Food Security (2023) 15:1437–1458
https://doi.org/10.1007/s12571-023-01407-y

ORIGINAL PAPER

Food system resilience measurement: principles, framework and caveats

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Received: 10 July 2023 / Accepted: 10 October 2023 / Published online: 8 November 2023

Abstract

There is growing recognition that a better understanding of how food systems respond to crises is critical to build and protect the food security of local populations. But rigorous and reliable methods to measure food system resilience are still missing. In this paper, we build on the current literature to develop an analytical framework aimed at assessing the resilience of food systems at local level. The novel element of the analysis lies in the levels at which resilience is considered. Combining the individual actor level with the notion of 'emergent properties' of food systems, we argue that the overall resilience of food system results from processes that take place – and need to be measured – at both individual and system levels. The framework is structured around three components: (i) the mapping of the actors and the local food system; (ii) the assessment of the resilience of these actors and that of the food system, and (iii) the outcomes of this resilience, assessed in term of local population's food security. For each of those components, indicators are proposed and the ways to collect them are discussed. The paper then presents the types of analyses that would be necessary to complete to gain a better understanding of the situation regarding the resilience of the local food system under consideration, including the analysis of "positive deviance" among food system actors. The paper concludes with a series of reflections about the caveats and challenges that one may face when attempting to assess food system resilience.

Keywords Food system · Resilience · Assessment · Measurement · Methodology · Food security

1 Introduction

As a concept, food systems have been discussed in academic literature for some time (e.g., Sobal, 1978; Kneen, 1989; Ericksen, 2008; Ingram, 2011). In contrast, *food systems resilience* is a relatively new subject of (applied) research (Eriksen et al., 2010; Bizikova, et al., 2016; Meyer, 2020; Zurek et al., 2022). Though the literature on food system resilience is still relatively scarce, there is growing recognition that a better understanding of how local, national, or international food systems respond to shocks and adverse events is critical to build and protect the food security of vulnerable populations at local and national levels (Pingali et al., 2005; Dury et al., 2019; Agyemang & Kwofie, 2021; Béné & Devereux, 2023). In addition to the effects of extreme weather events, recent disruptions induced by the COVID-19 pandemic and the Russian invasion of Ukraine offer vivid evidence of the urgency and global importance of the task (Dyson et al., 2023; Rabbi et al., 2023).

In the context of humanitarian and food security crises, the concept of resilience is, itself, a contested construct, still debated between several schools of thoughts guided by different mental models and epistemological assumptions (Ansha et al., 2019; Birhanu et al., 2017). In this paper, we follow one of the most widely adopted interpretations of resilience ("resilience-as-a-capacity"), and propose an analytical framework, along with a series of principles and caveats, on how to assess the resilience of food systems.

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The novel element of the analysis lies in the levels at which resilience is considered in this new framework. Combined with the conventional individual or household level found in the majority of the resilience literature, we will introduce here the notion of 'emergent properties' of food systems, arguing that the overall resilience of the food system reflects both the resilience of individuals or households and the resilience at higher levels that result from interactions among food system components.

Empirically the importance of elevating the analysis above and beyond the household and community level and to considering the higher level of resilience at the food system itself makes sense as it reflects more realistically some of the troubling observations often made in the context of protracted crisis or armed conflict affected areas (Maître d'Hôtel et al., 2023; Béné et al., in revision) where households may have managed to maintain/protect the resources and capacities necessary to remain (theoretically) resilient and food secure, yet end up in critical food and/or nutritional insecurity because the local food system and its actors are not resilient and have collapsed in the face of the crisis.

The paper is conceptual and methodological in nature and is directed at researchers and practitioners interested in assessing food systems' resilience. It is general, out of necessity, to ensure that it remains pertinent across many contexts – even if it must be tailored to context before being applied. It is intended to offer methodological and technical recommendations on how to measure food system resilience at the local level. Although it does not offer an exhaustive review of the literature (see, e.g., Tendall et al., 2015 or Zurek et al., 2022 for such reviews), it does acknowledge and build on those other works.

2 Principles of food system resilience measurement

2.1 Definition of food system resilience

Food systems encompass "all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation consumption [and waste management] of food, and the output of these activities, including socio-economic and environmental outcomes" (HLPE, 2017, p.23). In low and middle-income countries (LMICs), local food systems are both comprised of, and benefit, many of the world's poorest citizens (Smith, 1998; Gómez et al., 2013). At the production end, they include the vast majority of smallholder farmers, pastoralists or fisherfolks in these countries who produce, and trade plant staples, fruits, vegetables, wild and domesticated livestock. These producers commonly sell to local or regional markets through a series of (often but not always informal) "middlemen" (aggregators, wholesalers and brokers) (Porter et al., 2007; Veldhuizen et al., 2020). Further down along the supply chain, the retailing segment is also dominated by informality, both in the structures (open markets, street vending, and corner stores) and in the transactional process (informal contracts, and agreements) (Roever & Skinner, 2016; Smit, 2016). Local food systems feed the majority of the rural and urban population in LMICs, a large number of which are living under or close to the poverty line. As such, those local food systems are often the only source of affordable, nutritious food for both rural and urban poor communities.

As is often the case with new concepts, a growing number of definitions of food system resilience have been proposed in the literature (see e.g., Tendall et al., 2015; Bizikova et al., 2016). Building on this literature, we propose to 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."* This definition highlights several important considerations.

First, under this definition, resilience is conceptualized as the *ability* (or capacity) of food system actors to act, or react, in the face of shocks and stressors. From a resilience perspective, such actions and/or reactions would have a positive effect on well-being – or otherwise be considered maladaptive. This interpretation puts emphasis on actors and their agency – enacted through their capacities – as the key component of food system resilience analysis. As such, this diverges foundationally from the concept of resilience portrayed as the probability of individuals or other entity (e.g., household, community) to remain above a certain poverty or food security threshold (see, e.g., d'Errico et al., 2018; Cissé & Barrett, 2018; Vaitla et al., 2020; Hoddinott, 2023; Cattaneo et al., in press, for examples of this statistical approach to resilience). Instead, our proposed approach builds on the"resilience-as-a-capacity"[1] body of literature that has emerged in the past 10 years and which emphasizes actors' agency as the main entry point of resilience analysis (Bohle et al., 2009; Constas, Frankenberger & Hoddinott, 2014; TANGO, 2018; Henly-Shepard & Sagara 2018; Ansah et al., 2019).

[1] Resilience capacity comprises three types of capacities: absorptive, adaptive and transformative capacity. Absorptive capacity refers to the various coping strategies by which individuals and/or households moderate or buffer the impacts of shocks on their livelihoods and basic needs. Adaptive capacity involves making proactive and informed choices about alternative livelihood strategies based on changing conditions. Transformative capacity refers to systems-level transformative (structural) changes such as institutional reforms, behavioral shifts and cultural changes deemed to be necessary to ensure the long-term survival of the system (Béné et al., 2014; TANGO 2018; Manyanga et al., 2022).

It is important to highlight here that the resilience-as-a-capacity approach asserts unequivocally that resilience capacity is distinct from – but related to –"realized resilience" or resilience *per se* (Béné et al., 2015; FAO, 2020; Ansah et al., 2023). In the literature, realized resilience (hereafter referred to as resilience) translates into the stability/protection of household well-being (e.g., food security) over the course of a shock period (Smith & Frankenberger, 2022a). As a latent variable, it cannot be measured directly but can be approached by proxies such as self-assessed recovery to a specific shock (Béné et al., 2020; Langworthy et al., 2016). In contrast, resilience capacity can be directly measured and reflects a *potential* represented by the different assets and other resources that actors have at their disposal and that they *may* utilize to respond to a particular shock/stressor. Resilience and resilience capacity are therefore distinct, but both provide information critical for resilience analysis. The approach proposed here examines the relationship between resilience capacities, in this case of the food system actors, and resilience of the food system, as observed and assessed by the availability and affordability of sufficient, nutritious, and safe food for all *in the face of shocks*. This is akin to looking at resilience capacities and their relationship to well-being outcomes such as food security in household level analyses that also use the resilience-as-a-capacity approach.

Second, this definition highlights the mixed nature of food system actors, including both *individual and institutional* actors, thus recognizing that the resilience of a food system will result from the combined actions of those two types of actors. By individual actors, we mean the different groups of actors engaged in economic activities related to a food system: producers (farmers, fishers, agro-pastoralists, etc.), processors, transporters, wholesalers, retailers/vendors, and consumers.

By choosing the actors of the system as the main entry point for resilience analysis – as opposed to the food system's activities (farming, transporting, processing, retailing, selling) – we also reduce the difficulty created by the fact that in many local food systems, several of these functions are executed by the same actor(s). In LMICs, many producers also process and sell (part of) their own crops, livestock, etc. (Bisht et al., 2020), and in higher income countries, vertical integration means that the same company will often ensure transportation, processing, and storage (Becker, 2014).

Food system actors can be of various sizes (micro, small, or even medium enterprises). They are, by definition, part of the private sector. Institutional actors, on the other hand, refer to the different local, municipal, (sub)national institutions (statal or parastatal) and private organizations (e.g., cooperatives, chambers of commerce) that are involved in the support, management or regulation of activities related to a food system. This involves, but is not limited to, policies, regulations, rules and actions regarding food safety standards and regulations, labor and business laws, taxes, and consumer access to information, among others.

Third, the definition recognizes that food systems have several functions. We identify three of them as being instrumental in relation to individual and societal well-being. Often considered as the core function of food systems – and the one that should ultimately prevail – is ensuring the availability and affordability of sufficient, nutritious and safe food for all (Ericksen, 2008; Tendall et al., 2015). As such, our conceptualization of food system resilience is fully aligned with other works that stress that the ultimate outcome of resilience strengthening in development and humanitarian crisis contexts is well-being, usually at the household level (Béné et al., 2015; Constas, Frankenberger & Hoddinott, 2014; USAID, 2021). Thus, our approach builds on existing resilience measurement methodology related to resilience-as-a-capacity and realized resilience and applies it at the food system level.

In addition, we argue that two other core functions of food systems should be considered: the generation of decent livelihoods and viable incomes/profits for those who are economically engaged in food systems (Anderson, 2008; Fanzo et al., 2021; Klassen & Murphy, 2020); and the protection (or restoration/rehabilitation) of the environmental integrity of agro-ecosystems (IPES, 2016; Ranganathan et al., 2016). Both functions can also be used as secondary well-being outcomes to measure resilience of the food system. Thus, our definition is important because it maintains a focus on food and nutrition security but also underscores the need to consider livelihoods and acknowledges the environmental dimension of food systems.

Finally, our definition draws attention to the need to analyze the impact of disturbances. Building on the first three features means that it is necessary to conceptualize and analyze the ways in which various disturbances affect resilience capacities of different individual and institutional actors within the food system. It also means that it is important to understand how different functions (e.g., food nutrition security, livelihoods, and environment) are affected by disturbances, and the degree to which resilience capacities can be used to mediate these effects. This is consistent with household level resilience analysis that looks at the relationship between shock exposure, resilience capacities and well-being outcomes. However, in the case of food system resilience, the well-being outcome is the availability and affordability of sufficient, nutritious, and safe food for all *despite those disturbances* and, secondarily, the generation of decent livelihoods and environmental integrity of agro-ecosystems (i.e., the three food system core functions).

In sum, the value-added proposition of our definition is that it offers an integrated conception of food systems resilience that illustrates work at the intersection of capacities, functions, and disturbances.

2.2 Scale and boundaries

The resilience of food systems can be considered at different scales; local, regional/subnational, national, and international/global (Fanzo, 2023; Tendall et al., 2015). In this paper, we are interested in establishing the methodology to assess food system resilience *at the local level*. We make this decision because focusing on the local level allows one to understand the food system at a level of specificity needed to diagnose and remedy the functional integrity of the above noted food systems functions. From a measurement perspective, the scale at which resilience is considered has implications for the nature of the indicators that will be included in the analysis and the types of data/information that will be collected; but it does not (or should not) have implications for the way the overall assessment is to be conducted.

At first, boundaries of food systems can appear somewhat fuzzy. For example, should the suppliers of agro-chemicals or feed for livestock be included in the food system under consideration? If so, what about the international petrol companies that supply the diesel fuel used to operate agricultural equipment and machines, or the electric service provider contracted by the wholesalers to supply energy to refrigerate their stored products? Where do we draw the line? And what about the food products that are imported from other parts of the world; should they be considered in or out of a local food system?

Pragmatically, we propose to start the food system at the producer level by focusing on smallholder farmers/fishers/agro-pastoralists, etc.,[2] meaning suppliers (agrochemical, seeds, energy, etc.) would not be included as a primary object of measurement.[3] However, as will be detailed below, the potential effects of disruptions in activities or changes in strategies by those suppliers (referred to as "ripple effects" later in this document) will be accounted for. At the other end, the system will end with the consumers, considered as the ultimate beneficiaries of the principal core function of food systems (that is, the availability and affordability of sufficient, nutritious, and safe food for all), recognizing that all actors of the food system are themselves consumers, and in some cases, also consume their own production.

By local food system, we mean, therefore, food system run by *actors operating in a geographically delimited zone and connected through their livelihood and business activities*. This could be conceived as a district or possibly a province and would include both rural and urban areas. In that sense it is slightly different from what some scholars refer to as a "foodshed" (Peters et al., 2008). The term foodshed is generally used to describe a "region of food flows, *from the area where it is produced* (our emphasis), to the place where it is consumed, including: the land it grows on, the route it travels, the markets it passes through, and the tables it ends up on" (Feagan, 2007). Under this definition, foodshed may include places in other regions in the same country, or even other parts of the world from where food is imported. In contrast, our definition of local food system is based on the *actors living and operating locally*, not on the flow of food products.

2.3 Resilience as an emergent property of food system

Although actors (both individual and institutional) were identified as the main entry points for assessing the resilience of a local food system, we postulate that part of that resilience also results from *emergent* properties at *the system level*. Building partly on the existing literature on social and market resilience (Downing et al., 2018; Kummu et al., 2020; Berkhout et al., 2023), we observe that the following properties are often perceived (or assumed) to play a critical role in maintaining or building the resilience of food systems: connectivity, redundancy, diversity, rule of law/competitiveness, and inclusiveness. This assumption would have to be verified on the ground, but the incorporation of these system-level elements in the analysis – complementary to the assessment of individual actors – represents one of the major conceptual differences with resilience measurements as proposed so far in the literature. Indeed, most of the indicators that have been considered in the food security and humanitarian literature on resilience purport to characterize elements of resilience capacity at the household or community levels (e.g., Arouri et al., 2015; Birhanu et al., 2017; Tariq et al., 2021; Vaughn & Frankenberger, 2018). In the analysis proposed here, we will complement these approaches by adding indicators aimed at capturing system-level properties. Details about the nature of these emergent properties – and how we propose to measure them – are provided in Section 3.1.

2.4 Components of a food system resilience approach

Our approach draws on a generic framework that has its origins in the work of the Resilience Measurement

[2] The focus on smallholder farmers is justified by the fact that the majority of food production in developing countries is generated by smallholder farmers (Lowder et al., 2016; Paloma et al., 2020).

[3] Although farmers who are also local seed producers would be included as farmers.

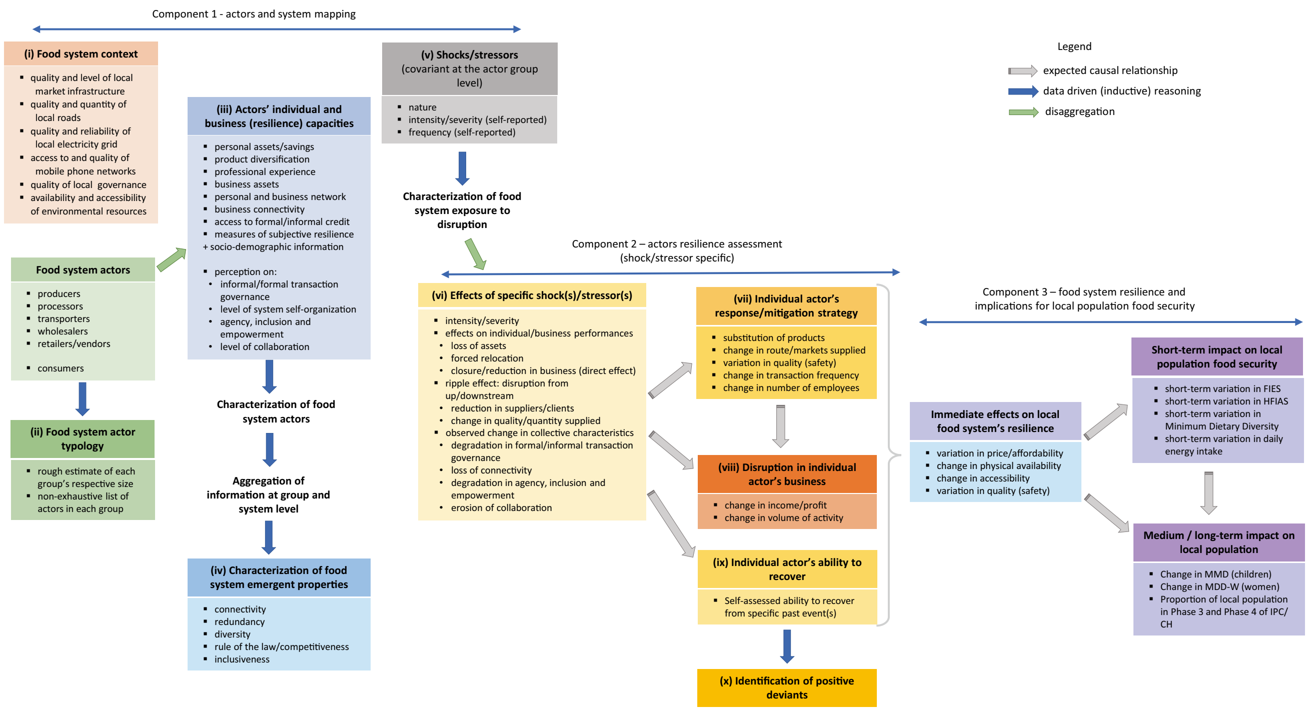


Fig. 1 Analytical framework for measuring food system resilience at local level

Technical Working Group (RMTWG).[4] The framework (Constas, Frankenberger & Hiddinott, 2014; Constas, Frankenberger, Hiddinott, Mock et al., 2014), which was tested in various contexts (see e.g., Langworthy et al., 2016; Béné et al., 2020; Manyanga et al., 2022), highlights the importance of several key components: (i) the typology of shocks/stressors affecting the system/community under consideration (ii) the identification of actors' individual and collective resilience capacities; (iii) the documentation of mitigating strategies (responses) adopted by these actors in the face of those shocks/stressors; and (iv) the long-term outcomes of the shock-response combination.[5]

The approach we propose here builds on this initial framework and these components. The detailed content and structure of the framework have been adjusted given our new objective of assessing resilience at a local system level. These adjustments are discussed in the next section.

[4] Comprised of approximately 20 international experts in food security measurement, the RMTWG operated under the Food Security Information Network under the auspices of the World Food Programme and the Food and Agriculture Organization. https://www.fsinplatform.org/resilience-measurement

[5] Some authors also include the ability to recover as a proxy measure of resilience (see e.g., Béné et al., 2016, 2020; Sagara & Smith, 2018).

3 The Framework

The overarching organization of the framework is summarized in Fig. 1 with details discussed in the text below. Annex 1 provides additional details. The framework is structured around three complementary components.

3.1 Actors and food system mapping

The task under Component 1 is to map the local food system under consideration and identify the different groups of individual and institutional actors engaged in it. This requires five different types of analysis, as follows:

(i) **Characterization of the local food system context.** The objective of this initial element of the mapping is to gather general information about the status of the local infrastructure systems that are expected to play an important role in the ex-ante functioning and ex-post recovery of food system activities after an unexpected shock. These include road, energy, communications (e.g., mobile phone systems, internet connectivity), and market infrastructures, as well as more general contextual variables such as level of technological innovation and overall governance. The information could be obtained through focus group discussions (FGDs) organized with different food system actors, and their insights possibly triangulated with direct observational studies. We propose that quantitative or semi-quantitative indicators are used to assess the following variables (acknowledging that other contextual variables could also be considered):

- quality and level of local market infrastructure
- quality and quantity of local roads
- quality and reliability of local electricity grid(s)
- access to and quality of mobile phone networks
- availability and quality of other contextual factors (e.g., environment, governance, innovation)

These indicators will be used later as control variables in various econometric analyses.

(ii) **Food system actor typology.** The objective of this second element is to identify the main groups of actors engaged in activities related to the functioning of the local food system and to develop a non-exhaustive list of individual actors for each of these groups. This list will constitute the pool from which a random sample for each group will then be drawn. The ambition is not to achieve a statistically representative sample of the entire system's population. Given that many of the small-scale actors engaged in local food system activities in LMICs are informal, using official lists of local businesses and enterprises would likely introduce a selection bias. Instead, the objective is to capture the diversity of the groups of actors engaged in food-related activities and, if possible, to gain a sense of the relative importance/size of each group.[6]

(iii) **Actors' resilience capacities.** The objective here is to collect data regarding each individual actor's resilience capacities as well as some basic socio-demographic information using both quantitative and semi-quantitative methods. This information will have to be collected through individual questionnaires administered to a sub-sample of randomly selected actors within each group. Resilience capacities include the different physical, financial, natural, social, political, and psychological capitals and assets that actors may use in response to an adverse event. For instance, financial assets and/or social capital are often reported as important elements for the recovery of farmers when they experience a shock (Aldrich, 2010; Woodson et al., 2016). Table 1 provides a list of variables to be collected as part of exploring the resilience capacities of food system actors. With the exception of business connectivity (i.e., the number of upstream suppliers and downstream clients with whom a given actor works), the other indicators are relatively similar to what is usually collected at the household level for resilience measurement and analysis.

Table 1 Individual actor's resilience capacity indicators

Indicators	Type of data
■ personal assets/savings	quantitative
■ product diversification	quantitative
■ professional experience	quantitative
■ business assets	quantitative
■ personal and business networks	quantitative
■ business connectivity	quantitative
■ access to formal/informal credit	binary or semi-quantitative
■ elements of subjective resilience	semi-quantitative

The subjective resilience element in Table 1 requires additional clarification. By "subjective resilience", we mean the perceptions that food system actors have about their own capacities to handle current or future adverse events. This concept of subjective resilience builds on the empirical observation that people usually acquire a cognitive understanding of the factors that contribute to their capacity to manage shocks and adverse events (Béné et al., 2019). As such, subjective resilience is strongly related to, and influenced by, psychosocial factors such as risk perceptions, cultural identity, religion, self-confidence and self-efficacy, and aspirations, as well as other more tangible elements such as individual's past experience to similar shocks or current socio-economic situation (Béné et al., 2019; Ensor et al., 2021; Jones & Tanner, 2015). Semi-quantitative psychometric indicators constructed using Likert scales can be used to quantify those different psychosocial factors at the individual level.

Finally, in addition to information related to resilience capacity, standard socio-demographic information (age, gender, education, household size, etc.) should also be collected as part of this first survey.

Complementing the capture of these resilience capacities at the individual level, we propose that elements of *collective* resilience capacities are also included in

Table 2 Actor's collective resilience capacity indicators

Indicators	Type of data
■ quality of formal/informal transaction system	semi-quantitative
■ level of system self-organization	semi-quantitative
■ level of agency, inclusion and empowerment	semi-quantitative
■ level/quality of collaboration	semi-quantitative

[6] For this, a general random sampling protocol can be augmented by using stratified sampling procedure and ensure that individuals from different groups are represented.

Table 3 Food system emergent properties of interest for resilience analysis

Emergent property	Definition
■ connectivity	Connectivity in a system can be defined by the degree and strength with which components of that system are connected to each other. In the context of food systems, connectivity could be proxied by the number of suppliers and clients with whom a given actor routinely interacts.
■ redundancy	Redundancy refers to the number of connections of the same nature or with the same function in a system. To some extent it is a sub-dimension of connectivity. In the context of a local food system, redundancy would be the average number of connections of the same nature that actors have upstream (suppliers) and downstream (clients). For instance, for transporters or wholesalers it could be the number of (urban or rural) markets they supply – or the number of producers from whom they get their merchandise.
■ diversity	In the system literature, diversity can be defined in many different ways, is measured through (too) many different indices, and is often seen in opposition to redundancy. In the context of food system resilience, we propose that diversity refers to the different types of products that each actor handles or trades. As such, it complements connectivity and redundancy (in terms of operations *between* actors) by adding information about operations *within* an actor's business.
■ rule of law / competitiveness	Rule of law/competitiveness refers here to the degree to which each actor is able to conduct business transactions in a fair (equitable), transparent and trustworthy manner. These characteristics (fairness/equity, transparency and trustworthiness) can be ensured and reinforced through either formal or informal mechanisms. This system property may sound more 'subjective' than the others above; it is however as critical, and it can be easily assessed and measured at individual level through self-reported semi-quantitative techniques.
■ inclusiveness	Inclusiveness can refer to many different 'things' in the literature. Here we consider it is the degree to which each individual actor feels their voice is being heard in the management/functioning of the local food system. It reflects whether every actor can contribute to the governance of the system or, to the contrary, whether some (powerful) sub-groups have a larger influence on the decision-making process within – and between – each group (e.g., transporter group, processor group).

the analysis. "Collective resilience capacities" refers to capitals and resources that are available or created at *the group level* among actors in a local food system. Conventionally, those would be measured at the community level (Ahmed et al., 2016; Álvarez-Mingote et al., 2020; Béné, 2020a; Thornley et al., 2014). In the case of a food system, the unit of analysis will now be the actor groups (producers, processors, transporters, etc.). Table 2 provides a list of proposed indicators for assessing these food system actors' collective resilience capacities. With perhaps the exception of the quality of the formal/informal transaction system, most indicators are comparable to what is collected at the community level when assessing the resilience capacities of farmers, pastoralists, or fisherfolks (see e.g., Bevington et al., 2011; Thornley et al., 2014; Saxena et al., 2016; Stanford et al., 2017). Semi-quantitative indicators should also be used to assess these collective resilience capacity indicators. Note finally that FGDs should not be used to generate this group-level information, because part of the data generated here is to be aggregated in the next analysis (emerging properties). Only individual data can be aggregated.

(iv) **Food system emergent properties.** Aggregating the information presented in Tables 1 and 2 at the group – and subsequently at the systems – level will offer very important additional information that can be used to assess what we refer to as the emergent properties of the food system (i.e., systems-level indicators). These emergent properties (not to be confused with collective resilience capacities) are properties/characteristics that are generally considered to be essential to build resilience at a system level. They include connectivity (Turnbull et al., 2018), redundancy (Mackay et al., 2020; Vlajic, 2017), diversity (Hertel et al., 2021; Page, 2011), rule of law/competitiveness and inclusiveness (Campbell, 2014; Derks & Field, 2016; Kilelu et al., 2017). Table 3 offers definitions of emergent properties in the context of food systems. It is important to point out that most of the research on these emergent resilience properties derives either from the theoretical socio-ecology literature (e.g., Biggs et al., 2015) or from supply chain modeling (e.g., Ivanov et al., 2016) and often lacks empirical ground. Virtually nothing is known about those emergent properties in the context of food system resilience in LMICs.

Importantly, because these properties are emergent,[7] they cannot be assessed at the individual level (i.e., food system actors). Rather, they emerge from

[7] Emergent properties are properties (e.g., capacities) that become apparent and result from interacting components within a system but do not belong to the individual components themselves (Perrings, 1998). In our model, the components and the way they interact are grounded in food system actors.

the aggregation process at the group level. Practically, this means that no specific group survey questions are needed. Instead, questions within the individual actors' survey should be phrased to ensure that information collected at that level can be aggregated to generate the data relevant for assessing emergent properties at the group level.

Documenting levels of individual and collective resilience capacities, along with food system emergent properties, before a particular shock/crisis occurs, and linking those to information about disruptions to individuals' businesses as well as their perceived ability to recover after a shock – and ultimately to the food security of local populations (see Section 3.2), will reveal critical information about what is important (or not) for maintaining the resilience of the food system and its actors, and for protecting the key functions of the food system.

(v) **Characterization of food system exposure to disruption.** The last type of information to be collected as part of this initial mapping exercise relates to the different shocks and stressors that affect the actors of the food system. This information is similar to what is collected at the household level for resilience measurement and analysis (Choularton et al., 2015) and includes the nature, intensity, and frequency of the different types of adverse events that actors have experienced in the recent past (e.g., the last 12 months). Data is collected through recall techniques and self-reported information. Although part of the information (e.g., date of an event) can be triangulated with external or secondary data, we recognize (and emphasize) that the impacts of adverse events, even if covariate, are by nature specific to the individual or household. In that context, self-reported information is the only way this specificity can be correctly recorded and accounted for. Questions on adverse events reflecting this specificity should be pre-coded however, to allow for comparisons and rankings across actors.

These questions should not focus just on shocks but also include indicators related to stressors. Paying attention to stressors, which are often less conspicuous than shocks, can help one assess how everyday systemic deficiencies (e.g., poor road infrastructure, weak governance, dysfunctional institutions) and challenging conditions (e.g., looming risks, existence of armed factions, eroding social cohesion) can threaten the integrity of local food systems and undermine the work of food system actors.

Overall, it is therefore advisable to consider – but also distinguish – between, slow-onset stressors (e.g., drought, soil degradation) and sudden-onset shocks (e.g., war, flood, earthquake).

3.2 Actors' resilience assessment

The second component of the analysis (see Fig. 1) corresponds to assessment of the individual actor's resilience and is structured around four major elements. The important point to emphasize is that the information in this second component is to be collected from the same individuals sampled in Component 1, that is, based on panel data. In that regard, note that the two components are to be completed using two distinct questionnaires, as some information generated through Component 1 needs to be processed (for instance the identification of the specific shocks/stressors on which the resilience analysis will focused) before Component 2 can be implemented. Note also that only events that have been reported as covariate at the group level will be considered; idiosyncratic events affecting individual actors will not be included in the analysis.[8] The four major elements are as follows:

(i) **Direct and indirect effects of the most disruptive shock(s)/stressor(s).** It is now well established that the impacts of shocks and stressors on people's livelihood and economic activities are exclusive and specific (Beauchamp et al., 2019; Choularton et al., 2015), as are the responses/ability to recover of the actors. From an analytical standpoint, it is therefore not advisable to pool together all the different adverse events that have impacted one particular actor (during the time frame of the analysis) as it would severely hamper one's ability to understand how households are affected by and respond to different types of shocks, and ultimately, how this affects their resilience. Instead, it is recommended to treat each of these adverse events – and the way actors responded to them – individually (Sagara & Smith, 2018). However, we also recognize that while it is analytically easier to treat shocks and stressors independently and separately, the reality faced by households (particularly in low-income countries) may seriously challenge this assumption, as several distinct adverse events often overlap and their impacts aggregate with each other (Béné et al., 2016). Survey questions should, therefore, be worded in such a way that they help respondents distinguish between individual events and their overlapping impacts.

Following this rationale, the first task in this part of the analysis will be to identify a limited number of

[8] Very severe idiosyncratic events which affect households during the time-period considered for the resilience analysis should be retained however, and included as part of the household socio-demographic roster. In particular, they could be useful in the identification/explanation of outliers.

Table 4 Information to be collected as part of the one-analysis-to-one-event assessment

Indicators	Type of data
■ intensity/severity of the event (already collected)	quantitative and/or semi-quantitative
■ direct effects on individual/business performance	
• gain/loss of assets	quantitative
• forced relocation	binary
• closure/reduction in business (direct effect)	binary or semi-quantitative
■ ripple effect: disruption from up/downstream	
• change in suppliers/clients	quantitative
• variation in quality/quantity supplied	quantitative
■ observed change in collective capacities	
• alteration in formal/informal transaction	semi-quantitative
• gain/loss of connectivity	semi-quantitative
• change in agency, inclusion, and empowerment	semi-quantitative
• erosion of collaboration	semi-quantitative

frequently occurring events that have happened (and are hopefully distinguishable) in the recent past and for which the resilience analysis will be completed. One possible approach is to select the most disruptive event(s) as perceived by the food system actors. An alternative would be to include in that list a specific event, if, for instance, this event is of particular interest to researchers/practitioners, or government, or donors. The important point is that all subsequent steps in the resilience assessment will have to be completed on a one-analysis-to-one-event basis because of the specific nature of adverse events and responses adopted by individual actors. Pragmatically, this means that the number of events considered in the rest of the resilience analysis should not be too large (we suggest one, perhaps two, and certainly not more than three events). If multiple events are chosen, *each would still have to be investigated separately*, which very rapidly increases the amount of information, number of questions and time necessary to conduct the survey.

The information used to select the event(s) should come directly from the '"characterization of food system exposure" described above (cf. (v) in Fig. 1). Once (an) event(s) is/are selected, new information will be collected from individuals from the same subsample of actors that were interviewed in Component 1 (see Subsection 3.1 above) using a panel sampling approach. Table 4 summarizes what types of information should be included in the second round of this panel survey. With the exception of"intensity/severity of the specific selected event", the information is new and should include: (a) the direct effects of the selected event on the actors' business performance; (b) the (indirect) ripple effects inflicted on that actor's business by the responses of the other upstream and downstream actors of the system; and (c) changes observed in the collective capacities of the actors following the adverse event. All these new data should be collected using carefully crafted quantitative and semi-quantitative recall questions.

(ii) **Individual actors' response/mitigation strategy.** In line with the principles of resilience assessment presented in the first part of this document, the next important task in the analysis will be to document the different responses and mitigation strategies[9] that the actors of the different groups adopted in anticipation of, or in response to, each adverse event selected for the assessment. Based on some recent research conducted in Burkina Faso (Maître d'Hôtel et al., 2023), we know that the nature and types of responses will differ, depending on the group of actors considered. Table 5 presents the type of responses/strategies that would be important to document, along with the groups of actors for which those responses are expected to be observed.

(iii) **Individual actor's business disruption.** Even if they are successful at anticipating or responding to the direct effects of an adverse event and to the ripple effects induced by the responses of other actors/groups of actors, it is likely that individual actors will experience some degree of disruption in their own activity. Documenting the self-reported changes in (i) weekly income/profit and (ii) weekly volume of activity[10] (i.e., changes in quantity of products harvested, transported, processed, traded, or sold) before and after a specific event is an

[9] The term mitigation is used here in its generic sense: "to make (something bad) less severe, serious, or painful", not in the more specific meaning used in the climate change literature.

[10] From experience, using a week as time period over which self-reported data are collected offers acceptable compromises between time variability and recall accuracy.

Table 5 Actors' responses and mitigation strategies

Types of responses	Groups of actors
■ change in type of products grown, transported, processed, retailed, or sold	all
■ change in route/markets supplied or operated	transporters, retailer/vendors
■ change in way to handle food	producers, wholesalers, retailer/vendors
■ change in frequency of transactions	all
■ change in number of employees	all

astute way to assess the level of disruption faced by individual actors in relation to that specific event. This information can be estimated relatively reliably using recall techniques.

(iv) **Individual actor's self-assessed ability to recover.** In addition to assessing the level of disruption that each individual actor has experienced following an adverse event, it is also important to explore the degree to which those actors consider they have recovered (or not) from those disruptions. This type of data, based on self-assessment techniques (Krosnick & Fabrigar, 1997; Schoch-Spana et al., 2019), has been used successfully in the context of producers' (farmers, fisherfolks) resilience measurement in several recent analyses (Béné et al., 2016; Smith & Frankenberger, 2022b). The idea is to replicate this type of analysis for all the different actors operating in the food system.

(v) **Positive deviance.** Information collected through the last two elements of the analysis above (actor's business disruption and self-assessed recovery) can be used to identify what is called "positive deviance" among food system actors. Individuals whose businesses appear to have been less disrupted by a specific shock than the rest of their fellows, and/or those who appear to have recovered faster than the majority are referred to as"positive deviants". Applied to resilience assessment, the concept of positive deviance (Herington & Fliert, 2018) can be interpreted as empirical evidence of higher levels of resilience among some food system actors (Sagara & Smith, 2018). Looking for systematic trends or patterns within the resilience capacities of those actors (element (iii) in Fig. 1, and Table 1) as well as in their responses/strategies (element vii in Fig. 1), while controlling for the food system environment (element (i) in Fig. 1) and the actors' socio-demographic characteristics (gathered as part of element (iii)) will allow us to draw some very important conclusions about who the more resilient actors are (i.e., positive deviants) and the potential contributions of their resilience capacities and responses toward building their resilience.

3.3 Food system resilience and implications for food security outcomes

The third and last component in the food system resilience assessment is the analysis of the impacts that local food system actors' resilience (or lack thereof) has on the resilience of the food system itself and ultimately on the local population's well-being, in particular their food security and nutrition status. Conceptually, this is relatively similar to what is usually proposed as the last component of a resilience analysis at the household level (Béné et al., 2015; Henley-Shepard & Sagara, 2018; Ansah et al., 2019). We propose to document this through a two-step process, collecting information about (i) the resilience status of the food system and (ii) the immediate and mid-to-long term outcomes measured in terms of local population's food security and nutrition. This means we concentrate our attention on the core function of the food system, which is "the ability of the system to maintain, protect, or successfully recover the availability and affordability of sufficient, nutritious and safe food for all."

As such, this core function will be assessed through indicators of stability over time of four dimensions of the food system: price/affordability; physical availability; physical accessibility; and quality (safety) of food products. Table 6 provides a list of potential indicators for these four dimensions. For each of them, we aim to document potential changes before and immediately after the event under investigation. In the case of clearly time-bound events,"immediately after" means a few days. In the case of stressors (e.g., drought, economic or political crisis), the concept of "immediately after" is more difficult to define and likely to vary depending on the stressor. In the case of drought, for example, "immediately after" may be closer to a few weeks. Regardless, several different loci should be considered when collecting this information (see Table 6), which should be based on recall techniques.

Information regarding the short-term and mid- to long-term consequences on the food security and nutrition status of the local population must also be collected. Table 7 provides a list of potential indicators (see also Fig. 1). Note that, with the exception of the IPC/CH score, it is unlikely that any of these indicators will have been recorded in the

Table 6 Indicators of food system resilience

Food security dimensions	Indicators of immediate outcomes	Data collection loci
■ price/affordability	variation[a] in local prices of food items	local markets/street vendors
■ physical availability	change[a] in postharvest and food losses	throughout the food system
■ physical availability	variability in availability of food items[b]	local markets/street vendors
■ food accessibility	change in number of places where food is sold	consumers
■ utilization – food safety	change in quality of food supplied	throughout the food system

[a] 'Variation/change' refers to observed differences in an indicator as measured before and immediately after an event

[b] Change in availability/supply (g/day/capita) of vegetables / animal-sourced foods / pulse / cereals-staples

local system prior to the event under consideration. In those circumstances, recall techniques will have to be used and the reliability of the results will, in large part, depend on the attention with which the questions have been worded.

Finally, it is worth noticing that many of those indicators may display some relatively high variability that will not be related to the effect of the event but to the way the data is collected (e.g., seasonality). Short-term changes (i.e., seasonal) will have to be interpreted with some caution.

3.4 One important limitation

Assessing the immediate and mid- to long-term impacts of food systems' resilience on the food security of local population is hampered by an important limitation. Degradation in the different dimensions of food security as they may be observed at the household or individual levels following a particular event (cf. Table 7) may in some cases not result only from failure of the food system to deliver its core function; it may also reflect the effects that this event has on the livelihood and income/purchasing power of the households themselves. Figure 2 illustrates this combined effect.

Local armed conflict is a relevant example to illustrate these combined effects. When insecurity and armed conflicts affect a province or an entire region, it is not just the actors of the food system who are affected. Often the entire local economy is impacted; many households experience disruptions or losses in their income and purchasing power (D'Souza & Jolliffe, 2013; George et al., 2020; Serneels & Verpoorten, 2015), irrespective of, or in addition to, the disruptions taking place within the local food system. To a large extent, the COVID-19 pandemic is another insightful illustration of this issue. It is now well established that the increase in food insecurity observed in many high, middle, and low-income countries during the pandemic was not just the result of disruptions in global and local supply chains, but also – and possibly mainly – the loss of purchasing power that households experienced following the shutdown of entire economic sectors (Béné et al., 2021; Hamadani et al., 2020; Robins et al., 2020; Ruszczyk et al., 2021).

The Implications for assessing the impacts of this type of event, be it armed conflicts or a global pandemic, are important. Untangling the respective effects of these events on the local food system and its actors from the direct effects that these types of events may have on households' food security

Table 7 Indicators of the local population's food security: short-term and mid- to long-term outcomes

Food security dimensions	Indicators of short-term outcomes	Indicators of mid- to long- term outcomes	Data collection loci
■ food access	change[a] in HFIAS[b] and/or FIES[c]		household
■ food access	variation[a] in daily energy intake	variation in energy intake	individual
■ nutrition/health		change in children's MDD	individual
■ nutrition/health	variation in MDD[e]	change in MDD-W[f]	individual
■ general food security		change in proportion of IPC/CH Phase 3 and Phase 4[g]	when available for the area under consideration

[a] 'Change/variation' refers to observed differences in an indicator as measured before and immediately after an event

[b] Household Food Insecurity Access Scale

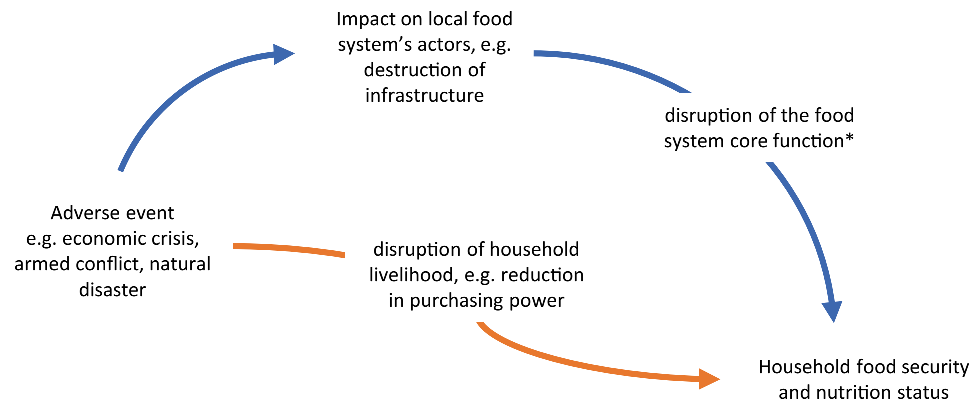
[c] Food Insecurity Experience Scale

[d] Minimum Dietary Diversity

[e] Minimum Dietary Diversity for women

[f] Integrated Food Security Phase Classification https://web.archive.org/web/20110731074553/http://www.fews.net/ml/en/info/pages/scale.aspx

Fig. 2 Combined effect of an adverse event on local population's food security. *Food system core function refers to ensuring the availability and affordability of sufficient, nutritious and safe food for all



and nutrition status is methodologically difficult unless the use of some form of (robust) counterfactual is possible.

4 Food system resilience analysis

The overall framework presented in Section 3 lays out the types of information we consider necessary for assessing local food system resilience. In this section, we now review *succinctly* the type of analyses in which the collected data could be used. We focus our attention on Components 1 and 2 as well as the food system resilience (part of Component 3) for the reasons mentioned above: it is methodologically difficult to untangle the combined impacts that an adverse event has on a local population's food security through its direct impact on households' livelihoods and its indirect impacts on the food system and its actors. As a consequence, the immediate and mid-to-long term effects on household food security and nutrition (the other part of Component 3) are not discussed here.

As such, two hypotheses are foundational to the entire assessment process and have critical implications from a policy or intervention perspective[11]:

1. Hypothesis 1: the final outcomes of Component 2 (measured in terms of disruptions in individual actors' businesses and their self-assessed ability to recover) are determined not just by the severity/nature of the initial shock/stressor under consideration, but also by (i) the resilience capacities (both individual and collective) that the actors have at their disposal and (ii) the type of responses that these actors adopted in anticipation of, or in response to, the event.[12]
2. Hypothesis 2: the degree of disruption in actors' businesses and their abilities to recover are also influenced by food system level processes, in particular, the emergent properties of the food system itself as well as any ripple effects.

These two assumptions, if confirmed empirically, would provide important information for identifying intervention and policy entry points. Hypothesis 1 would indicate which resilience capacities and positive responses should be supported through specific interventions/policies. This would also help identify those responses that turn out to be more detrimental or less effective from a resilience perspective (at the individual, group, and system levels) and should be discouraged. In parallel, Hypothesis 2 would provide relevant information about the type(s) of system-level emergent properties that are important for strengthening food system resilience. For instance, is redundancy more important than inclusiveness from a food system resilience perspective? Hypothesis 2 would also allow us to explore the additional complexity introduced by accounting for interactions between (groups of) actors. For example, adoption of responses that seem rational from an individual's business standpoint may create subsequent negative ripple effects for other actors within the food system (Béné, 2020b). A good example would be a transporter who decides to stop supplying rural local markets and instead focus only on townships and small urban centers due to a recent rise in roadblocks and illegal taxes imposed by local guerilla groups. From this individual's perspective, this strategy makes sense. But the implications for the local market actors in the remote rural areas previously served by the transporter are obviously more negative. This example is trivial but suffices to highlight the main point of this discussion: better understanding the extent to which some of these ripple effects appear to be systematically associated with larger disruptions to other food system actors' businesses is of relevance for policy and programme interventions. In particular, it is useful for better understanding concepts such as negotiated resilience (Harris et al., 2018).

[11] These hypotheses focus on the individual and collective levels only. Measurement of the impacts of systems-level interventions on local food system resilience is discussed in Section 5.

[12] This assumption is similar to these underlying resilience assessments conducted at household level.

Econometric models can then be constructed to test the two hypotheses (or some variants) using the level of disruption in individual actors' businesses and the subsequent self-assessed ability to recover as dependent variables, while various combinations of the other indicators presented in Tables 1, 2, 3, 4 and 5 are used as explanatory or control variables. As mentioned earlier, analyses can also be run with the sub-sample of individuals identified as "positive deviants" to determine whether certain of their behavioral and/or structural characteristics diverge statistically from the rest of the actors and could explain their resilience relative to the rest of the group sample (Béné et al., in revision).

Endogeneity is often identified as a potential issue in relation to resilience analyses (d'Errico et al., 2016). It will be important to ensure that the structure of the econometric models and the choice of the indicators/variables included in these models address this point. An initial strategy would be to ensure that, whenever possible, explanatory variables are chosen amongst indicators reflecting the situation prior to the impact of the adverse event considered. This would apply in particular to the resilience capacities at the individual and collective levels as well as the emergent properties of the food system. In other cases, however, more advanced econometric techniques will be necessary to reduce the risk of mis-interpretation associated with endogeneity, especially when exploring the potential effects of food system actors' responses on their own ability to recover from a shock.

5 Assessing food system resilience interventions

An increasing number of development projects/programs implement activities aimed at strengthening or building the resilience of local food markets or local food systems (e.g., Choptiany et al., 2021; Hudner & Hemberger, 2022; Krishnan, 2021). This section discusses how the framework presented here can offer some insights for rigorous assessments of such food system resilience interventions.

Generically speaking, development projects that claim to contribute to the resilience of local food systems are structured around activities targeting either (a) the different groups of actors engaged in economic activities within the food system (producers, processers, transporters, wholesalers, or retailers/vendors), or (b) the institutional actors that support these individuals/groups (chambers of commerce, cooperatives, etc.), or both. The objectives of these project activities are generally to build the individual and/or collective resilience capacities of the food system actors (i.e., element (iii) in Fig. 1 and indicators listed in Tables 1 and 2), or to improve the emergent properties of the food system (elements (iv) in Fig. 1 and indicators in Table 3). Those activities should, however, be informed by preliminary analyses that would identify which resilience capacities and food system properties are the most effective at supporting food system actors in their responses to specific shocks (cf. Section 4). Without such preliminary analyses, implementing activities would be equivalent to "shooting in the dark".

Assessing the effectiveness of the project will then be done by comparing indicators of business disruption and self-assessed ability to recover (elements (viii) and (ix) in Fig. 1) between the groups of actors who benefited from project activities (recipients) but who were affected by a specific adverse event in the course of the project, and groups of actors who were not included in the project (controls) but were affected by the same event. Theoretically, we expect that the recipient group would be characterized by a lower level of disruption in their business than the control group; or that the recipients would display higher level of recovery than the control group, or a combination of both. Of course, those are ideal scenarios, and the empirical analysis is likely to be much less clear-cut, as empirical data is seldom behaving as neatly as the theory predicts. But those initial working hypotheses should be used to structure the assessment. Matching techniques (e.g., propensity score matching, coarsened exact matching) could then be used to increase the power of the statistical comparison between the two groups (recipients and controls); and, the same way than analyses of positive deviants may reveal very useful information in identifying factors that contribute to their apparent higher resilience (Béné et al., in revision), focusing on these positive deviants may also reduce drastically the apparent 'messiness' of the empirical data at the programme effectiveness testing stage. In addition, causal analyses could also be conducted by comparing the direct and indirect effects of the adverse event (elements (vi) and indicators listed in Table 4) as well as the different individual actor's responses (elements (vii) in Fig. 1 and indicators listed in Table 5) between the two groups (recipients and controls).

6 Some important caveats

In this section, we highlight several important caveats – or limitations – to our approach. The first one is certainly the fact that the framework we presented here is a general framework designed for data collection that is somewhat detached from the reality of resource and time constraints that generally limit empirical research, in particular when the research is led by LMICs governments.

Feedback loops As previously discussed, analysis of food system resilience involves challenges introduced by the concurrence of two types of impact on households' food security and nutrition: the direct effects of an adverse event on households' livelihoods and purchasing power (e.g., flooding destroying farmers assets and crops) and the indirect effect it has through disruptions to the local food system and its actors (e.g., the same flooding destroying all the road infrastructure in a region, thus disrupting food distribution activities) (cf. Fig. 2).

Adverse events, however, can also impact the other two core functions of the food system: i) the generation of decent livelihoods and viable incomes/profits for those who are economically engaged in food systems; and ii) the protection of the environmental integrity of agro-ecosystems on which the food system depends. Although some aspects of the impact on decent livelihoods and viable incomes are captured in the framework (through direct and indirect effects of adverse events on food system actors' businesses; cf. Table 4), the effects on the environmental integrity of agro-ecosystems are not considered in the framework. This does not, however, mean that the interactions between food system resilience and these two key functions cannot be explored; but the analysis would be substantially complicated by the strong feedback loops that link resilience of the food system with these two functions (Fig. 3). This follows from the fact that the resilience of a food system is, itself, strongly dependent on the viable incomes/profits that actors of that system derive from their activities and also rests on the integrity of the agro-ecosystems on which the food system is built. Without economic viability and environmental integrity, it would be impossible for food system actors to handle most of the shocks they are facing on a regular basis.

Resilience versus sustainability Figure 3 is also useful to illustrate that resilience is not the same as sustainability, even if the two concepts are often confounded in the literature. Resilience is a necessary but not sufficient condition to achieve sustainability. Irrespective of whether we adopt a narrow interpretation of sustainability (i.e., environmental sustainability) or a more multi-dimensional definition integrating environmental, economic, and social considerations (Béné et al., 2019; Bhattacharyya, 2012; Eakin et al., 2016; Sharifi, 2021), sustainability should remain the ultimate goal of development (TANGO, 2009; Lomazzi et al., 2014); resilience is the means to achieve it. In our case, maintaining the environmental integrity of the agro-ecological system, along with the social and economic objective of generating viable and decent livelihoods, contributes to development programming's ultimate goal of sustainability, while the resilience of the food system is the means by which to secure those viability and integrity conditions in the face of an increasingly volatile and crises-affected world.

Making the conceptual distinction between resilience and sustainability also means that the objective of any food system resilience programming should *not* be to improve the resilience of the food system *per se*, but to maintain or protect the well-being (including long-term food security and nutrition) of the population who depends on that food system.

Evaluating resilience at the systems level Measurement of food system resilience and evaluations of food system resilience programming are also hampered by general limitations intrinsic to evaluating changes at a systems level; building counterfactuals at the system level is usually problematic. One will therefore need to remain realistic in one's ambition and make sure that no false expectations are created, especially with donors and other decision makers. That said, the framework presented above provides some clear guidelines

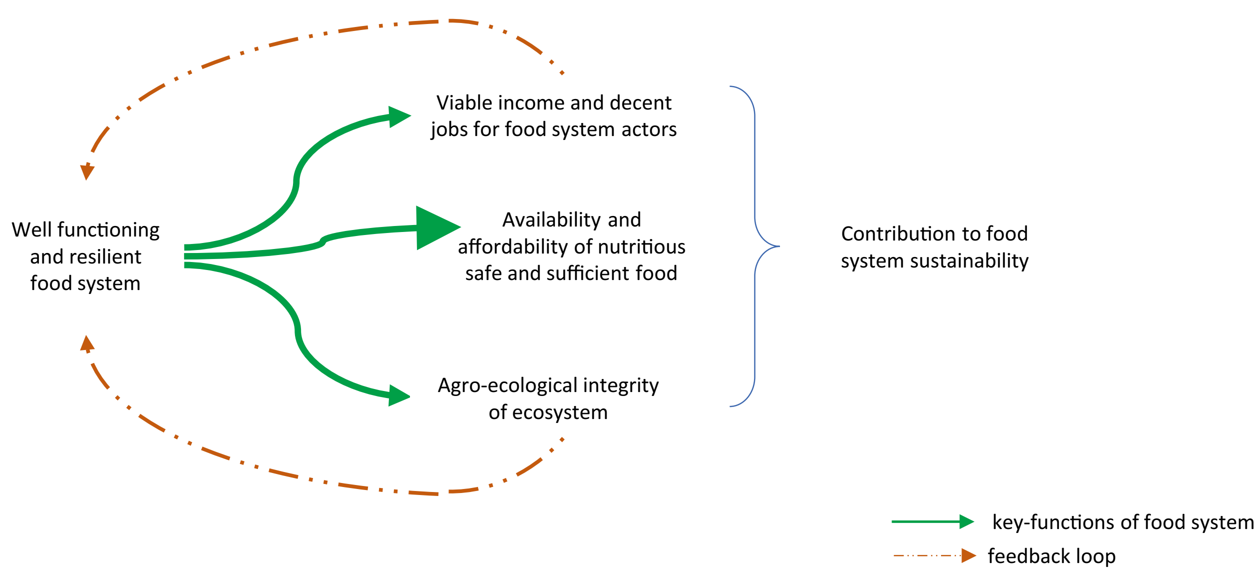


Fig. 3 Main feedback loops between the key functions of food systems and their resilience

for the implementation of robust evaluations of food systems resilience based on rigorous techniques, including quasi-experimental designs.

Resilience as a latent variable Measuring resilience (that is, realized resilience) will always remain an "incomplete" exercise in the sense that we are not measuring an absolute value of resilience. Rather, when we claim that we are "measuring resilience", what we actually measure is a *change* or *difference* over time in a proxy indicator, such as food security or other well-being indicators (Béné et al., 2015; FAO, 2020; Sagara & Smith, 2018). As a consequence, the best that can be inferred is that i) the resilience of an individual actor (or group of actors) has changed over time, for example, as a result of an intervention, or ii) that an individual actor (or group of actors) at a certain point in time displays a higher (or lower) level of resilience than another. But we will not be able to assign an absolute value to resilience. Likewise, there is no threshold above (or below) which a food system can be said to "be resilient" (or "not resilient"). In that sense, referring to "graduation" in relation to resilience programs (e.g., UNHCR, 2017) may be misleading, as there is no such threshold above which recipients become resilient. Again, when observing changes in outcomes (e.g., food security) in the context of shocks/stressors, we can only say that some households or communities have become more (or less) resilient than they were before; or in our case, by measuring the level of disruption in food system actors' businesses, that some actors are more (or less) resilient than others, but we cannot say that those actors *are* resilient.

Resilience trade-offs A direct corollary to the point above is the recognition that the resilience of some food system actors may be built to the detriment of other actors within the same system. This point was already mentioned in relation to the question of ripple effects (cf. Sub-section 3.2). However, beyond the technical issue of measuring ripple effects is the more fundamental issue of equity in resilience building (Makwatse et al., 2022; Williams et al., 2020). This issue was not considered critical when discussing building the resilience of (communities of) farmers or agro-pastoralists as it was assumed that the consequence of a change in behavior by the beneficiaries of the program was unlikely to have strong ripple effects on other beneficiaries in the same group. However, once the systemic nature of interactions and interdependence between groups of actors is included in the analysis, this assumption no longer holds. Instead, we now need to recognize that the change in behavior or in business strategy of a group of actors (in response to a shock/stressor) is likely to have significant – and potentially negative – consequences for other groups operating upstream or downstream within the same food system. These resilience trade-offs at the system level need to be considered, especially if they are created, or exacerbated, by program interventions.

We also note the potential for trade-offs over time in that the resilience of food system actors at one point in time (i.e., the short-term) may disadvantage, or make difficult, resilience in the long-term for other – or even the same – individuals and/or for the food system itself. Specific changes in the short-term that appear to make a food system more resilient could have long-term detrimental consequences. For example, subsidizing access to fertilizer to improve crop yield in the short-term as a strategy for improving farmers' resilience generally have negative impacts on the environmental integrity of the agro-ecosystem, thus jeopardizing resilience of the whole food system in the long-term (Adhikari et al., 2018; Redlich et al., 2021).

Informal food system actors The informality that tends to characterize the vast majority of food system actors in LMICs was briefly mentioned but not discussed in detail in the framework. Yet it has tremendous implications for the way rigorous assessments of food system resilience can (or cannot) be implemented. In particular, the informality of the majority of the actors means that identifying/locating them may be a challenge. Working with farmers is (relatively) easy. Working with some of the other food system actors is far trickier. Consider, for instance the young men transporting vegetables (or other food commodities) on the back of their motorbikes in northeast Nigeria, or the women processing their garden products in their kitchens in Cono Sur (one of Lima's many slums). How do we make sure that these and the hundreds of thousands of other informal actors who operate in the back streets of small or mid-size towns in Africa, Asia or Latin America, those who make the backbone of food systems and ensure the food security of millions of people in both rural and urban parts of LMICs, are included in our resilience assessment? Specific sampling techniques that have been developed for mobile populations (e.g., hidden population sampling, respondent-driven sampling, Crawford et al., 2018; Heckathorn, 1997) can be used, but even those will have to be adjusted for the specific context of the system to be assessed.

Non-tangible resilience capacities When it comes to potential interventions aimed at strengthening the resilience of food system actors, we need to make sure we don't consider only the tangible elements of resilience capacity such as income level, livelihood diversification, adoption of improved farming practices, enrolment in safety nets and other easily measured capacities. Evidence from numerous resilience analyses reveals that, beyond those tangible elements, a large part of people's resilience is built on less material, more'fuzzy ' – and difficult to measure – elements such as self-confidence, risk aversion or self-efficacy (Chantarat et al., 2011; Béné et al., 2019; Smith et al., 2019; Wang et al., 2021). We know from empirical experience, for instance, that social capital is key to resilience (e.g., Aldrich, 2010; Schwarz et al., 2011; Kerr, 2018). While most of this evidence has so far been generated with farmers or fisherfolk (Béné et al., 2016; Bunch et al., 2020; Stanford et al., 2017; Woodson et al., 2016), this was recently observed with food system actors in Burkina Faso, where it was shown that the number of people on whom food system actors can rely in times of crisis is critical to their resilience (Maitre d'Hotel et al., 2023).

National level food systems Finally, national level food systems have not been considered here and the framework presented is not suitable for assessing food system resilience and subsequent impact on food security at that level. In essence, although it aims at assessing resilience at system level, the proposed framework is still by nature a bottom-up framework; the main unit of analysis (and sampling) is the individual actor, which makes it ill-designed for national-level system analysis. Beyond this intrinsic design-related issue, interventions at the national level are often more difficult to assess than interventions at lower levels. Their impact is more elusive and difficult to assess due to the challenge of constructing rigorous counterfactuals at high/country level (de Janvry et al., 2011; Khandker et al., 2010). For example, do policies that encourage food sovereignty contribute to (or erode) national food system resilience? Or, does a national strategy aimed at boosting agro-ecology practices strengthen food system resilience? Although answering these questions would be important (and of growing interest to many policy-makers), it is difficult to propose an approach that would offer a rigorous assessment at the national/country level. Tackling the same question at a district level seems more feasible -even if we recognize it will remain methodologically challenging.

7 Closing remarks

This section offers a brief summary of the main points discussed in this paper and reflects on how our framework compare with other current approaches designed to assess household resilience.

Our work builds on, and expands, one of the most widespread approaches of resilience (resilience-as-a-capacity) as it was developed in the past 10 to 15 years in relation to humanitarian and food security crisis (Constas, Frankenberger & Hoddinott, 2014; Béné et al., 2014; TANGO, 2018; Henly-Shepard & Sagara 2018; Ansah et al., 2019). By deconstructing the relationship between resilience capacities, responses, and (realized) resilience in the context of specific shocks/stressors, the resilience-as-a-capacity offers important analytical gains over other approaches that focus only on outcomes, which reduces their ability to provide relevant programming information for resilience interventions.

Our framework closely parallels, both conceptually and analytically, the way resilience is being measured in this resilience-as-a-capacity approach. Conceptually, both approaches define resilience as the ability of local actors to adopt response strategies that mitigate the impact of shocks and stressors on their well-being. Our framework also embraces the idea that resilience is a means, not an end, similar to the way it is now conceptualized in most of the food security literature (Ansah et al., 2019; Barrett et al., 2021). In the case of food systems, resilience is the ability of the system to maintain or successfully recover its primary function, that is, the availability and affordability of sufficient, nutritious, and safe food for all in the face of adverse events. Food systems resilience is also the means to ensure the long-term objective of the system, that is, its sustainability in performing this function. While such sustainability (understood as a multi-dimensional concept) cannot be achieved if the system is not resilient in the current context of increasing local and global shocks and stressors, eventually the ultimate objective is food system sustainability over the long-term.

Intimately linked to food system sustainability is the well-being of local populations who depend on food systems. The emphasis on well-being in our conceptualization mirrors that of current assessments of resilience at the household level (Constas, Frankenberger & Hoddinott, 2014; Béné et al., 2015; USAID, 2021). The use of immediate and mid-to-long term indicators focusing on food security and nutrition encapsulates this well-being objective but recasts it into the specific context of this work on food systems -in a way comparable to when food security indicators are used as proxies of well-being in the case of household resilience assessments (Ansah et al., 2019; Smith & Frankenberger, 2022a).

Analytically, the parallel with household resilience is also clear. First, the core elements of analysis remain the same ones: shock/stressors; resilience capacities; mitigating strategies (responses); and well-being outcomes. In our case, the details of these core elements are adjusted to the food system context with the recognition that we are not dealing just with one socio-economic group (the producers) but six different groups: producers, processors, transporters, wholesalers, retailers/vendors, and consumers. But the underlying causal model is the same: when affected by an adverse event (or in anticipation of it), individuals build on, or use, some of the resilience capacities at their disposal to develop responses that mitigate the impact of the event. Ultimately, their ability to recover and their longer-term well-being outcomes are determined by the combined effect of the initial adverse event and the type of response(s) they adopt.

Second, when resilience-building programs are designed, they are generally expected to strengthen actors' resilience capacities in order to improve their abilities to adopt positive responses (those which help rapid and healthy recoveries) and deter the adoption of detrimental responses (those which may lead to further vulnerability). The theory of change is therefore somewhat comparable between resilience programs targeting households/communities and those targeting food systems.

There are, however, some important differences between the food system framework presented here and the way household resilience analyses are conducted. In addition to the fact that our framework involves several groups of actors as opposed to one (see above) and that this implies accounting for ripple effects, the main conceptual difference lies in the fact that the resilience of the food system is here conceived and assessed at two levels: 1) the actors' individual and collective level and 2) the system level. Although resilience dynamics at the actors' level are conceptually comparable to those typically included in household resilience assessments in relation to humanitarian/food security crises (see Hypothesis 1), those at the system level are new and correspond to the system's emergent properties described in Hypothesis 2. The way we propose to measure these system level emergent properties is also worth noting; they are built from the *aggregation* of individual actors' properties, in line with the conceptual definition of such emergent properties (Gilpin & Miller, 2013; Perrings, 1998).

This combination of actor and system level resilience processes is also what makes our approach unique and, we believe, conceptually more appropriate than some of the other recent frameworks proposed in the literature in relation to market system or value chain analyses (e.g., Campbell, 2014; Choptiany et al., 2021; Downing et al., 2018). In these analyses, the resilience of the system is assessed through market properties or flux of food or information. It means that perceptions, behaviors, and decisions of individual actors are not considered. The systems and their properties are therefore completely "depersonalized", which seems ill-fitted with the concept of food system where the social dimension is omnipresent and interactions/transactions between individuals/agents constitute the primary dynamic of the system.

Finally, and in line with this last remark, a third hypothesis not yet discussed here, is that the two levels at which resilience is expected to materialize may not be of equal importance. In particular, we posit that individual actors' resilience is ultimately what determines the overall resilience of the food system; if all the actors fail to bounce back after a particular adverse event and cease to operate, the system itself ultimately collapses. Thus, *the resilience of the overall system is built on the resilience of the individual actors and not the other way around*. This last observation is an additional reason why a bottom-up, actor-centered approach is relevant and why conceptualizing food system resilience only through system level processes is ill-advised.

To conclude, the approach presented here was motivated by the growing need for governments and humanitarian agencies to better understand how local, national, and international food systems respond – or fail to respond – to shocks and adverse events. Recent global crises and threats including the COVID-19 pandemic, the Russian war in Ukraine or the intensifying effects of extreme weather events, highlight the urgency and critical importance of the task. In this report, we propose an analytical framework and a series of technical recommendations for the measurement of food system resilience at the local level. It would be important to explore how similar analyses could be implemented at national/country (or multi-country) level.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12571-023-01407-y.

Declarations

Conflict of interest The authors declare no conflict of interest of any sort in publishing this manuscript.

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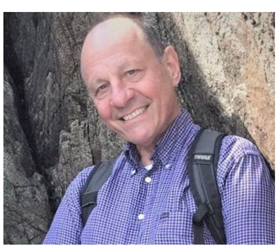

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