Laying the groundwork for modelling resilience in agrifood system pathways

FABLE Brief
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Contents

Headlines

- Geopolitical and extreme weather events, both major shocks to agrifood systems (AFSs), are expected to increase in frequency and magnitude in the coming years.
- As FABLE continues to develop modelling tools that support decision-making in AFSs, it will be important for these tools to assess the extent to which these systems can minimize negative impacts and continue to achieve goals despite shocks.
- Measuring resilience first requires an agreement on relevant indicators of desired AFS outcomes and should include multiple indicators that reflect not only the pillars of sustainability but also different stakeholder goals.
- Key metrics are critical to reflect resilience at different points in time, e.g., ex-ante characteristics such as network structure, the system's recovery process, and the system's properties after recovery, as well as cumulative impacts over time.
- As part of the Belmont Forum project 'SOLVE', FABLE will create new scenarios for climate shocks, highlight resilience-building interventions, and track outcomes for vulnerable groups.
- Because the quantification of resilience in AFSs is a relatively new field and is highly context-specific, collaboration with stakeholders and other researchers will be key.

About FABLE

The Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is a collaborative initiative to support the development of globally consistent mid-century national food and land-use pathways that could inform policies towards greater sustainability. The Consortium brings together teams of researchers from 24 countries and international partners from Sustainable Development Solutions Network (SDSN), the International Institute for Applied Systems Analysis (IIASA), the Alliance of Bioversity International and CIAT, and the Potsdam Institute for Climate Impact Research (PIK).

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1. Why is resilience important?

A system's resilience is its ability to preserve, recover and reorient to achieve desirable goals.

Agrifood systems (AFSs) are highly dependent on healthy ecosystems and suitable climatic conditions, meaning that the impacts of shocks are often severe and far-reaching.[1] Unmitigated risks can trigger food crises with a wide range of consequences, including reduced access to food, weakened public health, social unrest, and threatened livelihoods.[2,3]

Extreme weather and conflicts have been the main sources of shocks to AFSs.[2] According to the Intergovernmental Panel on Climate Change (IPCC)[4], anthropogenic climate change is causing unprecedented climate extremes including events such as prolonged droughts, heavy precipitation leading to devastating floods, and highly destructive tropical cyclones. These are expected to occur at increasingly larger scales, more frequently, at unpredictable times, in new places, and concurrently.

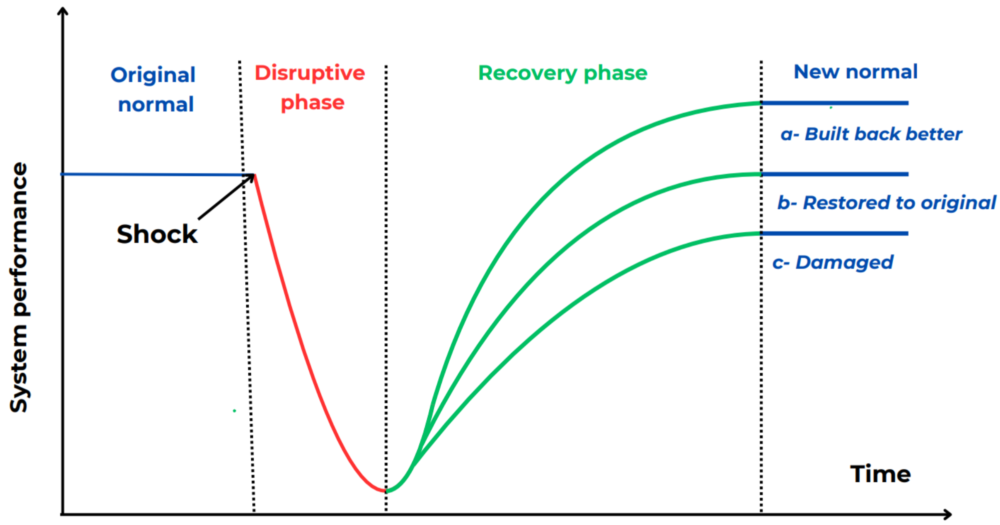
In a highly interconnected world, the consequences of local and regional shocks have knock-on effects across AFSs globally. Climate shocks and conflicts can lead to the destruction of infrastructure and productive assets, as well as block transportation routes. For instance, where Ukraine accounts for a large share of global grain output, the conflict with Russia led to a standstill of Ukrainian grain exports and a reduction of grain production due to damage to grain infrastructure. This led to inflation across grain commodities globally, exacerbating food insecurity in importing countries.[5]

While sudden-onset events can highlight the exposure and vulnerability of AFSs in spectacular ways, there are also critical long-term drivers of vulnerability. These include degraded social capital, i.e. the loss of social relationships and networks that can help mitigate food insecurity through mutual support, collective action and the exchange of information; loss of ecosystem services, particularly those that support sanitary food production in rural contexts and access to clean water;[6] as well as demographic changes where population growth may put further pressure on food systems.[7-9] Since these factors develop gradually, they can be more easily identified and addressed than shocks, if proactively monitored.

A system's resilience can be defined as its dynamic capacity to prevent negative impacts and continue to achieve goals despite disturbances and shocks.[10] In other words, it is a system's ability to preserve, recover, and reorient to achieve desirable outcomes in response to disruptions (Fig. 1).[7,11] While strengthening resilience in AFSs is becoming increasingly urgent, it requires careful consideration of associated tradeoffs. Diversifying inputs and processes and building in redundancies can help to blunt the impact of shocks. However, in normal conditions, streamlined processes and concentration of food production can yield economic and environmental benefits.[12] Resilience and efficiency are therefore often at odds, and finding the right balance is a delicate task for decision makers.[13]

This brief aims **to provide a foundation for the inclusion of resilience when modelling AFS long-term pathways in FABLE** to better support decision makers in their long-term planning.

Figure 1: Illustration of resilience



These resilience curves illustrate the evolution of system performance before, during, and after a disruption.
Source: Authors.

Table 1: Glossary of key terms related to AFS resilience

Agrifood systems	Comprise all actors engaged in the food sectors, as well as their activities, including production, processing, packaging, storing, retailing, distributing, consuming, and disposing of food. Actors can be people, companies, and institutions.
Shocks	Sudden-onset events.
Risks	These arise from the interaction of three elements: 1) hazard, 2) exposure, and 3) vulnerability.
Hazard	Refers to natural or human-induced disturbances and shocks
Exposure	Reflects the presence of people, environmental functions or assets in places that could be adversely affected.
Vulnerability	A predisposition to being adversely affected.
Absorptive capacity	Ability to preserve a system's normal function and prevent or limit the negative impact of shocks through intentional protective action.
Adaptive capacity	Intentional incremental adjustments to changing conditions through continuous learning.
Transformative capacity	It is the capacity to address the structural or root causes of risks to reorient the system.
System performance	The achievement of goals and/or desired outcomes.
System robustness	Ability to continue to function despite disturbances and shocks.
System resilience	Ability to continue to achieve goals and/or desired outcomes despite disturbances and shocks.

Source: Authors

2.What are the desired outcomes in AFSs?

Assessing resilience begins with defining desired long-term outcomes against which a system's performance can be measured. Models need to be able to compute relevant indicators that show the evolution of these critical outcomes under risk.

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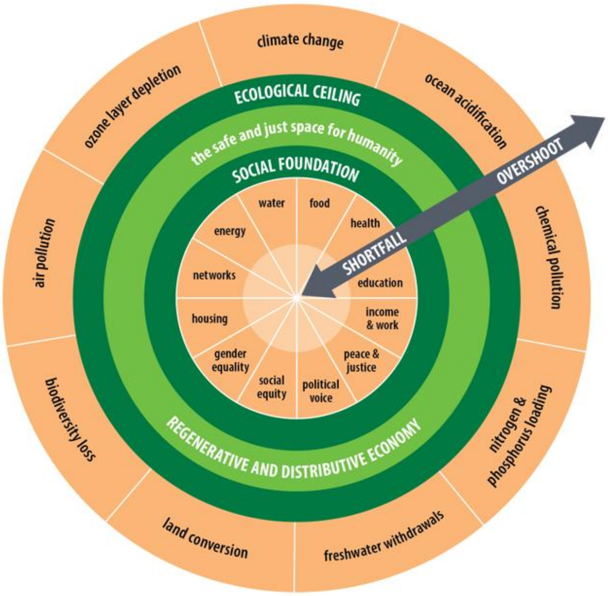
The performance of AFS could be assessed based on the level of **achievement of the SDGs**, at least 12 of the 17 UN Sustainable Development Goals (SDGs)[23] are linked to AFSs. The performance of the AFSs could also be measured by their **ability to maintain Earth's capacity to endure the impacts of human activity**. This is captured by the Planetary Boundaries framework[14], which outlines a safe operating space based on nine biophysical processes that regulate the stability of the Earth system. The Doughnut Economics framework[15] adds to the planetary boundaries constraint, twelve essential social foundations (Fig 2).[16]

Figure 2: The Doughnut Economics framework



Source: Adapted from Kate Raworth, Doughnut Economics, by the Finnish Prime Minister's office.[16]

In existing frameworks for AFS sustainability, metrics for 'nutrition and health' and 'climate and environment' are the most well-defined, while metrics for social welfare and economics are under-represented.[17] This is partly explained by data gaps.[19,20]

Finally, assessments of AFS performance also need to include indicators that can reflect **contrasting normative values and perceptions** of different stakeholder groups and contexts.

3. Which metrics can be used?

Once the desired long-term outcomes are well-defined for AFSs, metrics must be developed to compare system performance: (i) under different development pathways, (ii) with different combinations of shocks, and (iii) at different points in time or for different periods.

Literature associated with resilience curves provides an interesting range of metrics for ex-post evaluation of resilience (Fig. 3)[18]. They can be applied either to absolute values of performance indicators or to normalized values of performance indicators, i.e., with initial values corresponding to 1 or 100%. For instance, the following metrics can be used to monitor resilience at different critical phases or over a whole period:

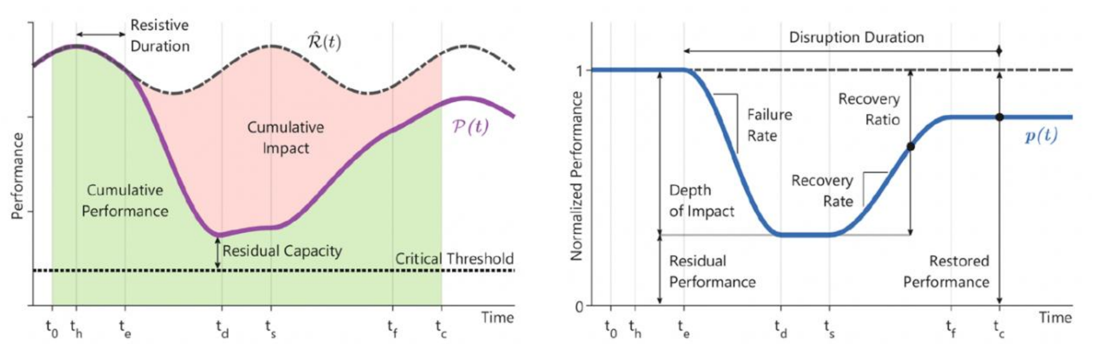
Resilience curves provide an interesting range of metrics for ex-post evaluation of resilience.

- **Robustness:** resistive duration; failure rate; depth of the impact; ability to remain above/below critical thresholds; residual capacity at the worst time.
- **Absorption capacity:** cumulative impact; cumulative performance; duration before the start of the recovery.
- **Adaptive capacity / flexibility:** recovery rate; recovery duration.
- **Transformative capacity:** restored performance.
- **Cumulative resilience:** cumulative impact of shocks; cumulative performance; disruption duration.

In addition, ex-ante assessments could be used to capture exposure, vulnerability, and resilience capacities.[7] The following indicators have been used in the literature: past GDP impacts, dietary sourcing flexibility index, food stock levels, prevalence of undernourishment, infrastructure proxied by mobile phone coverage or road density, Social Capital Index, agrobiodiversity index, and Coping Strategies Index.[19,20] Composite indexes are common, but selected stressors, outcome variables, and aggregation methods vary widely.[21]

Figure 3: Example of summary metrics associated with resilience curves

(a) With actual units of performance P(t) (b) With normalized units of performance p(t)



Note: In this illustration, the system does not fully recover within the control interval but the performance never falls under the critical threshold.
Source: Poulin and Kane (2021)[18]

Measures of resilience also **need to recognize interconnectedness in food systems, as well as risk transmission across regions**.[10,22]

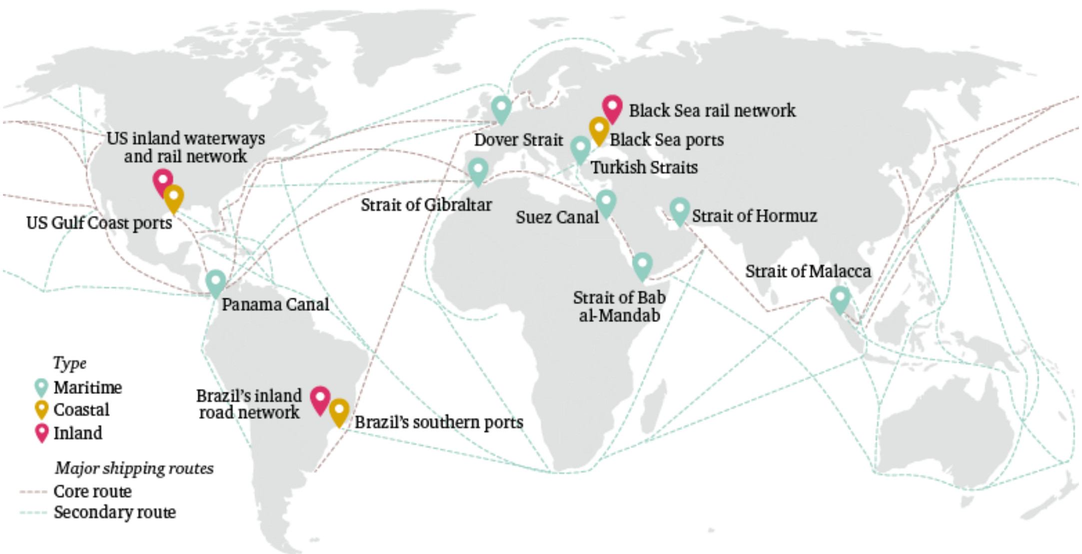
Network structures may have a drastic impact on the likelihood of systemic risk occurrence [23]. For instance, factors such as increasing system size, reduced redundancies, high pace of innovation and change, and denser networks, are associated with greater instability.[8] Network analyses reveal that countries highly exposed to external shocks tend to be highly globalized net importers, have a low GDP[24] or have low strategic reserves.[3,22] However, better firm-level data is essential to further analyze effective risk mitigation measures.[22]

AFSs are highly interconnected and require network-based metrics to capture risks associated with systematic threats.

High interconnectedness and reliance on global strategic maritime routes pose serious risks to the global AFS. There are 14 critical chokepoints for global AFS, where exceptional volumes of trade flow (Fig 4). [22,25] Combined with the threat of climate change, these increase the likelihood of major international supply disruptions. [22]

Threats to AFSs can be highly interconnected and triggered by, or lead to compounding events. The risk of co-occurrence of shocks affecting several sectors and/or several countries at the same time is increasing.[26] It is crucial to understand the risks and impacts of such systemic threats, for instance, simultaneous production failure in the major global breadbaskets. The combination of region-specific data on agricultural production, spatial climate statistics, and global trade could be used to quantify such risks. [27]

Figure 4: Major trade chokepoints for global food systems



Source: Bailey and Wellesley (2017),[25] adapted from Rodrigue, J.-P., Comtois, C. and Slack, B. (2017), building on trade data from the Chatham House Resource Trade Database

4. How can resilience be built?

Though *ex-post* measures may be most cost effective in response to one-off events, they can be very costly to implement over extended periods for recurring, simultaneous or compounding shocks. In contrast, *ex-ante* long-term planning, restructuring, and monitoring measures may be more costly at the outset but are expected to bring savings over time.[28]

Ex-ante long-term planning, restructuring, and monitoring measures can bring savings over time.

Resilience building means guiding the decisions and actions of stakeholders within the system towards a more sustainable and resilient state. It involves enhancing individual interactions of AFS actors, implementing measures to absorb or adapt to shocks, and making transformative changes that mitigate negative and enhance positive consequences of a shock (Table 2).[29]

Public policy can play a critical role in supporting or creating barriers to increased resilience. Securing multiple sources for key food staples as well as substitute options, and creating an enabling environment where multiple industry actors can participate may limit fluctuations and shock transmission.[3] Public discourse can also play a role in transforming prevailing norms and values.[3,30] However, suggested interventions for AFS transformation are often limited to technological improvements in agricultural practices and innovation without analyzing incentives to align competing interests.[30] While important, navigating power dynamics and address all actors along supply chains can be challenging. Food cooperatives and corporations hold significant power and may externalize risks onto smaller producers and consumers.[3]

Table 2: Examples of interventions to increase the resilience of AFSs

Reduce the impact of shocks	Increase the speed of recovery	Improve the properties after recovery
Ex-post: • Sell food stocks to dampen price fluctuations. • Mobilize and distribute food aid. • Emergency-livelihood support interventions. *Ex-ante:* • Change trade level and trade partners. • Address power imbalances to enable equal impact bearing.	• Implement and activate social safety nets offering cash transfers or food supplementation. • Facilitate farmers' access to critical inputs (e.g., credits with preferential rates). • Foster collaboration and learning between actors and components of the system. • Quickly deploy insurance funds. • Increase public funding and international aid to rebuild. • Forster room for maneuver for vulnerable actors	• Enhance diversity of food production, consumption, trade partners, and actors. • Establish/improve food security information and early warning systems. • Adapt agricultural practices and scale up agricultural innovations, including reduced societal and environmental impact. • Limit system size and connectivity. • Relocate activities to the less exposed area. • Increase insurance coverage. • Improve social security and develop conditions for communities to move out of chronic poverty and food insecurity.

Source: Authors.

5. Modelling resilience of AFSs: Next steps for FABLE

Shock scenarios

The FABLE database will incorporate new scenarios related to shocks and stressors. In the literature, climate shocks have been derived from historical climate and productivity data and/or future modelled climate projections.[31] Combined with other models, they can serve to assess the impacts of climate shocks on parameters of interest such as crop yields.

The FABLE database will incorporate new scenarios related to shocks and stressors.

Within the SOLVE (System Adaptation for OneHealth under Climate Change for Vulnerable Groups and Ecosystems), we will estimate climate extremes at global and regional scales using climate change indices from the Expert Team on Climate Change Detection and Indices (ETCCDI), by CICERO (leading FABLE Norway).

Separately, for trade shocks driven by geopolitical tensions or domestic events, we propose to use the Trade Alert Global Database[32] to identify past and current trade restrictions, and potentially derive scenarios for future trade policy shocks.

We will develop new scenarios in the context of high uncertainty, i.e., using a wide range of expected values and different combinations, on an annual basis.

Potential challenges include converting these shocks into values for specific model parameters, e.g., crop yields, livestock productivity, labor productivity, water availability, commodity and input prices[5], and address potential non-linearities.

Scenarios to build resilience

The FABLE Secretariat has been building tools to project future bilateral trade flows with two alternative and complementary methods: a method based on model-free Reinforcement Learning (RL) algorithms tailored to the multi-agent (MA) and multi-objective (MO) called the SmartLinker Platform (SLP), and a global spatial price equilibrium model. These will serve to account for the propagation of shocks through trade and **test trade strategies that can increase resilience and sustainability in AFSs**.

The FABLE Calculator allows stakeholders, who usually do not participate in modelling exercises, to 'play' with the model, and test the impact of alternative interventions on long-term trajectories. In SOLVE, FABLE teams will use this tool to **identify the most promising resilience-building interventions in each case study area**.

Desired outcomes

FABLE pathways generate results that can provide a multi-objective assessment of AFS performance. This includes, for instance, indicators or proxies for food security, GHG emissions, biodiversity, water, land, employment, agricultural production, agricultural trade, and costs in agriculture.

In the SOLVE project, FABLE teams will adapt tools to monitor outcomes for targeted vulnerable groups in each case study, e.g., livestock farmers, migrant, or remote consumers.

6. Conclusion

Quantification of resilience in AFSs is a relatively new field, meaning that developing the necessary tools and analytical frameworks for FABLE's purposes will also contribute to an emerging area of study. Further research, dialogue, and conceptual development are critical to refine definitions of resilience in AFSs, and, importantly, to develop indicators and methods that best capture network complexity.

Quantifying systemic responses to shocks and resilience can help to highlight opportunities for resilience and mainstream them in agrifood systems through policy. It can help to shed light on systemic responses to past crises and lessons learned, and inform stress testing frameworks, by clarifying tradeoffs between efficiency gains under normal conditions and the measures required for agrifood systems to bounce back after a shock.

Importantly, improved resilience assessments for AFSs may contribute to ongoing dialogue on access to finance to reinforce resilience, from traditional sources, including public finance and official development assistance, to newer sources of finance such as insurance and risk guarantees.

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