funded R&I for food system resilience

Resilience is already at the core of Horizon Europe (HEU), which is described as one of the EU's key instruments to *"steer and accelerate Europe's recovery, preparedness and resilience"* (European Commission, 2021). "Creating a more resilient, inclusive and democratic European society" is listed among the four key strategic orientations of the strategic plan for 2021-2024 (strategic orientation D). However, Horizon Europe cluster 6 (Food, Bioeconomy, Natural Resources, Agriculture and Environment) is set to contribute mainly to strategic orientations B *"restoring Europe's ecosystems and biodiversity and managing sustainably natural resources"* and to a lesser extent C *"making Europe the first digitally-enabled circular, climate-neutral and sustainable economy"*. Interestingly, in the description of strategic orientation B, resilience is never mentioned directly. In the presentation of the impacts of Cluster 6 under this strategic orientation, resilience is often mentioned as an outcome of R&I efforts towards increasing adaptation to climate change but rarely in tandem with the concept of a transition to more sustainable food systems.

This is probably a reflection of past European projects from Horizon2020, which focused more on the robustness and adaptability aspects of resilience and looked for ways of improving crop resistance from stresses related to climate change in a production-oriented food systems framing. This is the case for example of the ADAPT project, looking at stress-resistant potato cultivars; BRESOV, focusing on efficiency and productivity of several organic vegetables, BreedingValue, looking at berry production, SolACE focusing on crop efficiency for water and nutrient use or BUNGEE on New Genomic Techniques (NGTs) solutions and many others. Other projects looked more into the impact of climate change on key components of a farming system, such as the RECARE project that identified and analysed threats to soil protection. Animal science can also be mentioned here with regard to research on animal breeding to increase animal resilience (mainly to heat stresses), as in the case of the SMARTER project. Finally, HEALTHYMINORCEREALS contributes to the study of climate resilience by investigating minor cereal varieties for biotic and abiotic stress resistance.

The interpretation of resilience in the R&I narrative of Horizon Europe in the current strategic plan seems to change in relation to strategic orientation C, where the notions of social and economic sustainability and resilience are presented more explicitly together. R&I is called to strengthen them through a better understanding of the social, ethical, political and economic impacts of drivers of change (such as technology, globalisation, demographics, mobility and migration) and their interplay. Cluster 6 contributes to achieving this outcome by developing and monitoring innovative governance models enabling sustainability and resilience through community-led, multi-actor, risk-aware, place-based innovations that would benefit the whole food supply chain and beyond.

Such an approach is well reflected, for example, in the Horizon Europe Mission "A Soil Deal for Europe" through living labs and lighthouses and in the partnership on "Accelerating farming systems transition: agroecology living labs and research infrastructures", aiming at investigating the potential of agroecology to accelerate the transition towards resilient, sustainable, climate-, ecosystem- and social-friendly farming systems. Several projects also implemented this approach in the past, such as DiverIMPACTS, Diverfarming or LEGUMINOSE, that looked at technological, organisational and institutional barriers to the implementation of crop diversification and intercropping all along the value chains and within the sociotechnical system (policies, education, research, regulation) across Europe. Other projects like LANDMARK investigated trade-offs between soil ecosystem services, including soil functions that would improve soil resilience.

The need to approach resilience in a systemic way was also the main objective of the SUREFARM project. SUREFARM developed a comprehensive resilience-enabling framework, a set of advanced risk assessment and management tools as well as an improved demographic assessment model and a resilience assessment tool for policies. These tools were developed together with stakeholders, who were also directly involved in applying the integrated resilience assessment model and in co-designing implementation roadmaps on a few case studies. In doing so, the project applied the adaptability, robustness and transformability capacities discussed in section 2 and 3 of this paper to assess the resilience of farming systems and factored in a range of economic, environmental, and social challenges.

4.3 Knowledge gaps and recommendations for future resilience R&I

Overall, several research needs emerged from the study of past research projects and literature in relation to assessing the resilience of food and farming systems against stresses and shocks.

First, the **definition of concepts and system boundaries.** While a lot of research has already been carried out from a theoretical perspective, this paper has illustrated how resilience is better understood in a dynamic framework, especially if it is connected to sustainability and sustainable food systems, which require constant negotiation and agreement of the "*what*" and "*how*". As further research is carried out on the outcomes that sustainable food systems should pursue, it seems crucial that resilience is embedded in these reflections in an effort of dynamic and continuous conceptualisation. On the other hand, when looking at resilience, research should make use of a sustainability lens, making sure that resilience is not discussed as a standalone descriptive concept applied to today's food systems but rather as a property of the transition towards more sustainable ones. For this, even greater connections with social sciences could be explored to make sure that the social and economic elements are considered at every scale and from different stakeholder perspectives alongside the environmental perspective. Doing so would also help identify potential trade-offs between different desired outcomes that may contradict each other, thus providing a better understanding of how to move towards more resilient and sustainable food systems in the future. Avenues of future research could focus, for example, on the resilience and sustainability of short-term and long-term gains, as well as on the balance between diversification and specialisation, intensification and extensification, self-sufficiency and import dependency. The issue of food loss and waste, together with dietary shifts towards plant-based foods, should also be integrated in these research avenues. Using an SES frame would be useful to capture the many interactions between social and ecological systems, as well as their multiple actors, levels, and scales.

Second, future research should continue to focus on **identifying and further describing shocks and stresses** that might affect food systems directly and indirectly to increase our understanding of how they might overlap and combine, as well as the way they affect the different levels and actors of the food chain. For this, more research will need to be conducted on **establishing metrics and**

indicators to measure resilience in conjunction with sustainability considerations. Despite the many resilience theories from socio-ecological systems, there are still large limitations on what can be achieved in terms of understanding the starting point for a system as well as the metrics through which resilience should be measured. The lack of indicators to measure agroecosystem resilience has been pointed out over the years (Cabell and Oelofse, 2012; Roosevelt, Raile and Anderson, 2023). Several indicators have been proposed to measure resilience in farming systems, mostly linked to its economic dimension. One of them is yield and whether it can be maintained after disturbance. While straightforward to measure, it is a reductionist approach considering what has been described above. From a farmer's perspective, it also does not consider the fact that production costs might increase after disturbance to maintain yields (Pappo et al, 2023). Pappo et al (2023) suggested looking at profitability rather than yields since they say it is highest when optimal environmental conditions are given. However, this approach is also subject to how productivity is defined. Therefore, establishing metrics and indicators that are flexible and broadly applicable to quantify and monitor different aspects of resilience will fill a significant gap. This would also be an important step towards new **modelling approaches** to generate and integrate data across multiple spatial and temporal scales. In the context of climate change, such an exercise would increase our capacity to anticipate (if not predict) stresses and shocks and improve risk management practices.

Third, future research should investigate the **stakeholders' perceptions of resilience at different levels of the food value chain**, in comparison with the theoretical approach to resilience. For example, recent research has shown that farmers mainly assess resilience in terms of its short-term robustness capacity rather than in its transformative capacity (Perrin, Milestad and Martin, 2020). Understanding the roles and gaps that farmers and other food system actors can play when increasing system resilience is also needed (Soriano et al, 2023). Future research could investigate further in this direction and focus **on interdependencies between different resilience capacities**. What would change farmers' perception of resilience to include long-term transformative strategies aligned with sustainable food system transitions while maintaining existing robustness? Improving our understanding of farmers' perceptions should also orient research towards the development of better training and advisory programmes to support farm resilience to a variety of disturbances. This would be particularly relevant in relation to the challenge of generational renewal in agriculture, which is central to ensuring the continuation of farming (Coopmans et al, 2021). The same approach could be applied upstream in the food value chain and in relation to the study of food environments.

Fourth, research should continue to look at **measures and interventions that can strengthen the resilience of food systems**. Experimental research will still be needed across the food supply chain and beyond, building on the bottom-up approach of initiatives such as Horizon Europe's Missions and partnerships. Living labs, bringing together different stakeholders, facilitate an understanding of the political, economic, and social contexts as well as the different environmental and climate settings when testing innovative solutions. As research will look at both technological and nature-based solutions, it will be important to consider them as part of a broader picture and study how they would integrate into the system.

Technological solutions such as plant breeding for resilience, digital solutions, cellular agriculture or alternatives to chemical inputs such as biocontrol can contribute in different and complementary ways to increasing food system resilience (for example, by potentially reducing the exposure of crops to climate disruption) and have already emerged as key research areas in the past decade (Bapat et al, 2022). Data and digital solutions, including AI, are already an integral part of the food systems, and they are responsible for important transformations at different scales, from production to consumption. Alternative proteins, easing pressure on natural resources, are seen as part of the solution to meeting future global protein demand while staying within planetary boundaries (Søndergaard et al, 2023). As a system and balanced alternative to chemical inputs in farming, biocontrol provides plant protection while reducing chemical pressure in the environment (van Lenteren et al, 2018). However, while some of these technologies and innovations can be used to increase specified resilience, they come with potential challenges, costs and risks, e.g. in economic, social and ethical dimensions (Finger, 2023, Søndergaard et al, 2023). For example, potential benefits of digitalisation are currently unequally distributed within regions and cropping systems, and the current digital divide deepens inequality and concentration of power, with negative repercussions on the resilience of food systems at different scales (Finger, 2023). While some of these challenges have already been addressed by Horizon Europe,[3] more research needs to be carried out to address barriers to access as well as the safe and ethical use of digital technologies (e.g. data ownership and access, democratisation) as technologies continue to evolve (Marvin et al, 2022).

[3] See for example HORIZON-CL6-2023-GOVERNANCE-01-17 - Data-driven solutions to foster industry's contribution to inclusive and sustainable food systems, 2022-GOVERNANCE-10 "Piloting approaches and tools to empower citizens to exercise their "data rights" in food and nutrition" and HORIZON-CL6-2024-FARM2FORK-01-8 "Preventing and reducing food waste to reduce environmental impacts and to help reach 2030 climate targets".

Agroecological approaches, such as organic farming, can enhance socio-economic resilience through diversification and reduce dependency on external inputs (Poux and Aubert, 2018). Applying technological solutions to support these agroecological approaches (e.g. with regards to the study of plant responses to stresses and shocks, the impact on yield, crop quality and other parameters) could reduce the risk of overlooking wider socio-economic and political processes that could undermine general resilience and sustainability in the long term such as concentrating power in agri-food economies or separating agriculture from natural ecosystems (Fischer, 2016; Howard, 2022; Moyano-Fernández, 2023).

Fifth, all these elements point towards the need to address resilience within the governance of food systems. Research should be carried out to understand the **governance processes** that either build or hamper the resilience of food systems. Shocks and stresses can exacerbate existing inequalities and imbalances within food systems, which makes bouncing back capacities far from the ideal option according to a variety of stakeholders (de Steenhuijsen Piters et al, 2021). Several questions arise, which future research should continue to address to feed the bigger debate over the governance of sustainable food systems from a resilience perspective. How to make sure that all levels of governance are considered? How to find the right balance between top-down and bottom-up approaches, as well as between more formal and informal power structures, both in the West and in the Global South? What is the role of the private sector and of civil society? When addressing these questions, it will be crucial to link European research to other initiatives at the global level, such as, for example CGIAR Action Area Resilient Agrifood Systems[4] and the connected Regional Integrated Initiatives.

Looking at innovative solutions for resilience from an environmental, social, and economic sustainability perspective will help prioritise research and assess trade-offs and implications for their adoption locally, regionally and globally. Most importantly, it will provide opportunities for integrated, joined-up research solutions looking at both resilience and sustainability. In this sense, the work carried out by existing initiatives such as the "Global Network of Lighthouse Farms", "Agroecological Lighthouses" and "Seeds of Good Anthropocenes" provides a starting point in identifying disruptive yet realistic innovations and approaches on which to build and follow a sustainable transformation of our food systems in a "learning from the future exercise" (Valencia et al, 2022). Their integration into resilience thinking will help shift the focus from past system resilience to transformative pathways. What are these innovative approaches

[4] See here for more information on CGIAR work on resilience: https://www.cgiar.org/research/action-areas/

mixing nature-based and more tech-oriented solutions telling us regarding the current context of biotic, abiotic, and economic shocks and stresses? What kind of new needs and necessary changes would they require to function, as they might also be subject to external shocks from outside the scope of food systems (e.g. infrastructure for digital solutions and cybersecurity threats, vertical indoor farming and energy supply…)?

Strengthening the link between sustainability and resilience will eventually improve both. Research looking at exploring, identifying, and enhancing such synergies needs to be further supported and accelerated.

CONCLUSIONS AND RECOMMENDATIONS

Resilience appears to be a concept that can help build food systems' capacities to continue delivering sustainable outcomes in the face of both predictable and unpredictable disturbances.

This brief identifies the factors that contribute to food and farming system resilience and explores their links with sustainability. It concludes that resilience is an important factor that contributes to food system transformation that can guide decision-making processes, but that sustainability norms should be the framework under which resilience operates. Leaving the sustainability framework out can lead to situations in which system resilience is increased (in the short-term) at the cost of sustainability.

Strategies to increase the resilience of food and farming systems should focus on environmental, economic, and social aspects, in order to identify trade-offs and synergies at different scales. Policies should be put in place to accompany these changes. In the example provided in this brief, we observed that diversity is generally described as a central component of farming system resilience. However, despite this, evidence shows that EU agriculture has evolved towards efficiency and simplicity over time, leading to a reduction in environmental and social resilience. In addition, this has been accompanied by a reductionist view of resilience as economic robustness in farming policies, further limiting farmers' capacity to invest in adaptability and transformability measures that allow for longer-term responses to perturbations.

EU food systems could benefit from additional research on the resilience concept, its applicability to different contexts and links to sustainability. Currently, resilience is often studied in relation to adaptation to climate change and food security, while its transformative capacity is generally linked to agroecology projects, which also follow a systemic approach and address all dimensions of sustainability in a transforming effort. If resilience is to be intended as an intrinstic factor of food system transformation, it should continue to be applied to all areas of agricultural and food system research. In the meantime, further research should be funded to delve into the resilience concept and its application to food and farming systems, including developing metrics and tools, pursuing the efforts of projects such as SUREFARM. Identifying ways to build resilience, aligned with sustainability, through innovations or policies is also crucial to make space for new solutions and factor them in into transformative scenarios and modelling, following a "learning from the future" approach.

The EU food system could benefit from additional research on the resilience concept, its applicability to different contexts and links to sustainability.

Box 1: Four main areas for further research identified in this brief:

- ***Work on the definition of concepts and system boundaries***, in relation to resilience and its links to sustainability
- ***Improve the identification of shocks and stresses*** that might affect food systems directly and indirecty (both at present and in the future) and establish metrics and indicators to measure resilience
- Better understanding of stakeholders' perceptions of resilience and the interdependence between resilience capacities
- Explore measures and interventions that can strengthen the resilience of food systems, from knowledge exchange to nature-based and technological solutions.
- Understanding of the **governance processes** that can build or hamper food system resilience

Finally, guiding food system towards increased sustainability and resilience is a necessary task that will require the engagement of all actors in the food system. Research and innovation funding should ensure that the researched solutions encompass the widest range of contexts, scales and actors, and that today's responses to increase the resilience of the sector do not compromise its future delivery of desired outcomes.

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