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Responsible scaling for transformative impact: Lessons from the science and practice of responsible scaling for agri-food system transformation☆

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ABSTRACT

Innovation is central to achieving global agri-food transformation agendas, including those related to the 2030 United Nations Sustainable Development Goals. The effective use of technologies, along with process and institutional innovations, at optimal scale by farmers and other diverse clients is essential to addressing interconnected challenges such as poverty, malnutrition, biodiversity loss, and climate change. Over the past decade, notions about the "scaling" of innovations have shifted from simplistic 'copy-paste' models to acknowledging the context-specificity, complexity, and unpredictability related to innovation use at progressively larger scales. Despite this shift, many scaling efforts remain relatively unsustainable or irresponsible. They often fail to catalyze systemic change, remain supply-driven, and lack focus beyond project lifespans. In worst case scenarios, they may also generate unintended and negative consequences rather than broad societal or environmental benefits. Approaches like mission-oriented innovation policy, transformative innovation policy, and co-production have emerged to address these persistent challenges. While they promote more inclusive and systemic innovation, their integration into scaling practice remains limited, highlighting the need for more deliberate and aligned efforts.

This special issue seeks to deepen debates around responsible scaling for agri-food system transformation. It aims to address responsibility dimensions related to gender and social inclusion (e.g. sex, age, race, cultural diversity, class, wealth), anticipating and mitigating unintended consequences of innovation use at scale (e.g. heightened greenhouse gas emissions, social inequality, income gaps, etc.), demand-driven innovation and scaling (e.g. through user-centered design), responsible use of scarce resources (e.g. scaling prioritization tools and frameworks, innovation portfolio management), the (financial) sustainability of scaling investments (e.g. exit- and handover strategies, partnership and funding arrangements), as well as alternative scaling models (e.g. outcome-oriented scaling). We welcome theoretical, methodological, and empirical contributions, including case studies, that provide lessons on successes and failures of responsible scaling for transformative impact.

1. Introduction

Despite the potential of agricultural innovations to contribute to transformation agendas such as the United Nations 2030 Sustainable Development Goals (SDGs), many innovations remain "on the shelf" or fail to scale to the level needed for meaningful and lasting impact (Schut et al., 2020). This is often due to a narrow focus on technological solutions—such as new crop varieties or management practices—without sufficient attention to the complementary market, capacity, or policy innovations required to enable their uptake and sustained use (Barrett et al., 2020; Sartas et al., 2020). Moreover, innovation development and scaling efforts are frequently supply-driven; lacking alignment with the needs, priorities, and capabilities of farmers and other intended users (Béné, 2022; Resnick and Swinnen, 2023).

The complexity and political nature of agricultural transformation further exacerbate these challenges. Innovation teams and scientists are often ill-equipped to engage with the policy, institutional, and business processes necessary to enable systemic change. This reflects, in part, the fact that traditional research and innovation systems were never designed to support transformative change at scale (Byerlee and Lynam, 2020; Klerkx and Begemann, 2020). Reforming these systems is inherently difficult, as they are embedded in entrenched, path-dependent structures shaped by long-standing norms, funding models, and institutional mandates (Fountain, 2011; Kok and Klerkx, 2023; Schot and Steinmueller, 2018). In response, growing attention and investments have been directed toward developing a science of scaling—defined as the design, testing, and validation of scientific theories, concepts, and methods to guide the practical scaling of innovation toward societal outcomes (Schut et al., 2020).

This perspective marks a shift from earlier concepts such as

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technology transfer, innovation diffusion, adoption, and extension (Leeuwis, 2004; Rogers, 1962), toward a more systemic view on innovation scaling. The science of scaling acknowledges that innovations are embedded in, and shaped by, dynamic and unpredictable societal processes (Wigboldus and Brouwers, 2016). It aligns with broader thinking on innovation systems and transformation (Damtew et al., 2023; Glover et al., 2019; Sartas et al., 2020) and has been reinforced by calls for systems- and impact-oriented approaches to scaling (Kok and Klerkx, 2023; Woltering et al., 2019, 2024). This paradigm also recognizes that scaling is inherently political, with potential 'winners' and 'losers,' and has led to greater emphasis on inclusive innovation and responsible scaling (McGuire et al., 2024). At the same time, it challenges the assumptions behind top-down transformation narratives—such as those framed by grand societal challenges or mission-oriented innovation policies. Missions have been critiqued for their implicit solutionism, often being dismissed as overly idealistic and difficult to implement in practical settings (Fielke et al., 2025; Janssen et al., 2023).

To date, responsible innovation scaling —expanding optimal innovation use sustainably and efficiently, while anticipating and addressing potential positive and negative impacts— debates have primarily focused on addressing issues of social differentiation, gender inequality, and the unintended consequences of innovation use at scale. However, as the agenda shifts toward more impact-oriented and transformative forms of scaling, new dimensions of responsibility and associated trade-offs are emerging. These need to be described, understood and operationalized to guide investments and (practical) decision-making in agri-food systems transformation.

2. Considerations on responsible scaling for transformative impact

Responsible scaling for transformative impact presents research, innovation and scaling organizations with strategic considerations, dilemmas and choices. A first fundamental consideration is whether to prioritize scaling out—reaching more people—or scaling deep—fostering institutional change, or combinations of both (Wigboldus and Brouwers, 2016; Woltering et al., 2019, 2024). While broad uptake can trigger widespread transformation, deeper engagement is often necessary to disrupt entrenched structures, create alternative pathways for scaling-out, and achieve more structural change (Moore et al., 2015). These strategies can be complementary but may need different approaches and interventions, each with their own risks and costs. Decisions on 'what and how to scale' are often influenced by funding mechanisms, (shifting) donor agendas, and geopolitical interests (GDPRD, 2023). The unpredictability of financial flows, including overseas development assistance, impacts the ability to scale agricultural innovations particularly in instances where funding allocation is often driven by short funding cycles rather than long-term agri-food systems needs and transformation processes Unpredictable and short-term funding, especially in overseas development assistance, makes it hard to scale transformative innovations that require long-term support (FAO et al., 2024). As a result, innovation scaling processes that lead to 'quick wins' are often favored over scaling processes that may lead to lasting, systemic transformation and change (Schut et al., 2020).

A second consideration is related to the power dynamics of scaling innovation that shape whose demand is prioritized, what successful scaling looks like, and how radical the transformation should be (Berkhout et al., 2005; Eastwood et al., 2025; Leach et al., 2010; Scoones and Stirling, 2020). Ensuring that scaling is demand-driven is often perceived as something that is positive. However, demand-driven approaches often respond to immediate system needs (Klerkx and Leeuwis, 2009) and focus on rapid adoption and use. Yet, transformative change requires pushing beyond the immediate (known) needs and demands of stakeholders, disrupting the status quo, and engaging with resistance to change (Béné, 2022; Leeuwis et al., 2021). Additionally, there is a risk of confirmation bias in how demand is identified—relying on the same familiar partners repeatedly can limit diversity of perspectives and stifle innovation.

Thirdly, for broad and lasting change to happen, combined public and private sector scaling pathways need to be considered. While the private sector can accelerate uptake, market-driven scaling may undermine livelihood changes for disadvantaged groups (Schoneveld, 2020). Although – as part of corporate social responsibility – the private sector can embrace sustainability and responsibility principles as part of their business models (Schaltegger et al., 2016), these are still also very much associated with additional costs and risks. At the same time, public sector scaling pathways may lack the continuity and structural resilience needed to sustain transformation beyond project-based funding cycles and may also fail to support marginalized groups (Scheyvens et al., 2016). A key question remains how to combine public and private sector scaling pathways to benefit heterogeneous societal groups.

A fourth consideration is the complexity and unpredictability of transformation processes. Combined artificial and collective intelligence approaches offer new opportunities for guiding responsible innovation and scaling investment decisions at individual innovation and innovation portfolio level (Cui and Yasseri, 2024; Schut et al., 2024). Such intelligence can support optimizing impact in resource scarce environments, anticipating unintended consequences, may help to contextualize innovation bundles and packages, identify and navigate scaling bottlenecks, align supply and demand, and identifying synergies across diverse scaling pathways (Gama and Magistretti, 2025).

Lastly, the economics of (responsible) scaling remains an underexplored scaling science frontier. Scaling is often conceived as the replication of pilot successes, assuming uniform outcomes across diverse settings (Al-Ubaydli et al., 2017). This view neglects key economic considerations such as cost variations, diminishing returns, and local dependencies. The lack of robust economic modeling and cost-benefit analysis limits the ability to assess the financial sustainability and costs associated with responsible or irresponsible scaling strategies. Emerging concepts like "voltage drop"—the decline in innovation effectiveness at larger scales— can inform what is perceived as optimal scale and require greater scrutiny from an economic and operational standpoint, with careful attention to the specific contexts in which scaling occurs (List, 2024).

3. Special issue objectives and research questions

This special issue builds on two previous Agricultural Systems special issues: *"Science of Scaling: Connecting the Pathways of Agricultural Research and Development for Improved Food, Income and Nutrition Security"* (Schut et al., 2020) and *"Enabling Inclusive Innovation in Agriculture and Food Systems"* (Abera et al., 2024). While the earlier issues focused on important aspects of scaling science and inclusive innovation, this special issue aims to highlight the tensions and opportunities in achieving transformative responsible scaling and advance the discourse and conceptualization of responsibility in scaling.

The objectives of this special issue are to (1) broaden dimensions of responsible scaling and how they are used in the context of agri-food systems transformation, (2) highlight existing tensions and opportunities in integrating transformative and responsible scaling approaches, (3) offer cases or examples of practical solutions to address responsibility tensions or opportunities in transformative scaling, and (4) identify key ingredients, practices and tools for promoting responsible scaling with transformative impact. By doing so, we advance scaling science frontiers whilst also providing valuable insights for the practice of scaling. Findings from the special issue will equip researchers, practitioners, and policymakers with the knowledge and instruments to accelerate responsible scaling in the agri-food sector.

We invite submissions that align with, but are not limited to, the following themes and questions:

1. Incremental versus radical innovations for systemic change: In what ways does responsible scaling accommodate both incremental innovations that address immediate challenges and radical or disruptive innovations that drive long-term systemic transformation in the agri-food sector?
2. Identify optimal scale: What methods can help define optimal scale granularity, appreciating diversity in users and contexts and possible 'voltage-drops' while benefiting from efficiencies created by economies of scale?
3. Demand-driven scaling approaches: What strategies effectively align existing and future innovation demands with innovation development and supply to offer diverse, context-sensitive solutions? What approaches and experiences exist where farmers and other end-users are in the driver's seat in setting innovation agendas, ensuring that solutions are aligned with the real-world challenges they face?
4. Public-private collaboration for inclusive impact: What and how do models of public-private collaboration promote responsible scaling, ensuring marginalized groups benefit from innovations and no one is left behind in the transformation of agri-food systems? What kinds of co-creation processes, arrangements and models can support responsible scaling of public goods through private sector scaling pathways?
5. Efficient use of innovation and scaling resources: What portfolio-level metrics and methods can guide investments of scarce resources for responsible scaling and transformative change? In what ways do trade-off analysis, ex-ante impact assessment, and foresight contribute to informed decision-making around scaling priorities? How to monitor responsibility principles at the level of innovation portfolios?
6. Intelligence for responsible scaling: What combinations of artificial and collective human intelligence is needed for responsible and transformative scaling? What mechanisms can improve demand prediction, anticipate unintended consequences, and tailor scaling strategies to diverse local contexts for transformative impact?
7. Human-centered approach to scaling pathway co-design and evaluation: What approaches, frameworks, and tools can help research and innovation organizations to work more closely together with farmers, local communities or other innovation users, as well as with scaling partners, to ensure innovations are effective, affordable and compatible to address the real-world problems of its users?
8. Policy and institutional coherence for scaling: What institutional mechanisms, governance arrangements, and multi-level coordination strategies are necessary to overcome systemic barriers, mitigate unintended consequences, and promote responsible and sustainable agricultural transformation?
9. Adaptive management of scaling processes: What frameworks, indicators and metrics can help understand and navigate trade-offs, support real-time monitoring, and adaptive management of scaling processes?
10. Learning from failure: What lessons from past scaling failures and instances of irresponsibility in innovation scaling can inform the design of more effective and accountable scaling programs?

We invite scholars to explore novel and underexplored responsibility dimensions that are important in achieving transformative impact in agri-food systems. In addition to practical and methodological contributions, this special issue also welcomes more conceptual papers that engage with the theoretical underpinnings of responsible scaling. Such contributions aim to deepen our understanding of the principles and frameworks that should guide responsible scaling, offering fresh perspectives on how agri-food systems can achieve transformative and sustainable outcomes. We particularly welcome contributions that provide lessons from failures in scaling processes.

4. Key concepts and definitions used in this special issue

4.1. Scaling

Scaling is defined in two ways. First, as a natural phenomenon or process of change and transformation resulting from widespread use of innovations or solutions that occurs independently of any scaling intervention or project (Wigboldus and Brouwers, 2016). Second, as an intentional activity, project or intervention aimed at deploying strategies to accelerate innovation and scaling progress along impact pathways (Wigboldus et al., 2016). In both cases, we approach scaling as a process that occurs in networks of interdependent actors whose (collective) actions determine the extent to which innovations progress along impact pathways (McLean and Gargani, 2019), diffuse across broader communities and/or geographies, and result in positive or negative transformational impact (Eastwood et al., 2017; Schut et al., 2020).

4.2. Responsible scaling

Responsible scaling refers to expanding innovation use in a sustainable and efficient way while foreseeing and acting upon potentially positive and negative consequences, ensuring that scaling processes are inclusive and anticipatory of social, environmental and economic differentiated trade-offs (McGuire et al., 2024; Wigboldus et al., 2016). This means integrating ethical considerations, sustainability, and equity into scaling efforts, rather than focusing solely on growth or efficiency. The idea of responsible scaling is not about eliminating risk entirely but rather about effectively managing and mitigating it by enhancing anticipation (resilience against challenges and opportunities), inclusion (engaging diverse voices for legitimacy), reflexivity (self-examination of assumptions and knowledge limits), and responsiveness (adapting to stakeholder values and changing circumstances) (Stilgoe et al., 2013; Wigboldus and Brouwers, 2016).

4.3. Agri-food system transformation

Transformation refers to a fundamental shift in the underlying logic, structures, and practices of a system where innovations challenge and ultimately reshape dominant socio-technical systems (Geels, 2002). Leeuwis et al. (2021) emphasizes that transformation goes beyond diffusion and scaling by altering the deep-seated rules, norms, and power dynamics that govern a system, enabling long-term systemic change. Agri-food system transformation entails influencing the direction of transformation toward achieving Sustainable Development Goals related to fighting hunger, harnessing biodiversity, and protecting the environment among others (von Braun et al., 2023). This entails shift toward a new equilibrium or paradigm (Scoones and Stirling, 2020) and involves management of risks, trade-offs, and synergies across agri-food system dimensions such as access, safety, affordability, and resilience.

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