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An Analytical Framework for Measuring Food System Resilience in Fragile Situations

Elena Serfilippi[1]*, Alessandra Garbero[2]*, Francisca Castro[3]*, Timur Cipa[4], Tilman Brück[5] & Wolfgang Stojetz[6]

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Abstract
This paper introduces a comprehensive analytical framework for measuring food system resilience in fragile situations, integrating the concepts of resilience and fragility. Our proposed framework defines resilience as structural, institutional, and individual capacities at macro, meso, and micro levels. Fragility is characterized by weak institutional performance and heightened vulnerabilities at the macro level, and operationalized by individual and community perceptions and experiences of fragility at the meso and micro levels. The framework emphasizes a multi-level approach to food systems, clearly distinguishing systemic fragility from individual resilience capacities. It proposes a measurement framework with indicators across economic, environmental and climate, security and social, and political and institutional dimensions. This framework can be implemented empirically with an agile measurement system employing a combination of secondary data (including satellite imagery, event data, and administrative records) and frequent, short-duration primary surveys capturing both objective conditions and subjective experiences in challenging environments. Ultimately, the proposed framework serves as a robust tool to analyze how food systems respond to stressors in fragile situations, providing actionable insights for enhancing resilience.

Keywords
Food systems; Fragile situations; Conflict-affected contexts; Resilience

[1] Committee on Sustainability Assessment (COSA), Philadelphia, United States. Email: es@thecosa.org.
[2] International Fund for Agricultural Development (IFAD), Rome, Italy. Email: a.garbero@ifad.org.
[3] **Corresponding author.** ISDC - International Security and Development Center, Berlin, Germany. Email: castro@isdc.org.
[4] ISDC - International Security and Development Center, Berlin, Germany. Email: cipa@isdc.org.
[5] ISDC - International Security and Development Center, Berlin, Germany; Humboldt-University of Berlin, Berlin, Germany; IGZ, Großbeeren, Germany. Email: brueck@isdc.org.
[6] ISDC - International Security and Development Center, Berlin, Germany. Email: stojetz@isdc.org.
* Shared first authorship

1 Introduction

Fragile situations are environments characterized by significantly impaired institutional and governance capacity, when states are unable to deliver basic services effectively, unable to enforce the rule of law and the (legitimate) monopoly of violence, and unable to respond to shocks or crises. These systemic conditions often co-exist with or exacerbate active conflict situations, fundamentally challenging efforts to sustain peace, economic growth, and social development (World Bank, 2024). Within these contexts, food systems frequently face severe disruptions across production, distribution, and consumption, causing hunger and putting lives and livelihoods at risk.

Such conditions amplify pre-existing vulnerabilities, intensify food insecurity risks, and disproportionately impact marginalized and vulnerable groups, including women, children, indigenous people and displaced populations (Stojetz & Brück, 2023). Despite the pressing need to understand how food systems respond in fragile situations, significant knowledge gaps persist, particularly regarding how food system disruptions affect vulnerable populations in fragile settings. The anticipated increase in the frequency and intensity of shocks – driven by climate change, geopolitical tensions, and economic instability – underscores the urgency of developing effective approaches to strengthening food system resilience. Identifying risks and vulnerabilities at an early stage can facilitate timely responses and strengthen the adaptive capacities of food systems, thereby mitigating the risk of extensive hunger crises, especially so in fragile settings. Beyond immediate crisis management, sustainable strategies that systematically enhance food system resilience are essential in an increasingly unpredictable global landscape.

Current understanding of food system resilience in fragile situations is limited by both conceptual and methodological constraints. Conceptually, existing food systems frameworks require significant adaptation to capture the specific challenges of acute fragility (Frankenberger & Nelson, 2023). While micro-level approaches have proven useful for understanding food systems more generally, comprehensive frameworks that explicitly address how fragility and conflict interact and impact food systems globally remain scarce. Fragility has predominantly been analyzed at the aggregate level, particularly at the state level (Baliki et al., 2022), often overlooking its diverse and localized manifestations at community and household levels.

Methodologically, data collection in fragile situations faces security risks, logistical barriers, and collapsed information infrastructure, creating significant gaps in both the scope and quality of available evidence (Martin-Shields & Stojetz, 2019; Kayaoglu, Baliki & Brück, 2023). This scarcity creates a circular problem: without adequate information, interventions may be misaligned with actual needs, potentially worsening rather than alleviating food insecurity.

To address these conceptual and methodological knowledge gaps, we develop a comprehensive and integrated analytical framework for measuring food system resilience in fragile situations. First, we extend fragility analyses beyond the traditional state level to examine how institutional breakdowns

and service failures manifest at community and household levels, recognizing that fragility affects different food system actors in distinct ways. Second, we integrate fragility and resilience as complementary rather than opposing dimensions, distinguishing between fragility conditions (system failures and exposures) and resilience capacities (actor resources and capabilities). Third, we propose a multi-level measurement framework that can deliver insights in data-scarce environments while accounting for the essential interactions between the macro-level institutional failures, meso-level community disruptions, and micro-level household experiences.

This multi-level approach captures how fragility affects different parts of food systems simultaneously, revealing interconnections that single-level analyses might overlook. The framework offers practical value for policymakers, humanitarian organizations, and researchers working to strengthen food security in some of the world's most challenging contexts, providing targeted dimensions to monitor even when comprehensive data collection is impossible. While conflict is one significant driver of fragility, our framework focuses on measuring fragility conditions themselves – whether stemming from armed conflict, economic collapse, environmental degradation, or governance failures – enabling application across diverse fragile contexts.

In doing so, we contribute to several literatures on both fragility (Baliki et al. 2022a; Baliki & Brück, 2023; Stojetz et al., 2025) and resilience (Zaharia et al., 2021; Béné et al., 2016; Barrett et al., 2021; Constas et al., 2014; Cissé & Barrett, 2018; Carter 2024), paying special attention to the examination of both aspects through the lens of the food system (Béné et al., 2023; Frankenberger & Nelson, 2023).

This paper is structured as follows. Section 2 builds on existing literature to outline our conceptual approaches to food systems, resilience, and fragility. Section 3 builds on these pillars to develop our conceptual approach for analyzing the resilience of food systems in fragile situations. Guided by these measurement principles, Section 4 outlines our approach to measuring food system resilience in fragile situations. Section 5 presents the measurement framework. Section 6 concludes by reflecting on the measurement framework vis-à-vis data collection and applicability across settings.

2 Conceptual Foundations

2.1 Food Systems

Understanding what constitutes a food system is essential for food security, as it provides a framework to examine the connections between supply, demand, regulation, sociocultural and environmental factors. The High Level Panel of Experts on Food Security and Nutrition (HLPE, 2017) defines food systems comprehensively as encompassing all elements and activities related to the production, processing, distribution, preparation, and consumption of food, as well as impacts on nutrition, health, socio-economic aspects, and environmental sustainability. This holistic definition has been

widely adopted and emphasizes the need to study not just food supply chains but also food environments, consumer behaviors, and broader system outcomes.

According to the International Food Policy Research Institute (IFPRI), food systems are defined as "the sum of actors and interactions along the food value chain – from the production of crops, livestock, fish, and other agricultural commodities to their transportation, processing, wholesaling, preparation, consumption, and disposal" (Fan et al. 2021, p. 2). Similarly, Zurek et al. (2022) describe food systems as encompassing all activities critical to the production, processing, distribution, retailing, preparation, and consumption of food.

The UN defines food systems as encompassing "the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption, and disposal (loss or waste) of food products originating from agriculture (including livestock), forestry, fisheries, and food industries, within the broader economic, societal, and natural environments" (von Braun et al. 2021, p.7). This definition emphasizes that food systems not only include the activities and interactions of actors within the value chain but also the institutions that shape and regulate these processes. These include governmental bodies, international organizations, and private sector stakeholders, which play crucial roles in regulating food safety and influencing systems' functioning.

Several scholars have proposed frameworks to analyze food systems with a focus on achieving food security, environmental sustainability, and social well-being. For instance, Zurayk et al. (2022) and Van Berkum et al. (2018) offer frameworks that, while sharing common goals, emphasize different aspects and levels of the food system, such as supply chains, food environments, and individual consumer behavior. These frameworks highlight the systemic nature of food production and consumption, moving beyond linear value chain approaches to recognize feedback mechanisms and multi-level interactions. Building on these frameworks and the HLPE (2017) approach, we adopt a multi-level perspective that distinguishes between micro (producers, traders, consumers, households), meso (community and community organizations), and macro (national institutions, governance, endowments, competition) components – an approach that is particularly valuable for analyzing food systems in fragile contexts. This perspective also emphasizes the influence of external drivers, including socioeconomic factors and climate change, on food system components. Importantly, they recognize that food systems are embedded within broader social, economic, and ecological systems, making them vulnerable to disruptions from multiple sources (Tendall et al., 2015).

Food systems and value chain frameworks intersect along many dimensions and complement each other. The Food and Agriculture Organization (FAO) Sustainable Food Value Chain framework advances a systems-based view – drawing connections between core value chains, extended chains, and the enabling environment – and highlights the importance of analyzing interlinked subsystems to identify vulnerabilities and improve resilience within food systems (FAO, 2014, FAO & UNIDO 2024) Similarly, the International Fund for Agricultural Development (IFAD) emphasizes reducing food loss by mapping specific value chain nodes where losses occur and building supportive institutional

environments to enable corrective action (IFAD, 2022). More broadly, value chain analysis considers the vertical sequence of actors – producers, processors, traders, retailers – while also examining horizontal layers such as input provision, finance, and regulatory contexts that shape how chains function and affect inclusion, sustainability, and resilience (Kaplinsky and Morris, 2001). Integrating these approaches strengthens food system analyses by combining system-wide perspectives with targeted entry points for intervention, enabling strategies that enhance both system coherence and actor-level resilience.

2.2 Resilience

Resilience has been conceptualized in three primary and related ways by the literature: as a set of capacities, as a return to equilibrium, and as a normative condition. The capacity definition was introduced by Béné et al. (2012; 2015), embedded in the resilience measurement frameworks developed by USAID (2018) and FAO (2016), and later embraced by the UN (2021). This definition views resilience as the ability of individuals, households, communities, cities, institutions, systems, and societies to prevent, resist, absorb, adapt, respond, and recover positively, efficiently, and effectively when faced with a wide range of shocks and stressors while maintaining an acceptable level of functioning. In contrast, resilience as a return to equilibrium conceptualizes resilience as "recovery after decline" (Zaharia et al., 2021; Béné et al., 2016; Barrett et al., 2021). This ability to bounce back depends not solely on the shock's intensity but on the combination of impact and actor responses aimed at mitigating effects. Lastly, resilience as a normative condition (Constas et al., 2014; Cissé & Barrett, 2018) defines resilience as an individual's probability of achieving at least some minimal standard of living condition based on observable characteristics and exposure to stressors and shocks. Recently, Alloush & Carter (2024) introduced a related concept of resilience, measured as the cumulative economic losses that a household experiences over time in the wake of a shock, defined as the difference between a household's post-shock levels of economic well-being and a counterfactual measure of what the household's well-being would have been without the shock.

In this paper, we integrate the capacity and recovery approaches, viewing resilience as the collection of capabilities and resources that enable responses to shocks (Tanner, Bahadur & Moench, 2017; Béné et al., 2020), and the capacity to recover from shocks and stressors. In this regard, Béné (2020) makes an important distinction between resilience (i.e., recovery ability) and resilience capacities. Resilience refers to the actual ability to bounce back from a crisis or a shock: the outcome of the response process. Resilience capacity comprises the elements available for responding to a shock, including both tangible resources (financial assets, infrastructure) and intangible assets (community networks, governance structures). These capacities are thus critical measurement targets for our framework, and both resilience and resilience capacities can co-exist and be measured in a single framework.

This integrated approach allows us to identify specific dimensions (i.e., capacities) that can be strengthened through interventions and assess whether these capacities facilitate recovery from shocks and stressors (Stojetz et al., 2024). This is crucial in fragile contexts where building capacities and

recovery may be the most practical entry point. Since we analyze resilience at the food system level, we use the definition of Béné et al. (2023), who define food system resilience as "the ability of the different individual and institutional actors of the food system to maintain, protect, or successfully recover the key functions of that system despite the impacts of disturbances" (p. 1438).

A key feature of our framework is the acknowledgement that resilience exists at multiple levels, including the individual, household, market, community, and institutional levels (Béné et al., 2012). Further, the focus is not primarily on the resilience of the system, but on the resilience of the actors at micro, meso, and macro levels existing within the system. Understanding resilience across these scales is crucial for developing comprehensive strategies that address specific challenges at each level. The literature has established a clear set of indicators for assessing resilience at the producer (micro) level (e.g., FAO, 2016; USAID, 2018; Béné et al., 2017), while indicators for other levels remain fragmented. For example, at the farmer-community level, UNU-IAS et al. (2014), as well as FAO (2015), propose a set of indicators in the domains of landscape/seascape diversity, ecosystem protection, biodiversity (including agricultural biodiversity), knowledge and innovation, governance and social equity, and livelihoods and well-being.

Although the community represents a relevant meso level of investigation for resilience analysis, a comprehensive food system measurement framework for resilience should also account for indicators associated with the individual market actors (processors, traders, and vendors), as well as indicators capturing market dynamics such as the diversity of business models and the type of products and services (Vroegindewet et al., 2018). In particular, to capture the resilience of market dynamics, the literature identified some core market attributes (USAID, 2018, 2019; Béné et al., 2023; Vroegindewet et al., 2018). These attributes are related to maintaining the diversity and redundancy of system components (e.g., multiple types of farmers, processors, and/or distributors in a value chain, and commercializing multiple processed product lines), providing substitutes for components that may fail in the face of a disturbance as well as managing the connectivity between components to facilitate flows and contain the spread of a disturbance.

Recent literature has extended resilience analysis to agricultural value chains, including those operating in fragile and conflict-affected contexts. Studies drawing on social–ecological systems theory identify principles such as diversity, redundancy, adaptive capacity, and connectivity as central to value chain resilience, while emphasizing the need for integrating these principles into broader food system assessments (e.g., Tendall et al., 2015; Vroegindewey & Hodbod, 2018). In fragile settings, value chain actors face compounded risks from market disruptions, institutional breakdown, and environmental shocks, making collaborative risk management and adaptive governance essential (Vroegindewey & Hodbod, 2018). Tools such as the Market Systems Resilience Index (MSRI) have been developed to assess multi-dimensional resilience across both households and market actors, offering adaptable metrics for data-scarce environments (Choptiany et al., 2021; USAID, 2019). Incorporating value chain perspectives into food system resilience analysis allows for targeted identification of vulnerabilities along specific nodes (producers, processors, traders), while retaining a systems-level view

of how these nodes interact and adapt under stress. This dual perspective is particularly relevant for fragile contexts, where disruptions at one node can cascade rapidly through the system, amplifying impacts on livelihoods, food availability, and market stability.

Following this, resilience should be viewed not as an end in itself, but as a means to promote long-term sustainability and ensure lasting well-being, including food security, healthy diets, and poverty reduction (Béné et al., 2014; Brown, 2013; Constas et al., 2014; UNDP, 2014; Serfilippi & Ramnath, 2018).

2.3 Fragility

Fragility represents a condition of high vulnerability to natural and human-induced shocks (IFAD, 2024), encompassing climate, political, economic, security, and social dimensions. Originally developed in the natural sciences to describe system status (Tabel, 2013), fragility has expanded into social sciences, particularly economics, political science, international development, and peace and conflict studies.

At its core, fragility stems from limited institutional capacity and governance. The World Bank (2024) defines fragility as a systemic condition characterized by low institutional and governance capacity, which impedes a state's ability to function effectively, maintain peace, and foster economic and social development. This institutional weakness reflects the state's inability to protect, include, and unite its people, both socially and economically, resulting in a broken social contract due to the state's capacity or unwillingness to fulfill basic functions (Constas et al., 2021). Following Frankenberger & Nelson et al. (2023), the primary drivers include conflict, weak institutions, fractionalization, and ethnic tensions.

Existing frameworks have predominantly conceptualized fragility at the macro level. The OECD (2016) conceptualizes fragility as the combination of exposure to risk and insufficient coping capacities of states, systems, and communities to manage, absorb, or mitigate these risks. This framework considers fragility across six dimensions (economic, environmental, human, political, security, and societal), adding the human dimension, which is implicit in the IFAD's definition (2024). However, the OECD's (2022) operationalization remains predominantly focused on the state level. These macro-level approaches raise critical questions about how fragility manifests across different scales and actors.

To address this gap, we distinguish between *exposure* to fragility and *experience* of fragility. Exposure to fragility refers to the objective condition of being subject to potential harm, defined by the spatial and temporal intersection between a shock or stressor and the actors or systems concerned (Ide et al., 2014). At the macro level, exposure captures system-wide vulnerabilities such as the presence of conflict, climate hazards, or market collapse affecting an entire country or region. At the meso level (e.g., communities, cooperatives, and local governments), exposure describes the position of these collective actors within a risk environment – such as operating in a conflict-affected supply corridor or

in a drought-prone basin – before considering their specific coping mechanisms. At the micro level (e.g., individual households, farmers, other market actors, or small enterprises), exposure reflects the direct presence of the actor in relation to a hazard or fragility driver, such as farming on flood-prone land, relying on a single buyer in a volatile market, or living in an area affected by recurrent power outages.

Experience of fragility, in contrast, refers to how these exposures translate into actual impacts on functioning and well-being, shaped by the capacity to prepare, absorb, and adapt. At both the meso and micro levels, experience captures the realized effects of exposure in daily operations, which can vary significantly within and between actors, even in the same location, depending on characteristics such as organizational capacity, access to resources, gender, age, or socioeconomic status. The capacity to prepare, absorb, and adapt shapes how exposure conditions are experienced. Consequently, identical exposure conditions can produce vastly different experiences across people and organizations – from emotional responses and perceived threats to concrete operational disruptions and livelihood impacts. We make a fundamental distinction between the availability of basic resources and services at the micro level, which reflects fragility when limited, and their actual usage by actors, which demonstrates resilience capacities. When specific resources and services are at the disposal of the micro actors and are specifically designed to enhance resilience, such as failsafe mechanisms and risk transfer mechanisms, they belong to the resilience sphere.

To illustrate this distinction, limited electricity availability at the national level represents a macro-level exposure condition (reflecting systemic constraints), while frequent power cuts disrupting farm irrigation schedules constitute a micro-level experience of this exposure. Conversely, a household's actual use of electricity for productive purposes reflects a resilience capacity or endowment.

Recent research has connected fragility analysis more directly to agrifood value chain functioning, recognizing that fragile contexts amplify vulnerabilities across production, processing, and market systems. FAO (2023) emphasizes that value chains in conflict-prone and conflict-affected areas should be assessed through both a fragility and a resilience lens, identifying risk hotspots and designing targeted interventions to preserve critical flows of goods and services. Minten et al. (2023) illustrate how Myanmar's rice value chains adapted to political instability and market collapse, highlighting the importance of flexible governance arrangements, diversified market linkages, and social safety nets for value chain actors. Integrating fragility and resilience analysis into value chain assessments enables a more precise understanding of how shocks cascade through interconnected nodes, revealing both systemic weaknesses and entry points for resilience-building.

Our framework extends fragility across macro, meso, and micro levels, maintaining a clear distinction between resilience capacities and fragility exposure and experiences. When examining fragility, we focus on system conditions at a given level (exposure), while resilience refers to capacities – both tangible and intangible – available to actors operating at that level. Building on the exposure-experience distinction established earlier, fragility experience manifests differently across levels. This conceptual approach integrates food systems, resilience, and fragility into a coherent multi-level framework. By

distinguishing clearly between food system levels (micro, meso, and macro), adopting a capacity-focused approach to resilience, complemented by a recovery perspective, and differentiating systemic fragility from individual resilience capacities, we establish a solid foundation for measuring the interplay between fragility and resilience in food systems. This conceptual clarity supports the design of targeted measurement approaches that are both analytically rigorous and operationally feasible even in data-scarce and volatile environments.

3 Food System Resilience in Fragile Situations

3.1 Food System Resilience

Food systems' structure, functions, and evolution are driven by a myriad of factors such as climate change, urbanization, population pressure, policies, politics, and migration (Béné et al., 2020b). These drivers can have both positive and negative impacts, creating opportunities for growth or challenges that require adaptation. Actors within the food system respond to these drivers strategically rather than passively, seeking to exploit opportunities or mitigate risks (HLPE 2017).

Food System Resilience. In the context of socio-ecological systems, the concept of resilience is often understood as the capacity to withstand and manage unwelcome surprises in the face of external disturbances, thereby ensuring the continued provision of essential goods and services (Walker et al., 2006). This aligns with broader resilience theory, which not only considers a system's ability to withstand disturbances but also its capacity to adapt and transform in response to change (Manyena & Gordon, 2014).

When applied to food systems, resilience is thus defined as the capacity of a food system and its components to provide sufficient, appropriate, and accessible food to all, even in the face of unforeseen disturbances (Tendall et al., 2015). This concept encompasses the ability of various actors within the food system to maintain, protect, or recover key functions despite adverse impacts (Béné et al., 2023). In fragile situations, this resilience faces extraordinary challenges as institutional breakdown, security concerns, and market disruptions can simultaneously affect multiple components and levels of the food system, requiring a multi-scalar analysis that spans macro, meso, and micro dimensions.

Resilience of Whom? Food System Actors at micro, meso, and macro levels. Consistent with our multi-level framework, we identify key actors at each level of the food system. At the micro level, individual actors include producers (farmers, fishers, agro-pastoralists), processors, transporters, wholesalers, retailers/vendors, and consumers who directly engage with food production and consumption. At the meso level, actors include community organizations, cooperatives, producer associations, and market associations that coordinate and connect individual actors. At the macro level, institutional actors include national and local authorities, regulatory bodies, and governance structures as outlined by Béné et al. (2023). In fragile situations, the roles and capacities of these actors are often severely constrained or transformed. Informal actors may gain prominence when formal institutions

fail, creating alternative resilience pathways that traditional frameworks might overlook. The choice of focusing on micro, meso, and macro actors – and especially recognizing the pivotal coordination role of meso actors – is crucial in order to develop agrifood systems that are healthy, equitable, resilient, and sustainable (Barrett et al. 2022b). This multilevel approach is particularly important in the context of fragile situations, where the state's relationship with society is often weakened or contested. Browne (2013) notes that social cohesion across these levels significantly impacts how fragility manifests and is experienced by different actors. Strong social cohesion can mitigate fragility by increasing trust in state institutions and creating greater capacity for collective action, while its absence can exacerbate tensions and undermine resilience efforts.

Resilience Toward What? Food System Outcomes. The activities of food system actors lead to a variety of outcomes, which evolve as actors adapt their activities in response to changing drivers and external shocks. To effectively measure food system resilience, we must clearly define what outcomes the system is maintaining or recovering. Following established frameworks[7], we systematically organize food system outcomes into three interconnected domains.

First, food and nutrition security encompasses the classic dimensions of availability (sufficient food production and distribution), access (economic and physical ability to obtain food), and utilization (nutritional value, safety, and cultural appropriateness). These dimensions align with the short-term and long-term food security outcomes discussed by Béné et al. (2023) and reflect the primary function of food systems in meeting human nutritional needs. Second, environmental sustainability addresses the ecological impact of food systems, including effects on biodiversity, soil health, water resources, and climate stability. This domain recognizes that resilient food systems must maintain the natural resource base upon which they depend, particularly in fragile contexts where environmental degradation can compound existing vulnerabilities. Third, socioeconomic well-being captures outcomes related to livelihoods, income generation, equity, and social cohesion (HLPE 2017). These aspects are particularly vulnerable in fragile contexts where economic disruption and sociopolitical instability are common.

In fragile situations, these outcomes face unique threats across all three domains simultaneously. Institutional breakdown can disrupt food distribution (affecting availability), conflict can limit physical access to markets, and economic collapse can reduce affordability. Environmental degradation may accelerate due to resource exploitation during crises, while social support systems that protect livelihoods may collapse. Measuring these outcomes in fragile contexts requires approaches that can function despite limited data availability and rapidly changing conditions. This organization of food system outcomes provides clear targets for resilience measurement, aligning with established resilience

[7] These frameworks include: Foresight4Food, which provides a structured approach to analyzing food system outcomes and drivers; the HLPE (2020) framework, which emphasizes the need for food systems to deliver nutrition, environmental, and social outcomes; and Fanzo et al. (2021), which further develops these multidimensional outcome domains with particular attention to health and equality considerations.

literature that anchors measurement to food security and livelihood outcomes (Barret & Constas, 2014; Cissé & Barret, 2018; d'Errico et al., 2018).

Food System Resilience Capacities and Recovery Ability. Zurayk et al. (2022) provide a relevant framework for understanding the resilience capacities of food systems, building on the earlier work of Béné et al. (2012, 2015, 2017) on household resilience. These capacities are categorized into three main types: absorptive capacity (persistence), adaptive capacity (incremental adjustments), and transformative capacity (transformational responses). While Béné et al. (2012, 2015, 2017) originally developed these concepts for household resilience, Zurayk et al. (2022) and then Béné et al. (2023) applied them effectively to food systems, maintaining the same fundamental definitions.

A critical aspect of these capacities is their manifestation across different scales and boundaries. Local food system actors operate in geographically delimited zones and are connected through their livelihood and business activities. These localized systems exist within broader national and international contexts, creating nested scales of resilience where the capacity at one level influences outcomes at others (Béné et al., 2016; Tendall et al., 2015). Understanding these boundaries is key to properly measuring resilience in fragile contexts, where disruptions may be highly localized yet still have cascading impacts across wider systems.

3.2 Typology of Shocks and Stressors

Food systems extend beyond the central supply chain to include a broad network of actors, drivers, shocks, and stressors that affect the system's stability and resilience. These forces can disrupt the availability, accessibility, and quality of food in various ways. Understanding these elements is key to strengthening food system resilience.

3.2.1 Shocks and Stressors

The literature identified several major categories of disruptions affecting food systems: conflict and insecurity, economic downturns, biophysical and environmental disturbances, and biological threats to plants, animals, and human health (FSIN and Global Network Against Food Crises, 2024). In fragile contexts, institutional failures represent an additional critical category of shocks, as governance breakdowns can severely disrupt food system functioning even when other systems remain functional.

These disruptions can be classified by their temporal characteristics:

- Shocks are acute, sudden events causing immediate disruption: floods, conflict escalations, or market crashes (Tendall et al., 2015; Béné et al., 2016).
- Stressors represent longer-term pressures like land degradation, climate change, water availability, demographic transitions, regulatory deterioration, or biodiversity loss that gradually influence food systems (Constas et al., 2014; Frankenberger & Nelson, 2023).

Though more predictable, these chronic pressures can reshape food system operations and progressively erode resilience.

Disruptions can also be categorized as:

- Covariate – large-scale systemic events affecting broad populations and regions, such as widespread droughts, pandemics, or trade restrictions (d'Errico et al., 2018).
- Idiosyncratic – impacts on individuals or households, such as household illness, job loss, or localized crop failure (Béné et al., 2012).

Combinations of different types of shocks and stressors can create situations of "polycrises", where multiple significant disruptions occur simultaneously and interact in ways that generate impacts beyond the sum of their individual effects (Jervis, 1998; Lawrence et al., 2024; Stojetz et al., 2025). This represents a critical intersection between resilience and fragility, as continuous exposure to multiple overlapping shocks and stressors can erode resilience capacities and contribute to increased fragility.

Fragile situations are often also affected by armed conflict. Such situations are particularly susceptible to polycrises, as they often face weather shocks and environmental stressors from climate change alongside challenges stemming from conflict and violence. These challenges may interact in particularly destructive ways, creating compound effects (Stojetz et al., 2025; Castro et al., 2026; Stojetz et al., 2026). When a system's actors face both conflict exposure and environmental stress simultaneously, their ability to cope with either challenge diminishes, potentially creating multiplicative rather than merely additive effects (Lawrence et al., 2024). Resource limitations from environmental stress may restrict households' capacity to withstand conflict-related shocks, while conflict-induced disruptions to social and economic systems reduce resilience to climate pressures.

Table 1 offers a summary of hazard type and the possible primary and secondary data sources.

Table 1: Summary of hazard types, indicators, and suggested data sources

		Primary Data Sources	**Secondary Data Sources**
Hazard domain	**Shocks**	**Indicator**	**Indicator**
Environmental	Biophysical – Environmental	Number of biophysical or environmental hazardous events in a determined area	EM-DAT International Disaster Database; CHIRPS/SPEI (rainfall/drought); MODIS NDVI (vegetation)
Economic	Price spikes or drops (of inputs or outputs) and exchange rate volatilities	Number of price spikes or drops in a determined area	VAM WFP; FAO Food Commodity Price Index; IMF exchange rate data
Biological	Epidemics, pests, and food safety issues	Number of biological shocks in a determined geographical area	EM-DAT International Disaster Database; FAO Locust Hub

Political and governance	Conflict and population displacement	Number of casualties in a determined geographical area	Uppsala Conflict Data Program – Georeferenced Event Dataset (UCDP GED); ACLED data

3.2.2 Differentiated Impacts Within Food Systems

As discussed in Section 2.3, applying the exposure-experience distinction to food systems in fragile situations allows us to trace how a single systemic shock can cascade unevenly across value chains and system nodes. Macro-level exposures such as market collapse, climate hazards, or nationwide conflict represent broad systemic conditions, while at the meso level they translate into specific vulnerabilities for cooperatives, producer associations, and traders' organizations. At the micro level, these same exposures are experienced in tangible ways by households, farmers, processors, transporters, and small retailers, with impacts mediated by available resilience capacities. This differentiation is critical for fragile contexts, where disruptions often affect multiple levels simultaneously but with highly uneven consequences.

Food system actors experience these disruptions differently at multiple levels. While much research has focused narrowly on poverty and food security outcomes, our framework considers the full range of food system outcomes, including environmental sustainability and socioeconomic well-being. This broader perspective is essential because disruptions can affect different outcome domains simultaneously and in multiple ways.

Conflict, for example, affects both institutions and food systems. While external wars may strengthen state institutions (Tilly, 1975; Gennaioli & Voth, 2015), internal conflicts typically weaken them, creating conflict traps (Bates, 2001; Collier, 2003). This institutional weakening disrupts governance, reducing state capacity to provide essential services, regulate markets, and ensure food security. From an exposure-experience perspective, the presence of conflict in a given region constitutes a macro-level exposure, whereas farmers facing looted harvests, processors unable to operate due to supply chain breakdowns, or transporters halted by checkpoints are experiencing the micro-level impacts of that exposure. Conflict interferes with the flow of goods and services, highlighting fragility's effect on individual value chains within food systems (Frankenberger & Nelson et al., 2023). In these situations, non-state actors may assume control, providing public goods and exerting authority within their territories (Arjona, Kasfir & Mampilly, 2015).

Research demonstrates that conflict significantly affects food system actors and institutions across three main areas: economic activity, especially in agriculture, coping strategies, and food security metrics (e.g., Nillesen, 2007; Arias et al., 2019; D'Souza & Jolliffe, 2013; Ronzani et al., 2025). Conflict raises food prices and reduces dietary diversity in affected regions (D'Souza & Jolliffe, 2013; Dabalen & Paul, 2014). Micro-level actors such as transporters are especially vulnerable, with substantial reductions in economic activity during high-intensity conflict (Bar-Nahum et al., 2020), though strong social networks can buffer some effects (Maître d'Hôtel et al., 2023).

In conflict zones, food systems are influenced by both state institutions and local non-state governance, particularly in less developed regions where central governments fail to provide services (Justino & Stojetz, 2018). Local community involvement in producing public goods, such as market management, storage facilities, or road maintenance, can strengthen collective institutions, which are essential for resilience-building and social cohesion.

Despite growing attention to impacts on local food systems, midstream actors such as transporters, processors, and retailers remain under-researched (Béné et al., 2024). Béné et al. (2024) found that transporters are disproportionately affected by conflict, with road access being a critical factor (Brück et al., 2019). While actors with greater asset bases can mitigate some disruptions, they still experience significant contractions in business activities. Moreover, the existing research remains fragmented and often fails to provide an integrated analysis of food system institutions, governance structures, and actor-level dynamics under conflict conditions.

4 Measurement Principles

To guide the operationalization of our framework, we adopt the following measurement principles:

1. **Dual focus on exposure and experience**: Measuring both the objective conditions to which food systems are exposed (e.g., conflict incidence, climate hazards, economic volatility) and the subjective/observed experiences of actors within these systems (e.g., perceived insecurity, livelihood disruptions, coping strategies).

2. **Multi-scalar assessment**: Capturing fragility and resilience across macro (system/institutional), meso (collective organizations and market networks), and micro (households, farms, enterprises) levels, recognizing that shocks cascade differently across scales.

3. **System - outcome linkage:** Explicitly linking fragility and resilience indicators directly to food system outcomes (availability, access, utilization, stability, sustainability, equity), ensuring that measurement reflects both immediate and longer-term consequences.

4. **Capacity- and recovery-oriented metrics**: Assessing absorptive, adaptive, and transformative capacities, and evaluating recovery trajectories to determine whether capacities translate into improved post-shock outcomes.

5. **Context-specific and flexible**: Adapting indicator sets and data sources to fragile contexts by combining secondary spatial/event data with frequent, light-touch primary data collection to maintain relevance under rapidly changing conditions.

6. **Triangulation of data sources**: Using a mix of quantitative (e.g., geospatial, administrative, survey) and qualitative (e.g., key informant interviews, participatory mapping) methods to improve validity in data-scarce environments, drawing on agile data approaches (Serfilippi et al., 2022).

7. **Temporal sensitivity**: Accounting for timing, duration, and sequencing of shocks and responses, as resilience processes and fragility drivers may evolve over short timeframes in volatile contexts.

4.1 Fragility

Our conceptualization of fragility captures both the systemic exposure of food systems to fragile situations and the lived experience of fragility by actors at different levels. Building on IFAD (2024) – which distinguishes institutional, environmental and climate, and social dimensions of fragility – and incorporating the economic dimension from the OECD (2016; 2022)[8], we measure fragility at both macro and micro levels by applying the *exposure-experience* distinction proposed by Baliki et al. (2022b). This approach addresses an important gap in the literature, which has largely concentrated on national institutions and governance, by explicitly incorporating how producers, households, and other food systems actors encounter and respond to fragility in their daily operations.

Our measurement framework operationalizes this distinction as follows: at the macro level, exposure to fragility represents the spatial and temporal intersection between crisis events and food system infrastructure, measured through objective indicators such as geocoded conflict data, climate event mapping, institutional performance indices, and economic volatility metrics. These indicators capture system-wide vulnerabilities using official statistics and spatial data that document where and when crisis events occur. At the meso and micro levels, experience of fragility reflects how collective organizations and individual actors subjectively encounter and are affected by these macro-level exposures in their operations and livelihoods. Measuring experience requires survey-based approaches that capture self-reported impacts, coping strategies, perceived vulnerabilities, and direct disruptions to food system activities.

Institutional fragility involves four dimensions: weak institutions, dysfunctional systems, lack of infrastructure, and economic instability. Weak institutions imply government and governance failures, such as ineffective judicial processes, corruption, and an unstable rule of law. Dysfunctional systems refer to the inability of state and non-state institutions to deliver basic services necessary for food systems' functioning, resulting in service gaps that undermine production and distribution. The lack of infrastructure points to insufficient facilities and networks for storage, transport and market access, constraining both producers and consumers.

Environmental fragility comprises three dimensions: climate change, environmental degradation, and resource scarcity. Climate change refers to the increased frequency and intensity of extreme weather events, such as droughts and floods, heatwaves, and shifting weather patterns, which can severely disrupt agricultural production and food supply chains. Environmental degradation includes soil erosion, deforestation, pollution, and biodiversity loss, all of which reduce ecosystems' capacity.

[8] As previously mentioned, fragility, according to the OECD, is the combination of exposure to risk and insufficient coping capacities of the state, system, and/or communities to manage, absorb, or mitigate those risks. It occurs in a spectrum of intensity across six dimensions: economic, environmental, human, political, security, and societal.

Resource scarcity denotes the overexploitation and depletion of water and land, intensifying competition over inputs and aggravating food system vulnerabilities.

Social fragility includes the lack of social cohesion, exclusion, conflict, and insecurity. Social cohesion has been identified as a key driver of fragility, especially by authors who posit that state fragility is not just a result of weak institutions and governance. Populations with limited common experiences, few shared institutions, and no unifying identity tend to be found in fragile states (Kaplan, 2008). Exclusion refers to the systematic marginalization and discrimination of specific population groups, leading to unequal access to resources, opportunities, and participation in the food system, and is often coupled with economic inequality. Lastly, conflict represents a situation of acute insecurity driven by the use of deadly force by either state forces, organized non-state groups, or other irregular entities, with a political purpose or motivation (World Bank, 2024). Food systems are particularly vulnerable in conflict-affected areas. In 2023, conflict was the primary driver of major food crises and is expected to remain a key cause of acute food insecurity in 2024 (FSIN, 2024).

Economic fragility refers to macroeconomic volatility, including inflation, currency fluctuations, and unpredictable policies (Diaconu et al., 2020), which can destabilize production, distribution, and consumption via prices, costs, and investment decisions within the food system.

4.2 Resilience

Our paper builds on the capacity-based definition of resilience proposed by Béné et al. (2023) and adopted by the UN (2021), and we incorporate measures of recovery ability to assess whether these capacities translate into post-shock recovery, following an integrated resilience measurement approach.

Absorptive capacity of food systems is the ability of actors to minimize exposure to and recover quickly when affected by shocks. In fragile contexts, absorptive capacity may be constrained by depleted resources, weak institutions, and limited social safety nets, requiring different measurement approaches than in stable settings (Ansah, Gardebroek & Ihle, 2019). This involves preparedness strategies, such as early harvesting to avoid flood damage, or coping strategies like delaying debt repayments. While mere access to information and early warning systems may reflect fragility conditions, the actual use of this information by actors demonstrates resilience capacity.

Adaptive capacity is the ability to make informed choices about alternative livelihood strategies in response to changing conditions, exemplified by diversifying livelihood activities or adopting drought-resistant crop varieties. Fragility can limit adaptive capacity through resources and information constraints, yet may also accelerate adaptation through necessity-driven innovation (Béné et al., 2022). Our framework distinguishes resources and services availability, which reflects fragility when limited or absent, from actual use of these resources by actors, which represents concrete manifestations of resilience capacity.

Transformative capacity is the ability to alter the fundamental structure of the food system and to

address systemic shocks. In fragile situations, transformative capacity often requires engagement with peace-building and governance strengthening alongside traditional food system interventions (Brück and d'Errico, 2019). This capacity is enhanced by key attributes such as diversity, redundancy, buffering capacity, modularity, profitability, self-organization, and strong institutional networks (Tendall et al., 2015; Béné et al., 2016).

4.3 Conceptual Framework For Measuring Food System Resilience in Fragile Situations

Our conceptual framework (Figure 1) acknowledges the multiscale nature of both fragility and resilience, positioning food system actors at the center of dynamic loops where[9] drivers of fragility interact with conditions of fragility, mediated by resilience capacities. In our framework, classical food system drivers (e.g. market and environmental change) interact with the food-system activities, affecting the relationships between all supply chain actors at the micro level (producers, processors, transporters, wholesalers, consumers), collective organizations at the meso level (cooperatives, producer and market associations), and institutional actors at the macro level through feedback loops, and, in turn, affecting the final food system outcomes.[10] Together with classical drivers of the food system, we also account for specific fragility drivers identified by Frankenberger & Nelson (2023) as conflict, ethnic tension, fractionalization, and weak institutions. We clearly distinguish between the drivers of fragility (the processes/events generating stress, such as conflict) and the conditions of fragility (the resulting systemic state), and we show how the drivers of fragility can affect the condition of fragility (for example, conflict can disrupt markets - economic fragility, and simultaneously affect food security outcomes).

Crucially, our framework recognizes that fragility manifests itself differently across scales, as depicted in Figure 1. Macro-level exposure is observed in institutional and structural vulnerabilities, whereas meso and micro-level experience is seen in how organizations and individuals are directly affected. Continuous exposure to shocks gradually erodes both individual and collective resilience capacities, reducing future coping ability and increasing vulnerability (Béné, 2020; Pingali et al., 2005). Meso-level organizations such as cooperatives or market and producer associations act as critical intermediaries between individual actors and broader institutional structures, translating policies into practice and aggregating local needs upward, thereby buffering shocks and coordinating collective resilience strategies.

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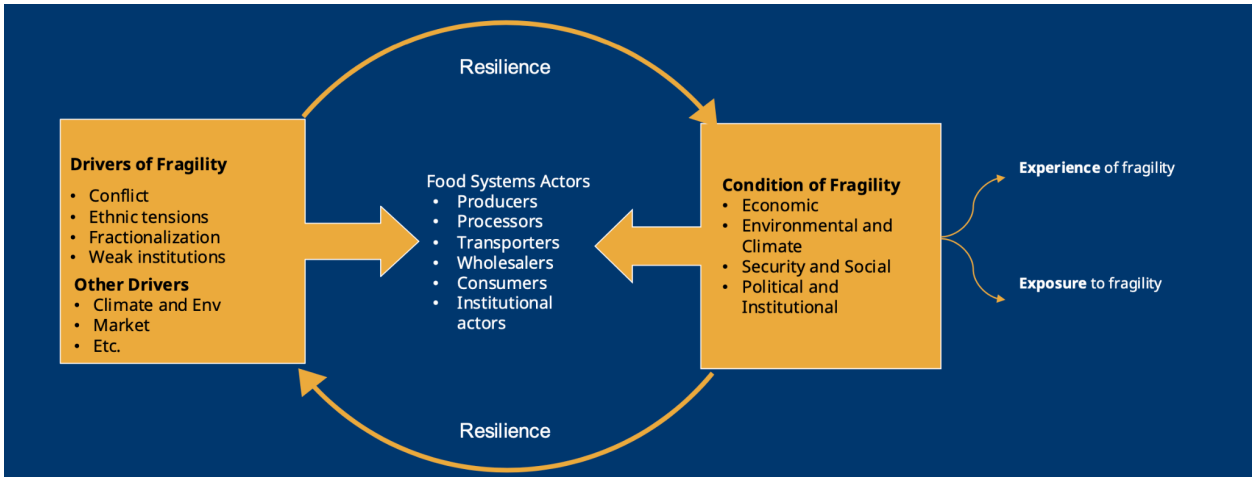
[9] Multiple levels: individual actors (or micro actors) who are different groups of actors engaged in economic activities related to a food system such as producers (farmers, fishers, agro-pastoralists,etc.), processors, transporters, wholesalers, retailers/vendors, and consumers); macro actors like national institutions, and meso actors like community groups and organizations.

[10] For example, climate environment drivers indicate the biophysical context in which the food system operates. One environmental driver is biodiversity. Biodiversity (i.e., the variety of plant and animal life) provides different services to the food system activities, such as biomass and firewood, as well as animals for domestication, microbes that guarantee soil quality, and a diversity of plant and animal species that enable pollination. The expansion of the agricultural area and climate change pose a direct threat to biodiversity, and the threat to biodiversity affects all food system actors and, in turn, the final food system outcomes.

The measurement framework proposed here assesses both experience and exposure to fragility, providing a structured basis for resilience assessment in fragile situations and linking them directly to food system outcomes.

Figure 1: Conceptual Framework: Measuring Food System Resilience in Fragile Situations



Source: Authors' own elaboration from Frankenberger & Nelson (2023)

5 Proposal For A Measurement Framework

Guided by the conceptual framework and measurement principles discussed in the previous sections, Table 2 outlines our proposed framework for measuring food system resilience in fragile situations. This framework organizes fragility and the resilience indicators into core dimensions corresponding to the conditions of fragility identified in the literature (Frankenberger & Nelson, 2023): 1) Economic; 2) Environmental and Climate; 3) Security and Social; and 4) Political and Institutional. Each core dimension is further subdivided into specific domains, and under each domain, we propose a set of indicators. Those indicators are assessed using both resilience and fragility lenses and measured at multiple scales (micro, meso, and macro). The classification of indicators proposed in Table 2 is intentionally designed for flexibility, allowing easy alignment with the resilience capacity approach.

Table 2: Measurement Framework

Dimension	Domain	Indicator
Economic	Economic Instability	• Price volatility • Productivity • Fiscal health
Environmental and Climate	Natural Resource Scarcity	• Water • Land
	Climate Change	• Technology and services • Climate vulnerability
	Environmental Degradation	• Deforestation and pollution • Soil degradation and erosion • Water quality
Security and Social	Lack of Social Cohesion	• Trust and support • Civic participation rates • Ethnic fractionalization
	Exclusion	• Inequality
	Conflict and insecurity	• Safety • Displacement • Conflict intensity • Mobility
Political and Institutional	Weak Institutions	• Governance effectiveness • Control of corruption
	Dysfunctional System	• Bureaucracy • Government leadership • Policies and regulations
	Lack of infrastructure	• Transportation • Health • ITCs • Energy and fuel

We derived the fragility and resilience indicators from an extensive literature review and a targeted outcome measurement mapping exercise. The definition of the indicators follows an agile data strategy, enabling the use of satellite imagery, geospatial analytics, and secondary datasets wherever possible to minimize the burden on respondents and reduce dependence on lengthy surveys. Tables 3a to 3d provide a detailed mapping of the indicators within each domain, specifying the relevant data sources for both satellite-based and other secondary indicators. In Table 3a-d, we did not specify the indicators associated with the food system outcomes, such as food and nutrition security outcomes (food utilization, access, and availability), economic and social well-being outcomes (income, livelihood, employment, wealth), since those are the classical indicators already well defined by the literature, as in Kennedy et al. (2020) and Van Berkum (2018).

To reconcile our framework with existing resilience literature, we adopt a consistent classification rule for the indicators presented in Table 3a-3d. In this framework, fragility indicators capture *conditions and constraints* in the system (such as barriers, deficits, systemic weaknesses), while resilience indicators capture *capacities, enabling factors, and actions taken by actors* (e.g., use of services, adaptation strategies, redundancy, diversity). In all cases, the use of resources and services is considered an expression of resilience. Availability is generally classified as a resilience capacity at meso and macro levels, except in the case of basic services (e.g., electricity, markets, fuel, water), where limited or absent availability is itself a direct manifestation of fragility. For all other domains, availability is treated as an enabling condition for resilience rather than as an indicator of fragility. This convention ensures conceptual alignment with the resilience literature while maintaining operational clarity, and it is applied systematically across all dimensions to ensure coherence between conceptual framing and operational measurement.

While the framework was developed with a primary focus on food systems, its conceptual logic and measurement structure extend well beyond the agri-food domain. By organizing fragility and resilience into the four core dimensions of Economic, Environmental and Climate, Security and Social, and Political and Institutional, our approach offers a comprehensive lens for analyzing systemic risks and adaptive capacities across sectors. The multi-level design – distinguishing macro-level systemic conditions, meso-level collective structures, and micro-level individual actors – enables its use for assessing resilience in diverse domains such as public health systems, infrastructure networks, or local governance arrangements. This broader applicability is reinforced by the classification rule that separates capacity-based resilience from experience-based fragility, a principle that can be consistently applied regardless of sector. As such, the framework contributes to the wider fragility–resilience measurement agenda, providing a unifying structure that can support comparative analysis, cross-sector learning, and integrated policy responses in fragile and conflict-affected situations.

Table 3a. Food System Fragility and Resilience Measurement Framework (Economic Dimension)

Domain	Indicators	Fragility			Resilience		
		Macro (Institutions)	**Meso (Community and community organizations)**	**Micro (Producers and other market actors)**	**Macro (Institutions)**	**Meso (Community and community organizations)**	**Micro (Producers and other market actors)**
Economic Instability	**Price volatility**	• FAO Food Commodity Price Index	• Disruptions in local prices of cereals/vegetables/ meat, and animal products (IFPRI secondary source)[11] • Barriers to accessing financial services	• Experience of input and main crop price volatility (self-reported) • Quality of financial services	• Availability of policies (e.g., rules of the game)promoting the economic integration of AFS actors into financial services, input supply chains, and produce markets (VSG, microfinance, credit associations) • Availability of risk transfer mechanisms (insurance, contract farming, price control, contingent credit) • Level of pricing control	• Availability interventions (e.g., development intervention) promoting the economic integration of AFS actors into financial services, input supply chains, and produce markets (VSG, microfinance, credit associations) • Availability of risk transfer mechanisms (insurance, contract farming, price control, contingent credit)	• Use of risk transfer mechanisms (i.e., insurance, contract farming) • Use of financial services (i.e., credit)
	Income and Productivity	• FAO/GIEWS Country Cereal Balance Sheet • Normalized Difference Vegetation Index • Share of smallholders and farmers living below the national poverty line	• Decrease in availability of cereals/vegetables/meat, and animal products (IFPRI secondary source) • Changes in community economic conditions	• Experience of decreases in income and productivity (self-reported)	• Availability of failsafe mechanisms (cash transfers, food vouchers, in-kind direct transfers, cash-for-work, employment assistance)	• Redundancy (i.e., multiple market actors and organizations performing the same functions) • Diversity (i.e., multiple market channels for sales of inputs and outputs in the community) • Availability of failsafe mechanisms (cash transfers, food vouchers, in-kind direct transfers, cash-for-work, employment assistance)	• Use of failsafe mechanisms and/or agricultural assistance programs • Average number of income sources (i.e., diversification of livelihoods) • Amount of net income • Yield of main food items (crops and livestock) per unit of production
	Market	• World Bank debt-to-GDP ratio • World Bank monthly currency exchange rate estimates • Real GDP growth, inflation, total expenditure, and overall fiscal balance	• Market disruptions (*see above in price volatility)* • Market challenges • Presence of local markets in the community	• Experience of market disruptions • Distance to the nearest market (minutes) • Distance from main road (minutes)	• Availability of fiscal policies to prevent future economic instability • Availability of policies to support diverse income-generating activities • Availability of policies supporting public procurement of food from local markets	• Connectivity between communities and within the community (e.g., share of the production is traded and to whom internally and externally) • Availability of interventions to support diverse income-generating activities	• Share of households selling crops/livestock through formal channels (percent) • Share of households selling crops in the local markets (percent)

[11] See Siddig et al. (2025).

Table 3b. Food System Fragility and Resilience Measurement Framework (Environmental and Climate Dimension)

Domain	Indicators	Fragility			Resilience		
		Macro (Institutions)	**Meso (Community and community organizations)**	**Micro (Producers and other market actors)**	**Macro (Institutions)**	**Meso (Community and community organizations)**	**Micro (Producers and other market actors)**
Natural resource scarcity	**Water**	• FAO Water Use and Scarcity • EPI drinking water score • Access to improved water source index (WHO) • Per capita water use from agricultural production	• Experience of water shortage • Perceptions of water quality • Presence of water points in the community	• Experience of water shortage (self-reported) • Distance to safe water (minutes)	• Availability of water conservation policies	• Availability of measures to protect and restore natural resources (water) • Availability of participatory resource management mechanisms • Availability of water conservation programs	• Use of water at a reasonable travel distance • Share of population accessing (i.e., using) water at a reasonable distance (less than 30 mins) • Use of water conservation practices • Use of safe water/water facilities • Use of measures to prevent water contamination
	Land	• World Bank share of land used for agriculture • ESA WorldCover • Share of arable land equipped for irrigation	• Number of disputes over land in the community	• Experience of land conflicts	• Availability of land conservation policies	• Measures taken by the community to restore and protect natural resources, e.g., land) • Availability of land conservation programs	• Land use
Climate change	**Technology and services**	• Agriculture R&D expenditures as a share of agricultural GDP	• Type of service disruptions and severity	• Experience of service disruptions (self-reported) • Quality of agricultural information and services	*See Table 3a Fiscal Health: Availability of policies to support diverse IGAs*	• Availability of agricultural extension services and new ag tech (agroecology and CSA)	• Use/adoption CSA • Use of post-harvest extension, input, and commercialization services • Use of agricultural social support
	Climate vulnerability	• Weather trends (precipitation and temperatures) from TerraClimate • SPEI (drought index) • ND-GAIN Index	• Weather trends (precipitation and temperatures) from TerraClimate • SPEI (drought index) • ND-GAIN Index • Type of climatic shocks and severity	• Experience of climate hazards (self-reported) • Perceptions of climate change	• Availability of agricultural emergency response programs and policies	• Availability of community-based risk-proofing infrastructure • Availability of community-based early warning systems	• Use of early warning systems • Use of risk-proofing infrastructures • Coping capacities • Use of agricultural emergency response programs
Environmental degradation	**Deforestation and pollution**	• UN FAO forest resource assessment • World Air Quality Index • Per capita GHG emissions from agricultural production		• Experience of deforestation and pollution	• Availability of pollution control regulations • EUDR regulation compliance	• Measures taken by the community to restore and protect natural resources (Forest)	• Number of trees planted and removed
	Soil degradation/ erosion	• Normalized Difference Vegetation Index (NDVI)	• Normalized Difference Vegetation Index (NDVI)	• Experience of soil fertility decline	• Availability of soil and water conservation programs and policies	*See Land indicator*	• Adoption of measures to conserve soil and soil moisture balance

Table 3c. Food System Fragility and Resilience Measurement Framework (Security and Social Dimension)

		Fragility			Resilience		
		Macro (Institutions)	**Meso (Community and community organizations)**	**Micro (Producers and other market actors)**	**Macro (Institutions)**	**Meso (Community and community organizations)**	**Micro (Producers and other market actors)**
Lack of social cohesion	**Trust and support**	• Afrobaromete (state-level)	• Quality of safety nets	• Self-reported experience of loss of social support • Perceptions on trust	• Availability of policies to strengthen social bonds	• Availability of safety nets and self-help groups in the community	
	Civic participation rates	• V-Dem Polity V Index • Turnout last general election (from % of individuals eligible to vote) • Freedom House Index		• Exclusion perception/experience	• Availability of national-level programs fostering inter-ethnic cooperation, peacebuilding, and equitable resource distribution	• Availability of community groups and their level of influence • Availability of local conflict resolution and mediation mechanisms that address inter-ethnic disputes	• Use of community groups (i.e., participation) • Influence of community groups • Use of mediation or dispute resolution mechanisms to resolve ethnic tensions in business or production
	Ethnic fractionalization	• Historic Index of Ethnic Fractionalization (HIEF)	• Intergroup relations	• Self-reported experiences of discrimination or exclusion from services, markets, or employment based on ethnicity			
Exclusion	**Inequality**	• Gini Coefficient	• Quality of safety nets and social programs targeting vulnerable populations • Observed disparities in access to community services (e.g., education, healthcare, markets) between groups within the community • Concentration of land or productive assets	• Perceived discrimination • Self-reported experiences of discrimination, exclusion, or barriers to participation in services, markets, or community governance	• Awareness campaigns on anti-discrimination • Availability of social programs targeting vulnerable and marginalized groups • Availability of policies/programmes promoting inclusion	• Participation of women and other vulnerable groups in community meetings • Availability of social safety nets	• Use of safety nets and social programs
Inequality	**Safety**	• Global organized crime index	• Frequency of security incidents within the community • Breakdown of local dispute resolution mechanisms	• Personal safety perceptions	• Availability of grievance and redress mechanisms to address inequities or abuses. • Coverage of social protection programs targeting marginalized populations	• Availability of training for law enforcement and community vigilance	• Use of the law for personal safety
	Displacement	• Displacement tracking matrix (DTM)	• Displacement tracking matrix (DTM) at community level (community level surveys or NGO assessments)	• Displacement experience	• Existence and implementation of inclusive national displacement and relocation policies for all displaced groups (statistics on coverage of IDPs in safety nets; proportion of displaced people with legal IDs enabling service access)	• Availability of temporary housing and resource centers • Availability of community-based displacement support systems	• Displaced individuals successfully engaging in local markets, accessing land, or securing employment, indicating inclusion in economic and social life (data on income restoration post-displacement?)

	Conflict	• UCDP geo-referenced conflict occurrence • UCDP number of civilian casualties of conflict • Global terrorism index	• UCDP geo-referenced conflict occurrence at the community level • UCDP number of civilian casualties of conflict at the community level	• Experience of violence and theft • Death of HH members due to conflict		• Community plans to support the victims • Availability of conflict resolution mechanisms (peace committees, etc.)	• Participation in conflict-resolution mechanisms
	Mobility	• National investment in public transport infrastructure in disadvantaged regions	• Measures in place to restrict mobility (e.g., presence of restricted zones or curfews) • Local governance or market actors prioritizing mobility infrastructure in wealthier or politically connected areas	• Experience of mobility restrictions, including road closures, damaged infrastructure, transport insecurity, or isolation, limiting market access • Disruption of common labor arrangements due to imposed physical distancing • Long travel times to markets, health facilities, or services due to lack of affordable transport options (*see specific indicators Table 3a Market and Table Td Health*)	• Strategic investment in rural roads and inclusive public transport infrastructure • Availability of national transport policies ensuring equitable access to mobility for rural, remote, or marginalized populations	• Community-based transport initiatives • Local advocacy and planning, ensuring mobility services reach marginalized neighborhoods	• Use of improved or diversified transport options to access markets, jobs, and services • Participation in mobility support programs (e.g., subsidized fares, safe transport for women)

Table 3d. Food System Fragility and Resilience Measurement Framework (Political and Institutional Dimension)

Domain	Indicators	Fragility			Resilience		
		Macro (Institutions)	**Meso (Community and Community organizations)**	**Micro (Producers and other market actors)**	**Macro (institutions)**	**Meso (Community and community organizations)**	**Micro (Producers and other market actors)**
Weak Institutions	**Governance effectiveness**	• World Bank Government Effectiveness Index	• Quality of social protection services • Weak performance of local councils/producer associations • Poor enforcement of local bylaws and market regulations • Limited capacity of cooperatives to advocate for members' needs	• Experience of social protection services disruptions • Low trust in formal institutions (self-reported) • Lack of access to grievance mechanisms or dispute resolution • No legal protection for land tenure or contracts	• Availability of social protection services and policies (government transfers, subsidies, and expense support, land tenure or contracts) • Availability of food systems-related interventions/policies • Availability of policy frameworks for an inclusive food system	• Community-level monitoring of service/programme delivery	• Use of social protection service • Use of formal dispute resolution channels
	Control of corruption	• World Bank Control of Corruption Index	• Corruption in service delivery	• Experience of corruption	• Availability of anti-corruption bodies • Transparent systems (public disclosure)	• Community monitoring of local projects • Transparency mechanisms in groups	• Adoption of certified traceability or compliance schemes
Dysfunctional Systems	**Bureaucracy**	• World Bank Worldwide Bureaucracy Indicators	• Inefficient local administration of agricultural inputs, subsidies, or extension services	• Time spent on bureaucratic procedures • Number of visits/contacts required to complete administrative processes • Informal fees paid to expedite procedures	• Streamlined regulatory frameworks for agrifood system actors • Digitalization of government services to reduce administrative burden	• Availability of community support centers or cooperatives providing administrative assistance to members	• Use of administrative support services • Use of digital platforms to apply for permits, subsidies, or licenses
	Instability of government leadership	• Stability of Democratic Institutions Index	• Local development initiatives disrupted or abandoned following changes in district or municipal leadership	• Experience of governance instability • Perceived lack of predictability in public support to producers	• Availability of institutional safeguards ensuring policy continuity	• Availability of cooperatives/associations to advocate for stability in program implementation	• Use of diversified support channels • Engagement in farmer networks
	Policies and regulations	• World Bank regulatory quality indicator	• Quality of policies and regulations • Experience of exclusion of cooperatives/producer organizations from formal policy dialogues	• Experience of business constraints due to regulatory compliance	• Availability of sector-specific policies and regulations	• Participation of groups (cooperatives, producers organizations) in national/regional policy dialogues	• Use of enabling policies (subsidies, tax exemptions, input support programs) • Adoption of quality standards • Satisfaction score with regulatory requirements
Lack of infrastructure	**Transportation**	• Transport composite index • FAO accessibility maps • Government investment in roads (% of agricultural budget allocated to rural road maintenance and upgrades) • Kilometers of paved rural roads per 1,000 km²	• Average distance to the nearest all-weather road from community center (minutes) • % of communities reporting seasonal isolation due to road inaccessibility • % of transport cooperatives or associations inactive due to lack of infrastructure	*See Table 3a (Market) and Table 3c (-Mobility)* • Experience of mobility restrictions, including road closures, damaged infrastructure, transport insecurity, or isolation limiting market access.	• Integration of transport resilience measures in national disaster risk management plans	• Availability of communities with year-round reliable transport services • Availability of community-level road maintenance groups or public works programs	• Use of different transportation options • Use of the nearest market • Use of innovative transport solutions

		• Road density index					
	Health	• OECD indicators of maternity/infant mortality and life expectancy • Government investment in health	• Presence of medical care in the community • Availability of functional community health centers/clinics Average travel time to the nearest primary health care facility from the community center • % of communities reporting seasonal inaccessibility of health services (e.g., during floods, conflict) • % of inactive or under-staffed community health facilities	• Experience of health problems • Experience of inability to access health services when needed • Experience of delayed or forgone treatment (due to lack of nearby facilities) • Experience of maternal or child health emergencies without timely care	• Availability of health policies and reform • Availability of legislation on ingredient labelling on packaged foods • Availability of legislation on nutrition labelling • Availability of National Food Composition Tables (FCT) • Availability of Food-Based Dietary Guidelines (FBDGs)	• Availability of health and food information (hygiene, vaccinations, good nutrition, Food-Based Dietary Guidelines) • Availability of community-based health committees • Availability of alternative service delivery models • Availability of community-led health insurance or solidarity funds • Availability of rural health outreach programs • Availability of rural health facilities with functional early warning and disease surveillance systems	• Use of health insurance • Use of health information • Use of telemedicine
	ITCs	• UN Telecommunication Infrastructure Index	• Quality of network distribution	• Experience of network shutdown	• Efforts made by the government to leverage digital economies		• Use of independent communication technologies (i.e., smartphone, telephone, etc.)
	Energy and fuel	• Total Energy Supply (TES) • Nightlight savings • Government investment in energy • Share of non-renewable energy use (percent)	• Quality of energy distribution • Presence of electricity (i.e., limited electricity available)	• Experience of power cut-off	• Availability of renewable energy policies and reforms		• Use of energy sources • Costs for purchasing or producing energy

6 Conclusion: Reflecting on the Framework and Future Applications

Our paper introduces a novel analytical framework for analysing and measuring food system resilience in fragile situations. While focused on food systems, the conceptual logic and measurement approach put forth extend well beyond the agri-food domain, enabling further research on the intersection of fragility and resilience.

On the conceptual level, we view food system resilience as the capacity of the system to sustain and enhance its provision of food security, environmental sustainability, livelihoods, and other essential services in the face of disturbances, through the capacities to prepare, adapt, respond, and recover from unexpected shocks. Our focus is on food system actors across macro, meso, and micro levels, including their actions and interactions, and the institutional systems that regulate and shape them.

A critical contribution of this framework is the operational clarification of resilience and fragility at different scales. We treat resilience as reflecting endowment-based capacities (structural, institutional, and individual resources) that can be measured at the macro, meso, and micro levels. In contrast, fragility manifests differently across scales: at the macro level through exposure to systemic risks and institutional weakness that can be objectively measured, and at the meso and micro levels through experience-based variables that capture how collective organizations and individual actors subjectively encounter these systemic constraints. This exposure-experience distinction is fundamental to our measurement approach, requiring distinct methodological tools for different scales.

On the methodological level, our measurement approach emphasizes two key areas: (1) maximizing the use of existing secondary data, including satellite imagery, event and administrative datasets, and (2) developing cost-effective, field-appropriate measures for collecting primary data on food system resilience in fragile situations through an agile measurement system that distinguishes between capacity-based resilience metrics and experience-based fragility indicators.

As we aim to measure attributes, capacities, and external factors affecting food systems' resilience in fragile contexts, it is necessary to adopt data collection strategies that function in insecure, data-scarce, and logistically challenging environments. Therefore, we propose integrating agile methodologies for applying the measurement framework. This approach recognizes that shocks and stressors can be both objective (measured through geo-located data, institutional performance indices, and market information systems) and subjective (meso and micro-level experience requires survey-based approaches that reflect perceived impacts, coping strategies, and vulnerabilities).

Data collection should be based on short-duration, high-frequency surveys, using digital field technologies. We recommend organizing the surveys as a series of smaller, thematic modules, each focused on a specific dimension, aiming to reduce the general burden on respondents, minimize fatigue, and improve response quality. Ideally, the newly collected variables will complement existing baseline datasets that capture time-invariant characteristics of suppliers, consumers and other value chain actors, aligned with the domains outlined in Table 2. Such an approach aims to target actors

across all levels of the food system: individual producers and consumers at the micro level, collective organizations at the meso level, and institutional actors at the macro level.

While the proposed framework is designed for flexibility and application in diverse fragile contexts, we acknowledge several limitations. First, the accuracy and coverage of secondary data sources (e.g., geospatial, event, and administrative datasets) can vary substantially across contexts, potentially affecting completeness and comparability. Second, primary data collection in fragile situations remains subject to practical and ethical challenges as well as to potential access, security, and response biases, even with agile, short-duration survey formats. Third, the framework breaks some important grounds towards integrating and distinguishing fragility and resilience indicators across macro, meso, and micro levels. Due to its innovativeness, certain indicators – particularly those capturing enabling conditions versus outcomes – require further empirical validation to ensure conceptual and operational coherence. Fourth, future work is required to pilot and test the framework in multiple contexts, assessing its adaptability, refining the classification rules for indicators based on field evidence, and exploring integration with predictive analytics to support early warning and proactive response. Lastly, engagement with national statistical systems, humanitarian actors, and local organizations will be critical to further institutionalizing the framework, scaling its use, and embedding it in decision-making processes that extend beyond food systems to other domains affected by fragility and resilience dynamics.

The integrated framework we propose advances the field by providing a principled yet adaptable approach to measuring food system resilience and fragility at macro, meso, and micro levels, while maintaining the operational flexibility needed in fragile situations. By combining objective and subjective measures, distinguishing between capacity-, exposure- and experience-based metrics, and embedding these in a multi-level systems perspective, our framework offers a practical, evidence-based tool for guiding policy, programming, and investment decisions. Future applications could include integrating these measures into early warning systems, resilience scorecards, or monitoring platforms suitable for monitoring programs in highly fragile settings, thereby enabling more timely and context-specific interventions and learning.

Statements and Declarations

Competing Interests

The authors declare no competing interests.

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Contribution Statement

ES contributed to Conceptualization, Methodology, Investigation, Formal Analysis, Validation, Writing-Original Draft, Writing-Review and Editing, Visualization, Supervision, Project Administration, Funding Acquisition.

AG contributed to Conceptualization, Methodology, Investigation, Writing-Original Draft, Writing-Review and Editing, Supervision, Project Administration, Funding Acquisition.

FC contributed to Conceptualization, Methodology, Investigation, Formal Analysis, Writing - Original Draft, Writing - Review & Editing.

TC contributed to Conceptualization, Methodology, Investigation, Formal analysis, Writing - Review & Editing.

TB contributed to Conceptualization, Methodology, Writing - Review & Editing, Supervision, Funding acquisition.

WS contributed to Conceptualization, Methodology, Investigation, Writing - Review & Editing, Supervision, Funding acquisition.

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