What do we know about THE FUTURE OF FOOD SYSTEMS INNOVATION?

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Key messages

- Innovations have been and will continue to be critical drivers of food systems and societal change.
- Predicting "game-changing" technology ahead of time is not possible, and silver bullets do not exist.
- Novel innovations can alleviate some challenges, but unintended consequences always arise.
- Foresight research can help to identify undesirable outcomes early on and align investments and incentives with social and environmental objectives.

RECENT TRENDS AND CHALLENGES

Innovations have been critical to shaping the food systems we know today, contributing to many historical food system transitions as new technologies, practices, and food products have redefined humanity's connection to food and food production (Herrero et al. 2020, 2021; Loboguerrero et al. 2020). Food systems innovation, industrialization, and infrastructure have been intertwined and self-reinforcing, with increasing agricultural productivity acting as an important driver of past transformational sociopolitical and economic change (Gollin, Parente, and Rogerson 2002).

Agricultural productivity growth has been critical to allow food systems to respond to the growing global population while increasing food availability and affordability, as the risk of hunger has been falling for decades, despite recent increases (Barrett et al. 2020, 2022). Nevertheless, sustained productivity growth is being challenged, with evidence suggesting that agricultural productivity growth is slowing (Fuglie 2018a) and that it is getting harder to develop groundbreaking innovations (Bloom et al. 2020; Chu and Evans 2021; Park, Leahey, and Funk 2023), while climate change is eroding past gains (Mbow, Rosenzweig, et al. 2019).

All innovations, revolutionary or incremental, come with unintended consequences (Merton 1936; Baert 1991), which can be both positive and negative. The industrialization of food systems has been accompanied by many undesired consequences, including unbalanced and unhealthy diets and unsustainable environmental practices (IPBES 2019; IPCC 2019; Swinburn et al. 2019; Willett et al. 2019).

Innovations are needed to help respond to these undesired outcomes, including development of more climate-resilient agriculture, as well as a shift toward more holistic approaches to food systems that consider the social, environmental, and health consequences of innovation. The call for a "Great Food System Transformation" (Vermeulen et al. 2020; Béné 2022) highlights the need for more responsible or mission-oriented innovation in food systems, to more systematically consider power dynamics and potential unintended consequences to better assess potential winners and losers. Reviews of historical food system innovations have highlighted that successful adoption of innovations requires a range of social processes, such as establishing permission, developing a fostering enabling environment, and enacting active and adaptive policies in the face of unintended consequences (Thornton et al. 2024). This suggests that future innovation will need to more intentionally embed social processes in the technological development process to contribute to more sustainable food systems (Barrett et al. 2022). Figure 1 highlights a framework for accelerating more responsible innovation that identified 10 accelerators and enablers for food systems innovation.

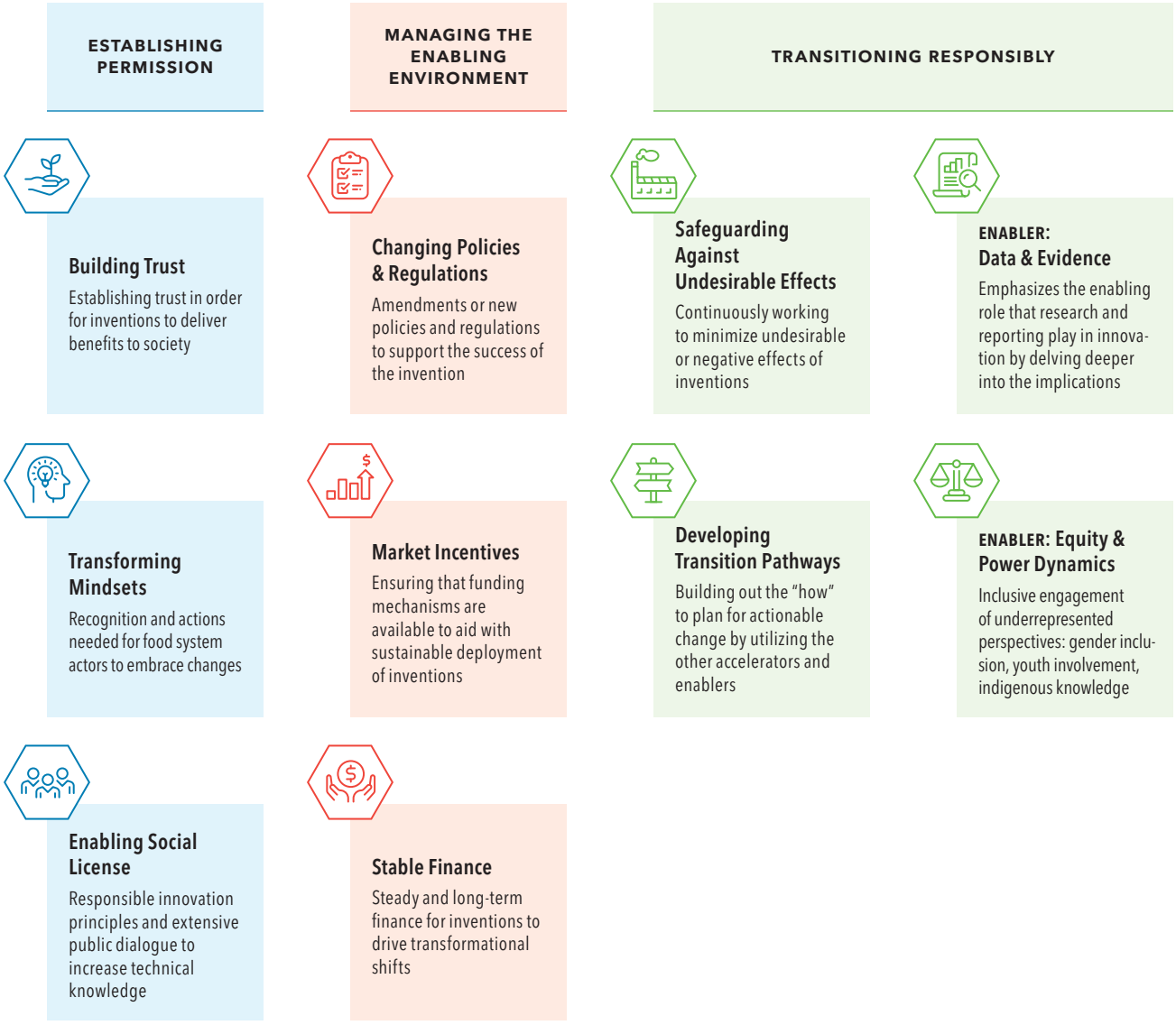
Recent policy shifts toward more activist industrial policy (Aiginger and Rodrik 2020) offer new potential opportunities for more mission-oriented research and development (R&D). However, without an intentional approach to innovation policy and a rebalancing of the food system to align incentives with desired environmental, social, and health outcomes — for example, True Costing of Food (Baker et al. 2020; FAO 2023; Kennedy et al. 2023) — increased public sector involvement in the innovation process will not ensure that future innovation contributes to healthier and more sustainable food systems.

LATEST FORESIGHT RESEARCH

Food systems innovation is a complex sociotechnical process. Foresight research focusing on food systems innovation seeks to better understand how these processes function and could be improved, as well as how their outcomes can contribute to positive and/or negative change. Much of the research assessing the potential of food systems innovation focuses on assessing specific technologies (or combinations of technologies) or the consequences of novel policies. Additionally, a growing body of literature considers how sociocultural changes can alter consumer preferences as well as paradigms of what is valued by society. Figure 2 summarizes some of the broad areas of foresight research focused on food systems innovation.

The spatial scale of foresight analysis can range from the individual/firm level to the global level. More microanalysis has tended to focus primarily on private benefits and costs and the adoption process, exploring questions of how and why individuals and firms choose to adopt new technologies and practices. Various methods are applied in this area including agent-based (for example, Bell 2017;

FIGURE 1 Accelerators and enablers of innovation



Source: Mason-D'Croz et al. (2023), adapted from Herrero et al. (2020, 2021).

Giabbanelli and Crutzen 2017; Kaaronen and Strelkovskii 2020; Marvuglia et al. 2022) and system dynamic models (for example, Dizyee, Baker, and Rich 2017; Varia et al. 2017; Dizyee et al. 2021). More macro studies tend to explore somewhat different questions, focusing on questions of R&D investment (for example, Mason-D'Croz et al. 2019) or policies to encourage more innovation (for example, Sodano 2019; Moberg et al. 2021). Some studies explore the role of various actors in the innovation ecosystem (for example, NARS vs CGIAR), often with a goal of better understanding the process of technology diffusion (for example, Aghion and Jaravel 2015; Fuglie 2018b). This work often implicitly frames technology in terms of Pareto efficiency (that is, adopted innovations move the technological frontier out, or help to move us closer to the frontier), and that knowledge generation occurs in core countries nearest the technological frontier, with catchup and diffusion assumed for peripheral countries farther from this frontier. National and global studies also assess potential unintended consequences of adoption at scale, particularly with respect to negative environmental or social consequences (for example, UNEP 2023).

FIGURE 2 Examples of food systems innovation foresight research

R&D systems

Improve the representation of the innovation process to inform innovation policy

For example:

- Endogenizing technological development [1]
- Linking R&D investments to productivity [2]
- Reorienting R&D systems [3]

Technological

Assess impacts of adopting, scaling up, and/or combining technologies and policies

For example:

- Impact of alternative proteins [4]
- Climate resilient agriculture [5]
- Mitigation potential [6]
- Circularity [7]

Governance

Assess impacts of policy innovations targeting the food system

For example:

- Fiscal policies [8]
- Trade policies [9]
- Land-use and climate policies [10]
- Poverty alleviation and social safety nets [11]

Socio-cultural

Assess impacts of changes in norms and consumer preferences

For example:

- Dietary transitions [12]
- Degrowth [13]

Selection of sources:

1. Baker and Shittu 2008; Dietrich et al. 2014; Hong et al. 2014.
2. Rosegrant et al. 2017; Mason-D'Croz et al. 2019; Sulser et al. 2021.
3. Nordmann 2014; Hall and Dijkman 2019; Conti et al. 2024.
4. Gerhardt et al. 2020; Humpenöder, et al. 2022b; Mason-D'Croz et al. 2022; Kozicka et al. 2023; UNEP 2023.
5. Sulser et al. 2010; Rosegrant et al. 2014; Ignaciuk, Mason-D'Croz, and Islam 2015; Robinson et al. 2015; Islam et al. 2016.
6. Havlík et al. 2014; Frank et al. 2017, 2018.
7. Parodi et al. 2018; van Selm et al. 2022.
8. Springmann et al. 2017; Springmann, et al. 2018a; Laborde et al. 2021; Springmann and Freund 2022.
9. Siriwardana, Meng, and McNeill 2017; Bellora and Fontagné 2020; Janssens et al. 2022.
10. Cohn et al. 2014; Dixon et al. 2016; Tabeau et al. 2017; Henderson et al. 2018; Roe et al. 2021; Humpenöder, et al. 2022a.
11. Laborde et al. 2016; Chichaibelu et al. 2021.
12. Stehfest et al. 2009; Springmann et al. 2016; Searchinger et al. 2018; Springmann, et al. 2018b; Eker, Reese, and Obersteiner 2019; Willett et al. 2019; Humpenöder et al. 2024.
13. Bodirsky et al. 2022; Li et al. 2023.

The scope of innovation foresight research can be sector-specific or economywide. Economywide analysis allows for assessing potential spillover effects from one sector to another, spurring economic growth more broadly, but the wider scope of analysis tends to come with more stylized representation of innovations.

KEY GAPS AND OPPORTUNITIES FOR FORESIGHT RESEARCH

Predicting future groundbreaking innovations is impossible (King and Baatartogtokh 2015; Fink et al. 2017; Hall and Dijkman 2019; FAO 2022; Thornton et al. 2024), but growing calls for a food system transformation (Webb et al. 2020) and the need for responsible (Nordmann 2014; Brier et al. 2020) and mission-oriented innovation (Klerkx and Begemann 2020) highlight a critical role for foresight research. Such research will be fundamental to helping better orient the application of science to solving critical environmental, economic, and human wellbeing challenges, while emphasizing the potential undesired consequences of transformation.

While improvements in modeling capability and data collection on innovation (including how to apply artificial intelligence approaches) are critical to improve our understanding of the process of innovation as well as its consequences, we focus our key gaps on research and scenario design. To date, much of foresight analysis on food systems innovation has focused on "What If" questions to consider the impacts of the wide-scale adoption of an innovation, for example: What if alternative proteins

displaced conventional meat?; What if investments in R&D increased?; or What if a paradigm shift led to healthy diets? This valuable first step helps to highlight potential innovations worthy of consideration and investment but leaves several key questions unanswered, as follows.

1. ***How do innovations compete with and complement each other?*** The innovation ecosystem is highly dynamic and volatile. Yet most foresight studies explore individual innovations as one-offs or, if in a bundle, in a very stylized way. Relatively limited exploration exists of how innovations coevolve, and what these implications might mean for designing bundles of innovations and appropriate policies.

2. ***What is the theory of change?*** Relatively few foresight studies have explored in detail innovation and transition roadmaps, instead focusing more on the ends than the means. However, historical experience reveals that the impacts of innovations are path-dependent, and the sociotechnical interface of adoption and obsolescence largely determines the winners and losers of innovation. Exploring such roadmaps will require greater engagement with multiscale and multidisciplinary research to better understand how innovation processes scale and diffuse. It also will require developing or adapting new modelling tools to simulating plausible pathways across relevant time and spatial scales.

3. ***What role can low- and middle-income countries (LMICs) play in spurring innovation?*** Technology development and diffusion is represented too simplistically (that is, core-periphery and Pareto efficiency), with novel technologies developed predominantly in advanced economies and then spread to the rest of the world. Foresight research needs to consider more pluralistic futures (Mangnus et al. 2019), reexamining what is meant by progress in varying regional and cultural contexts (Ritzer 2003; Pereira et al. 2021). It should explore how innovation processes can be started in LMICs and potentially spread to high-income countries (for example, frugal innovation) (Hossain, Simula, and Halme 2016).

4. ***Can we build consensus on desirable futures?*** Food systems are complex and fractal. Micro and macro analyses highlight the fundamental complexity and unknowability of the whole system. Nevertheless, foresight approaches can help to highlight different stakeholder perspectives and facilitate dialogue across alternative and potentially competing visions of the future (for example, group-based model building [Gerritsen et al. 2020; Anastasiou et al. 2023] or participatory scenarios [Chaudhury et al. 2013; Mason-D'Croz et al. 2016; Aguiar et al. 2020]), a critical first step for collective action.

Answering these questions requires developing more nuanced scenarios that simulate the innovation process in a less linear fashion. Greater application of foresight methods such as backcasting (Holmberg and Robert 2000; Robinson 2003) and three horizons (Sharpe et al. 2016) could help enrich scenario development that feeds into quantitative analyses of food systems innovation. This will provide not just a quantification of an endpoint but of the pathway between the present and an alternative future. It should also incorporate growing literature on innovation readiness and scaling (Herrero et al. 2020; Sartas et al. 2020; List 2022; Woltering et al. 2024). Achieving this will require broader and larger scenario sets and a wider range of foresight models to better capture key relationships and feedbacks, learning and expanding on previous multimodel efforts not only to understand model uncertainty (Nelson et al. 2014) but also to allow representation of a wider range of behaviors described in these more pluralistic scenarios. Failing to do this will reduce the applicability of future foresight research to inform strategic decision-making, such as in the design of innovation bundles (that is, prioritization and investment).

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Related chapters on the future of food system drivers and impacts, regional and national perspectives, food commodities, and foresight tools are available in our Table of Contents.

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