Renewable Agriculture and Food Systems

www.cambridge.org/raf

Fostering transformative research and innovation capacity in agroecosystems through stakeholder engagement: a case study on the long-term agroecosystem research network

Claire N. Friedrichsen[1], Gwendŵr Meredith[2], Zachary Hurst[3], Alia DeLong[4] and JD Wulfhorst[5]

[1]Northern Great Plains Research Laboratory, USDA-ARS: USDA Agricultural Research Service, Mandan, USA; [2]School of Natural Resources, University of Nebraska-Lincoln, Lincoln, USA; [3]Playa Ventures, USA; [4]Archbold Biological Station, USA and [5]University of Idaho College of Natural Resources, USA

Research Paper

Cite this article: Friedrichsen C.N., Meredith G., Hurst Z., DeLong A., and Wulfhorst J. 2026. Fostering transformative research and innovation capacity in agroecosystems through stakeholder engagement: a case study on the long-term agroecosystem research network. *Renewable Agriculture and Food Systems*, **41**, e26, 1–13
https://doi.org/10.1017/S1742170526100441

Received: 08 September 2025
Revised: 24 March 2026
Accepted: 13 April 2026

Keywords:
communication; coproduction; networked science; research strategy; stakeholder engagement; sustainable agriculture

Corresponding author:
Gwendŵr Meredith;
Email: gmeredith@unl.edu

Abstract

Agricultural research in North America has shifted across three paradigms in the last century. Each research paradigm has a different assumption of what the research and innovation process is, the expected outcome of the research, and the focus of change within an agroecosystem. Now research institutions and networks are in the process of shifting from the research paradigm of eco-technology, which prioritizes technology as a means for limiting the negative impacts of agriculture, to a transformative research paradigm. However, there is limited knowledge on how to support an intentional paradigm shift toward transformative research. This case study aims to identify the research capacities and characteristics of transformative research in agriculture using interviews with leaders in the Long-Term Agroecosystem Research (LTAR) network. Semistructured interviews with 18 research leaders across the network reveal characteristics of transformative research and lock-ins that limit their ability to transform the research at their site. Four transformative research characteristics and capacities are identified, and lock-ins at different levels of the scientific system are identified that prevent transformative research from occurring. We propose stakeholder engagement as a tool to facilitate a paradigm shift in agricultural research. Tools for integrating stakeholder engagement within the research process are discussed, including stakeholder typologies and stakeholder engagement typologies. A focus on using stakeholder engagement as a means to create transformation by increasing a research site's capacity includes facilitating stakeholder engagement that (1) supports systems-level innovation and social outcomes, (2) emphasizes research that fosters learning and adaptation processes, (3) incorporates multiple ways of knowing within research, and (4) increases perceived agency to create systems-level change. This research provides a methodology and tool for understanding how research paradigms shift and evolve.

Introduction

Agroecosystem research and innovation (R&I) needs to evolve for addressing the pressing, complex, global, social–environmental challenges. Traditionally, research agendas have been following established pathways toward specific innovations. What research is, how it is conducted, and by whom it is conducted are tacitly held assumptions by individuals, institutions, and society. Research paradigms are socially acceptable bounded performative spaces meant for science and innovation to occur (Schlaile et al., 2017). This includes scientific behavioral norms that determine the who, what, when, how, where, and why science is conducted. Research paradigms define acceptable challenges that need to be tackled and also provide the necessary methods, modes, and modalities of stakeholder engagement for this. Research paradigms define a specific range of solutions and also highlight the scope for innovations (Vanloqueren and Baret, 2009; Darnhofer, 2015). Examples of research paradigms in food system sustainability include efficiency, genetic engineering, consumer demand-driven aspects, food system transformation, and agroecology (Vanloqueren and Baret, 2009; El Bilali, 2018).

These paradigms define what research problems are acceptable for solving and further identify the appropriate methods to solve those problems, who should be conducting the research, and what solutions are possible to obtain (Vanloqueren and Baret, 2009). Barriers that maintain the established research paradigms are known as lock-ins. Lock-ins are self-reinforcing mechanisms that keep the current research trajectory or paradigm in place, impeding change in direction, scope, agency, methods, stakeholders, value, and/or orientation of the research paradigm (Cowan and Gunby, 1996; De Herde, Maréchal and Baret, 2019). Lock-ins include societal discrimination, institutional structure, access to resources, existing research equipment, educational pathways,

© The Author(s), 2026. Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

and funding resources (Meynard et al., 2018). Lock-ins prevent research from changing and adopting new paradigms that address new problems, incorporate alternative methodologies, are more inclusive, and address inequality in terms of who benefits from the research.

Transformative agroecosystems require a reimagining of how R&I is being conducted, as well as future pathways that need to be developed from multiple perspectives by researchers, business, and policy sectors (Spielman and Birner, 2008). For example, Jacquet et al. (2022) propose that plant disease-management challenges are not adequately solved by R&I introducing new pesticides. Alternatively, they require multitiered, dynamic solutions that redesign agricultural systems that will (1) enhance prophylaxis, (2) diversify business models, (3) provide agricultural technologies that support not large monocultures but small diversified fields, (4) allow plant breeding to support functional biodiversity, and (4) support private–public policy initiatives. These R&Is require coordination, communication, and parallel efforts by multiple sectors to improve sustainable plant disease management (Jacquet et al., 2022). In addition, these multitiered solutions cannot be completed in isolation, therefore requiring effective stakeholder engagement as critical to achieving change.

A considerable volume of literature has articulated the idealized transformative research and stakeholder engagement strategies to achieve change, but limited research has documented this shift with empirical data (Fazey et al., 2018). To fill this research gap, the Long-Term Agroecosystem Research (LTAR) network was chosen as a case study because it is North America's largest and most comprehensive agricultural field -based research network examining environmental and social outcomes of field-level agroecosystem R&I (Donovan et al., 2025). Officially founded in 2015, the full history of the LTAR network can be found in Robertson et al. (2008) and Tsegaye et al. (2024). At the time of data collection in 2019, the LTAR had 18 research sites pursuing a common mission through a common experiment across the United States (now the research network has 19 sites) (Tsegaye et al., 2024). Each LTAR research site is a subset of network actors learning, experimenting, exploring, and pursuing a specific innovation or a set of innovations advancing the common research mission of the LTAR network (Kemp, Schot and Hoogma, 1998).

Research paradigms

In North America's agricultural systems, there have been several research paradigm shifts within agroecosystem R&I, paralleling paradigm shifts in innovation policy (Table 1) (Schot and Steinmueller, 2018). Following World War I, the Green Revolution focused on developing agronomic crop varieties that increased yield so as to increase production and reduce hunger. However, a paradigm concentrated on efficiency resulted in a reductionist research paradigm, engrossed only on the yield outcomes, and this resulted in many negative environmental impacts. This efficiency paradigm was centered around scientists developing innovations that were economically adaptable at the field level by agriculturists. The innovations sought to control the environment, but they did not address the multidimensional aspects of food security (Klerkx, van Mierlo and Leeuwis, 2012).

As a consequence of externalities from the Green Revolution, a research paradigm known as the eco-technology paradigm evolved. The eco-technology paradigm focuses on technology as a tool to mediate the environmental externalities of agricultural systems. This broader perspective considers environmental drivers in its framework, and outcomes are targeted for providing ecosystem services to society. The eco-technology paradigm perceives the environment as an entity separate from the society and as a resource for society (Vanloqueren and Baret, 2009; Tilman et al., 2011; Klerkx, van Mierlo and Leeuwis, 2012).

From the eco-technology paradigm, a transformative research process has emerged. It focuses on supporting the socio-ecological system's well-being drivers, processes, and outcomes. The transformative paradigm encompasses ecosystem services plus supports dynamic and interdependent individual and community well-being in agricultural systems (Bentley Brymer et al., 2020). This R&I paradigm first arose from the practice of international development in the global south (Ashley and Carney, 1999). The transformative paradigm considers multiple sources of knowledge to understand system dynamics. Under this paradigm, researchers and research programs perceive production, environment, and society as integrally linked. It is because they are inseparable from one another that this paradigm creates conditions to provide environmental and social well-being outcomes of research (Vanloqueren and Baret, 2009; Holt-Gimenez, 2010; El Bilali, 2019).

These research paradigms create parameters that determine acceptable challenges to tackle; provide the methods, modes, and modalities of stakeholder engagement; and define the range of solutions as well as scope of R&I (Vanloqueren and Baret, 2009; Darnhofer, 2015). In the next sections, we define transformative R&I, the role of stakeholder engagement in transformative R&I, and effective stakeholder engagement.

Transformative agroecosystem R&I

The rapid development of technology, access to information, expanding social learning, and multidimensional global change require a new approach to how R&I is conducted—a transformative approach. Transformative R&I includes the incorporation of the complex, compounding social and environmental drivers, processes, and outcomes of agricultural systems (Meynard et al., 2017; Schot and Steinmueller, 2018). Transformative research needs to be democratic, inclusive, and action-oriented and must

Table 1. Efficiency, eco-technology, and transformative paradigm research characteristics

	Efficiency	Eco-technology	Transformative
R&I process	Stakeholders as recipients (one-way communication)	Stakeholders as collaborators (two-way communication)	Stakeholders drive the decisions within learning and adaptive management processes
Outcome of R&I process	Increased profits and environmental conservation	Adoption of new digital technology	Systems-level innovations and social outcomes
Perception of the agroecosystem	The agroecosystem is objective	The environment can be understood and controlled through digital agriculture	Multiple ways of knowing and change needs to occur throughout the system

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

integrate multiple ways of knowing (Fazey et al., 2018). Transformative R&I creates radical change that disrupts power dynamics and requires fundamental reflexivity on how to rebuild systems to address the fundamental social inequality and environmental degradation externalities of our global agroecosystem. Many concepts and frameworks have been developed to understand how science and society interact with one another to create change. However, R&I is a blanket term that can encompass many terms (that is, national innovation systems, agricultural innovation systems, mission-oriented agricultural innovation systems) that are embedded within specific research disciplines and paradigms (Kok et al., 2019).

Transformative research must be reflexive and address current power dynamics in order to create radical change (Schot and Steinmueller, 2018). Four dimensions to reflect upon within a transformative R&I are (1) Directionality—What futures will be created by a R&I pathway? (2) Diversity—Are a variety of R&I pathways taken to address the challenge? (3) Distribution—To what extent will the impact of R&I be just? and (4) Democracy—How can the R&I process be egalitarian? (Kok and Klerkx, 2023). This reflexivity will help researchers transcend current R&I methods and disrupt our current systems to create the necessary change to meet pressing global challenges (Fazey et al., 2018).

Efficiency and the eco-technology R&I literature emphasize the importance of stakeholder engagement in increasing the adoption and improving the relevance of the R&I being conducted. Recently, there is a shift toward seeing stakeholder engagement as an adaptive learning process with stakeholders (Schmidt et al., 2020). At first, stakeholders were only identified as producers and then also as environmental conservationists (El Bilali, 2018). Currently, the understanding is to create a radical change wherein the stakeholders need to represent the holistic agroecosystem (Table 2) and work together to implement change through a reflexive approach (Schlaile et al., 2017; Schot and Steinmueller, 2018; Kok et al., 2019). However, this shift in stakeholder engagement within R&I has had limited implementation due to the disciplinary nature of research, lack of funding for action research, lack of skill capacity by research to creating change, an ineffective evaluation and award system for researchers, lack of clear methodology, and limitations for stakeholders from engaging for extended periods of time (Kok et al., 2019).

Effective stakeholder engagement

The degree of stakeholder empowerment and the scope and methodology within R&I are key determinants of the research paradigm (Vanloqueren and Baret, 2009; Klerkx, van Mierlo and Leeuwis, 2012). Stakeholders are individuals or organizations who may have the power to either facilitate the implementation of innovations or be impacted by innovations. Stakeholder engagement is any process that integrates stakeholders' perspectives, values, and ways of knowing within the innovation system (Schmidt et al., 2020). Transformative R&I requires the integration of the values, worldviews, epistemologies, and ontologies of stakeholders across the agri-food system within the research process (Schmidt et al., 2020). Effective stakeholder engagement includes open communication, diverse participation, unrestrained thinking, constructive conflict, democratic structure, multiple sources of knowledge, extended engagement, and facilitation' (Schulser, Decker and Pfeffer, 2003). Each stakeholder has different needs and desires on how, when, where, and why they would or would not like to be engaged in the process. Additionally, the stakeholders' interest and their power and influence to create change are important considerations moving forward (Eaton et al.,2022).

Table 2. Example typologies or categories of stakeholders that may provide a more holistic agroecosystem perspective, adapted from Worldlink (2026)

Farming	Economic	Social	Environmental
Water	Food wholesalers	Health system	Waste management
Seed	Food companies	Food security	Biodiversity
Energy	Farmers markets	Food safety	Climate change
Agro-chemicals	Grocery stores	Prevention	Land use
Consultants	Restaurants	Care wellness	Restoration
Labor	Lobbying	Food culture	Animal welfare
Transport	Research	Education	
	Subsidies	Awareness	
	Regulations	Media	
	Trade		
	Taxes		

One common pitfall of stakeholder engagement within agri-food R&I is the over reliance on replicating a particular best methodology without reflecting on the impacts of the chosen methodology and the desired outcomes of the engagement (Schmidt et al., 2020; Turnhout et al., 2020). For example, the current literature base tacitly assumes the best method of stakeholder engagement is by a group of individuals sitting around a table and making decisions by consensus. This assumed methodology limits the number of worldviews that can be incorporated into the research process because it requires significant time and resource commitment on the part of stakeholders to participate (Wilmer et al., 2017). Consequently, stakeholders who lack the time, resources, power, or interest to be involved in research do not have their beliefs, values, and worldviews incorporated into the research process. This may reinforce rather than mitigate uneven power relationships by developing R&I that caters to a specific group of elite stakeholders who show up at the table (Turnhout et al., 2020).

Addressing power, politics, and empowerment is essential to stakeholder engagement in order to create transformative social change. One way to do this is to recognize that stakeholder engagement is political (Turnhout et al., 2020). Additionally, effective stakeholder engagement requires unique professional skillsets. However, in agriculture, there is a considerable knowledge gap in improving the effectiveness of stakeholder engagement. Often times, stakeholders are left to stumble through the process via inexperienced facilitation and long, drawn-out processes without clear outcomes (Eaton et al., 2022). Retention and long-term engagement due to resource and time requirements by stakeholders are major barriers to their inclusion within the R&I process (Kok et al., 2019).

R&I network structure

A research network consists of self-organizing research sites, actors, stakeholders, institutions, resources, rules, and mechanisms that demand and supply innovation within a hierarchical structure (Fig. 1) (Hall et al., 2006). A shared vision and mission facilitate effective coordination of R&I across a breadth of research trajectories in a network (Johnson and Macy, 2001; Klerkx, van Mierlo and Leeuwis, 2012; Schlaile et al., 2017; Pigford, Hickey and Klerkx, 2018).

A research paradigm drives who, what, when, where, and how R&I is conducted and is a system of institutional and social structures. For transformative research to happen, a shift toward a

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

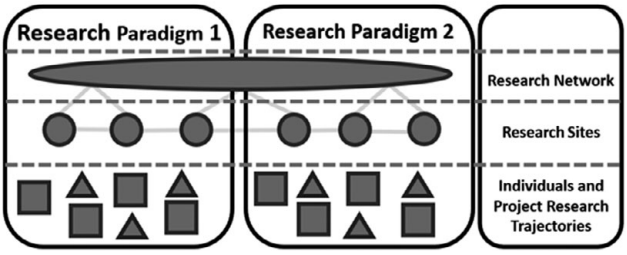


Figure 1. The figure depicts the hierarchical levels of an R&I network and how multiple research paradigms and trajectories exist within a research system. The two outlined squares show how a research paradigm is all encompassing in how a research network, research sites, individuals, and research trajectories approach science, creating this top down force in how science is conducted. The next level is the research network, which sets a common mission for research sites, individuals, and projects trajectories to align with. The next hierarchical level down is the research sites, which create a bounded space through infrastructure of what and how research can be conducted. And finally, individuals and research project trajectories are at the bottom hierarchy receiving a preconceived bounded space in which science can occur based upon the research paradigm, research network, and research site. Figure adapted from Kok et al. (2019).

transformative research paradigm away from eco-technology and efficiency paradigms needs to occur. How to cause a research paradigm shift is complex but it can be driven by multiple drivers within the agricultural system. Research sites face complex conditions when considering a transformative approach to overcome perceived lock-ins to support innovation (Elzen et al., 2012; Darnhofer, 2015; El Bilali, 2019). Lock-ins prevent an agroecosystem from shifting to a new R&I paradigm, maintaining the system's directionality and research trajectory. Leverage points are actions within a system that can cause a cascading change in the fundamental structure of a system, overcoming lock-ins (De Herde, Maréchal and Baret, 2019). There are several leverage points for supporting a shift toward a new R&I paradigm—expanding or changing social networks so that they support and provide new opportunities and potential leverage points; facilitation of 'outside-the-box' thinking; exposure to external systems; or technical, financial, or institutional changes (De Herde, Maréchal and Baret, 2019).

Despite identifying leverage points in the literature, there is limited empirical information about what and who influence a research network, how to support a paradigm shift of a agri-food research network, and what methodologies can be used to study changes of an R&I system (Elzen et al., 2012; Schlaile et al., 2017; Klerkx and Begemann, 2020). How to foster transformative R&I remains challenging and has not yet been accomplished within the agri-food system (Kok et al., 2019; Khan et al., 2021). Additionally, most of the research on supporting agroecosystem transformation recently has been limited to case studies in Europe and Australia (Kok and Klerkx, 2023). Also, much of the literature is aspirational, discussing what should happen instead of analyzing empirical data to determine how transformative R&I occurs (Turnhout et al., 2020). Therefore, our research question is what is the potential for stakeholder engagement to support a shift toward a transformative agroecosystem R&I system within a research network? Our objectives to answer this question are:

(1) determine if a site discreetly fits within one R&I paradigm;
(2) identify characteristics of a transformative agroecosystem R&I system;
(3) determine how lock-ins manifest across and within various levels of a hierarchical R&I system; and
(4) discuss the potential for stakeholder engagement as a leverage point to shift toward a transformative paradigm.

As society navigates as to how to overcome dynamic and complex environmental, social, and economic challenges, the need for transformative R&I is imperative. This research seeks to make a compelling case for embracing stakeholder engagement as a strategic tool for catalyzing a paradigm shift in research to create the transformative and radical change necessary to address urgent global challenges.

Methods

Context

The LTAR network was established to be a transformative leader in US. agriculture in the wake of the exponential impact of global change drivers threatening the resiliency of agroecosystems. The original mission of the LTAR was to promote sustainable intensification, which morphed into supporting production, environmental quality, and rural prosperity (Robertson et al., 2008). LTAR provides an important resource by conducting long-term research to support the transition to sustainable agriculture. Currently, LTAR's mission is 'finding solutions that maintain or increase agricultural productivity, environmental quality, and people's well-being' (LTAR Research Network Home, 2023). In 2011 and 2012, all 18 sites joined the LTAR network. Sites receive funding (~ USD $1 million annually) from the USDA Agricultural Research Service to support infrastructure, data management, research, outreach, and stakeholder engagement. LTAR is governed by a rotating board consisting of research leaders from selected sites. The network consists of a group of USDA-Agricultural Research Service experimental farms, not-for-profit agricultural research farms/ranches (i.e., Archbold Biological Station), and university experimental farms/ranches (i.e., Kellogg Biological Station and University of Florida).

To create a united research effort, all sites conduct a common experiment (CE), which allows for a comparable data set to assess the potential for experimental innovations across the continental United States (Fig. 2). The CE was designed to compare two field level treatments: prevailing practices and alternative practices (Liebig et al., 2024) (Fig. 2). The prevailing practices reflect the local dominant agricultural system. The alternative practices treatment advances the sustainable intensification mission of the LTAR at the field scale (Spiegal et al., 2018). Efforts are underway to develop indicators and metrics (e.g., Spiegal et al., 2022) and stakeholder engagement strategies (e.g., Reimer et al., 2023) for facilitating deliberation of tradeoffs between innovations among stakeholders.

Sampling and data collection

This study followed the Consolidated Criteria for Reporting Qualitative Research (COREQ) reporting guidelines (Tong, Sainsbury and Craig, 2007). All authors belonged to the Human Dimensions working group of LTAR and the first three coauthors were newly hired into the role of network-wide human dimensions postdoctoral research fellows (within six months of employment) at the time of data collection and analysis (Meredith et al., 2021). We interviewed each of the 18 LTAR site leaders, as a list of site leaders existed and they would have the capacity to see bigger picture trends of the R&I capacity and the direction of the research network (Bernard and Ryan, 2009). We chose to interview the site leader in order to standardize and capture the research paradigm and the research trajectory of each LTAR site. Therefore, interviewing research site leaders would capture site and network trends, and

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

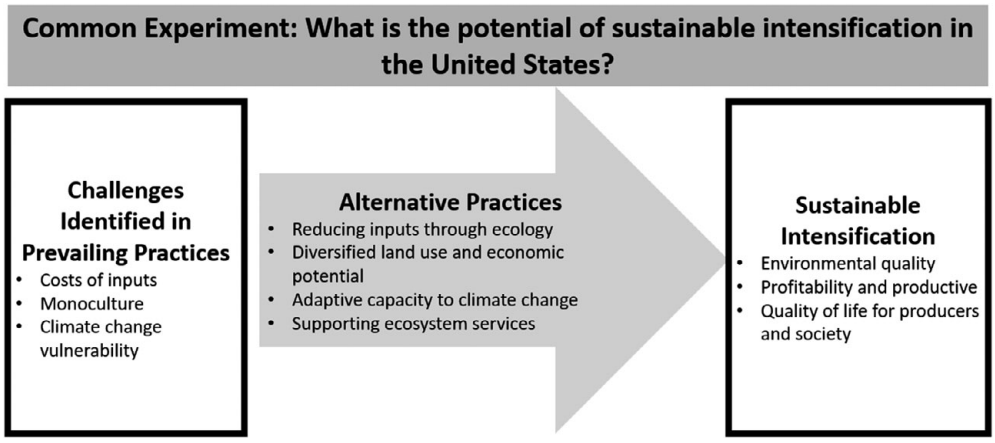


Figure 2. LTAR common experiment—challenges, solutions, and vision. Adapted from Spiegal et al. (2018). The figure aims to show how LTAR will address problems within the current agricultural system to their envisioned common mission of what agriculture should look like in the future. The LTAR envisions two worlds—the current agricultural system, the prevailing practice, which is an agricultural system challenged by cost of inputs, monoculture, and climate change vulnerability. And a sustainably intensified system where new R&I are able to advance equally environmental quality, profitability, and productivity, as well as quality of life for producers and society. LTAR envisions that their R&I [arrow in the middle] will shift the agricultural system from the prevailing to alternative practices.

stakeholders. Interviewing only research site leaders created a bias toward only understanding the bigger picture, limiting the ability to understand day-to-day decision-making and the ability to determine the exact extent of interaction with all stakeholders. It was outside the scope of this study to snowball interview other individuals who might play a central role in the R&I at each site, such as stakeholders, partners, and collaborators. Demographic information of the participants was not collected as part of the interview process in order to maintain as much confidentiality as possible when engaging a limited pool of individuals. All site leaders had terminal degrees and were considered an expert in their field of agriculture. This research was approved by the University of Idaho Institutional Review Board (Project #19–223).

We used a cross-sectional design to compare the research paradigm of each LTAR site as separate, independent research sites. This design allowed us to investigate the breadth and diversity of each LTAR site and compare innovation processes across the research network through interviews with leadership for a glimpse of the shift toward transformative research paradigms (Bernard, 2011).

We conducted semistructured interviews with 18 participants. Participants were recruited via email. Semistructured interviews elicited the participants' perceptions of who and what influences their choice of alternative practice treatment, the process they went through to determine their alternative practices, and the meaningfulness of stakeholder engagement and outreach (that is, 'Explain the current alternative practice treatment you are working on and the research process you went through to get to where you are?') Interviews lasted between 0.5 and 2 hours, and 15 were conducted via videoconferencing and 3 of them in person. The interview guide consisted of eight main questions and specific follow-up prompts for each response (Table 3). We prompted participants with a list of potential influences by category to encourage full elicitation of all perceived influences involved in determining the alternative practices (Johnson-Laird, 2013).

The first three authors each conducted one-third of the interviews based on their expertise area in agriculture and geographic focus: rangeland, cropping, or integrated cropland livestock systems. The quality of coding was enhanced across the three interviewers by: codeveloping a semistructured interview guide, listening to and reflecting upon each other's first interview, and iteratively adjusting the interview guide (Bernard and Ryan, 2009; Charmaz, 2014). All interviews were audio recorded, transcribed, and the transcripts were checked by the interviewer (Bernard, 2011).

Table 3. Interview guide

1.	Do you want to tell me about your role within LTAR? What institutions are you affiliated with?
2.	Can you tell me about a current alternative systems research project you are working on and the research process you have gone through to get to where you are? *Prompt: What is the local cropping system? Ask about specific stakeholders or influencers related to alternative practice development. Ask as necessary to understand the extent of the relationship. How frequent? How long ago? Is this a constant collaborative thing or something that happened once?*
3.	Who or what influences your (1) alternative systems research agenda and (2) perception of the food system? *Prompt: What is the local cropping system? Ask about specific stakeholders or influencers related to alternative practice development. Ask as necessary to understand the extent of the relationship. How frequent? How long ago? Is this a constant collaborative thing or something that happened once?*
4.	Why are your influences on the alternative system research agenda different than your influences on the perception of the food system?
5.	How do you define outreach and stakeholder engagement?
6.	How do you feel your outreach and engagement are meaningful?
7.	Have there been any barriers to you while working on your alternative systems research project?
8.	Do you have anything else to add or anything we did not cover today?

Data analysis

The data analysis process was an emergent, inductive, and iterative process in order to develop transformative R&I characteristics and also the barriers to transformative R&I (Bernard and Ryan, 2009; Charmaz, 2014). The data were analyzed by the same group of researchers who conducted the interviews and collected the data. To establish the code book during the first round of coding, each

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

researcher inductively coded one of their own interviews and identified emergent inductive themes. These potential codes were subsequently discussed by coauthors, grouped together into categories, and a standard list of codes were agreed upon (Bernard and Ryan, 2009).

After the first round of coding, these themes were presented at a member check with LTAR scientists and site leaders (Bernard, 2002). The participants' reactions and feedback were recorded to the preliminary themes. Following the member check, a second round of coding occurred, using the coding tree developed from the first round of coding and the member check. Next, we discussed the differences in coding between coders, developed claims, and identified direct quotes to support our claims (Bernard, 2002; Charmaz, 2014).

Finally, a standardized code book was created based upon theoretical constructs from Klerkx et al. (2012). The third round of coding identified a typology for each site by identifying the research site paradigm (Klerkx, van Mierlo and Leeuwis, 2012). One-third ($n = 6$) of the sites had to express a lock-in for it to be included as a culturally held belief within the LTAR (Vuillot et al., 2016). Additionally, during the third round of coding, stakeholder engagement typologies were operationalized and categorized as provided in Table 4.

Triangulation of results occurred through the member check, repeat presentations of results to the entire LTAR network, receiving informal reflections from network members, reflection of the first three coauthors over the course of a three-year process of serving in the role of human dimension research capacity development for the LTAR network, and multiyear involvement in the LTAR stakeholder engagement working group (Bernard, 2002).

Results

The results are organized around three claims on how to support a shift toward a transformative research paradigm by increasing R&I capacity.

Research sites are not found discretely within one research paradigm

Research sites were not discretely found within one research paradigm (efficiency, eco-technology, transformative), but the data reveal that a research site's R&I process, desired outcome of the R&I process, and perception of the agroecosystem could all fall within different paradigms. For example, site 3. Their desired outcome was environment conservation (efficiency) and social learning (transformative), but their perception of the agroecosystem was focused only at the production scale (efficiency) and not on the holistic food system scale (transformative). However, their stakeholder engagement was collaborative adaptive management, which empowered stakeholders to make decisions for the research design, questions, and analysis (transformative). Not only did sites fall within multiple research paradigms, it is difficult to categorize and describe what paradigm each part of their R&I process falls within. For example, site 1 used to collaborate with partners on social science aspects to drive their research experiments, but had not done it in 25 years; yet, those survey results still impact their research direction now and they really would like to integrate social science. What is consistent is each site's desire to increase their capacity and continue to strengthen their research capacity.

Shift toward a transformative paradigm requires increasing diversified capacity

We identified four characteristics of transformative research processes that can be supported through increasing research capacity: (1) systems-level innovation and social outcomes, (2) emphases on R&I that fosters learning and adaptation processes, (3) incorporation of multiple ways of knowing within R&I, and (4) perceived agency to create systems-level change. To achieve these transformative R&I characteristics, sites expressed a need for increased R&I capacity.

Characteristic 1: systems-level innovation and social outcomes

A research capacity that focuses on the systems-level innovations and social outcomes allows sites to work across complex challenges and global change to create the positive, far-reaching impact of their research and to take a complex-adaptive systems lens to their R&I.

> I've tried to orient the solutions around not just what you can implement on the farm or field, but to address larger challenges within production systems or watershed policies. [Research] pursues things to look at root causes…. Invariably you end up looking at the structure of agriculture, the way it relates to markets, and the role of the consumer. (Participant 14)

For participant 14 to take this approach required them to increase their capacity from single disciplined, siloed thinking to a holistic systems-level awareness.

> Probably need somebody with a broad perspective like you (interviewer) to help us do that. That is one of the things that we are a little bit limited. We don't have a [social scientist] in house that [can bring that] sort of perspective and we probably should think about how we should broaden [our capacity}. (Participant 1)

Participant 1 also noted the lack of human capacity and the necessary skillsets to conduct research beyond the field or plot level so that their research can create a systems-level impact.

Characteristic 2: fostering learning and adaptation

A site with the research capacity that can indulge in learning and adapt to the managing or experimenting with stakeholders allows the site to act in line with global change and the rapid changes in knowledge and technology taking place over time. However, this requires specific skillsets and personnel to do so. Participant 1 talks about their site's intention to create a stakeholder engagement process to incorporate adaptive management and learning.

> I imagine what we will try to do, is, you know, bring in a group, about 6–8 external people which includes 2–3 producers, extension, maybe 1–2 extension people, and 1–2 from NRCS. What we should do, I think, is try to lean on some of our university colleagues that have some training as facilitators to try to keep this going and try to make sure it is not us trying to drive, drive the discussion so much. (Participant 1)

Participant 1 noted the need for R&I capacity to effectively conduct stakeholder engagement that supports adaptive learning across stakeholders without falling back on one-directional decision-making. For an R&I process to focus on learning and adaptation, it requires the R&I capacity to be increased by incorporating new human skillsets for supporting effective learning with stakeholders.

Characteristic 3: incorporating multiple ways of knowing

Participants expressed three research capacities to incorporate multiple ways of knowing agroecosystems within the research process: (1) collaboration with Black or Indigenous institutions and organizations, (2) incorporation of social science to understand social drivers and outcomes, and (3) representation of varied

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

Table 4. Perceived stakeholder engagement typologies revealed through interviews with LTAR research leaders

Type of stakeholder engagement	Amount of new research capacity to establish and maintain	Definition	Representative quote
Passive network	Conscious assertive effort	Influencers who are interacted with on a regular basis and passively absorb their worldview within the research (i.e., media, staff, sales associates, family, and friends).	'You go to the supermarket now and you there's this whole organic section', (Participant 5)
Passive environment	Conscious assertive effort	The agronomic context most prominent and with the most power. This context becomes the reality of what the researcher's perception of agriculture is and the need of agriculture.	'We take a lot of our research directions from those kind of consistent interactions we have'. (Participant 7)
Key stakeholder	Normal	Individuals with a high level of interest and power whose worldviews are driving forces for the direction of the research and flow of resources (i.e., university partner, commodity board, etc.).	'He (key stakeholder) told us—'I used your soil moisture and your soil temperature data. I was able to get my crops planted two to three weeks ahead of everybody else here and they told me I was crazy. It was too early. But I had a better crop then they did… Those kinds of feedback'. (Participant 16)
Active network engagement	Normal	Individuals and organizations that the researcher actively takes a role within or actively attends their events (i.e., soil and water district, professional organizations, commodity boards).	'I used to be on the [Removed Org. Name] Advisory Committee, but that was one that brought all kinds of stakeholders who are engaged in [conservation effort]'. (Participant 14)
Active environment	Normal	Agronomic context the researcher actively searches to engage with (i.e., field days, specialty interest groups, professional meetings).	'But getting out in front of farmer groups, meeting with those end users are the stakeholders'. (Participant 5)
Partner	Normal	Colleague for which the interchange of ideas should be mutually beneficial.	'They're (Farmer group) wanting us to look at these things and so that's what I mean by engage. They're reaching out to us'. (Participant 4)
Customer focus group	Medium: Meets regularly	Exclusive formal group of individuals who the researchers meet with regularly to present findings, seek resources and gain feedback/input.	'We have fairly strong farmer groups that engage themselves in telling us what they are interested in us doing'. (Participant 4)
Collaborative adaptive management	High: Requires change in thinking of how to do science, what to measure, how to analyze data, and develop conclusions.	Formal relationship between the researcher and individuals where the individuals respond to the data generated by the scientists, provide interpretations, and make decisions about next research steps.	'Looking at how we could do research in a full production manner, explicitly involving stakeholders and consumers throughout the entire experimental process'. (Participant 3)
Social science	High: Requires creating new positions, dedicated scientists, and acceptance of other forms of science.	Research where data are collected about the worldviews of stakeholders who aren't represented in other ways, and/or need to be measured systematically. Can range from qualitative ethnographic research with immersive active environment to quantitative survey work to measure frequency of beliefs.	'Before and after the interview, I talked with [Another researcher at the site] and they made it a point to bring up the farmer surveys in 1992 and 2004/2006, and it was important to know that they had conducted those and those had influenced their alternative practice treatment'. (Memo from Participant 1 Interview)
Community action research	Exceptionally High: Requires change in institutional structure (i.e., promotion and tenure, time and resource allocation, and values and beliefs in the workplace).	Research where the end goal is to create change in the community. Relationship building is the main focus. Includes all of the forms of stakeholder engagement listed above and involves visiting community events, holding community events, has active adoption/dissemination activities integrated as part of the research process, and active data collection from individuals who do not have the interest or ability to otherwise engage.	'The researchers, because they're getting better support from the community. They enjoy working with the students. I think the producers like the fact that these students are coming in you know, getting to understand the production systems, and they're doing so, I think, it just makes us stronger community'. (Participant 10)

agricultural systems within their alternative practice treatment (e.g., organic).

> We try and engage the tribal colleges quite a bit. That's one thing that we've done a fair amount of learning and we've engaged in some collaborative research, and have been learning more about native knowledge and information on the land and ecosystem. I think this has been helpful for us in broadening our understanding. (Participant 9)

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

However, participant 9 said this collaboration has been limited by their R&I capacity, such as funding cycles. The inclusion of multiple ways of knowing of agroecosystems allowed for a wider breadth and diversity of innovations across the research network. Sites that were able to incorporate multiple ways of knowing within their alternative practice treatment had trained personnel and devoted resources to do so.

Characteristic 4: perceived agency

Perceived agency to make a systems-level change is the final transformative R&I characteristic. Sites ranged in their perceived agency from a protectionist approach to a change-making perspective. In a protectionist view, participants perceived they must protect the environment from society, an identity where they perceived they were part of the current system and helping to make the existing system better. For changemakers, perceived agency meant that the current agroecosystem must undergo change and that they are the change agents creating a new, more effective system.

> This idea of a circular economy where you constrain the energy flows—to some extent, and energy can be tracked as water, you could track carbon, etc. But the idea being is that you tighten up that loop and do a better job of mimicking more natural systems so that the energies, the nutrients, we think about these systems—we just don't have the resources to do a better job of tracing the nutrients. (Participant 15)

Here the participant indicated an intention to work toward building a new circular agroecosystem but was constrained by the current research capacity.

Framing a research paradigm shift as an increase in the breadth of research capacity is an insightful and useful lens that may help innovation systems change. A transformative paradigm supports creating goals to foster change in the R&I process instead of labeling them deficient. Instead, it helps to identify where to devote the needed R&I resources. The key insights we have highlighted in this section are participants' identifying characteristics of the R&I process that, through increased capacity, allowed the sites to pursue transformation research.

Hierarchical lock-ins limit transformative research implementation

Participants perceived that hierarchical structures of lock-ins often created a cascade of barriers that limited their ability to implement alternative practice innovations. The lock-ins were found at each hierarchical level—the research paradigm, research network (LTAR), research site, and participants' own cognitive barriers. Both real and perceived imposed barriers resulted in limitations on the type of research process that was possible and the range of acceptable innovation outcomes.

At the research paradigm level, perceived lock-ins included: (1) uncertainty on how to manage personal values at a systems-level to remain objective and (2) the availability of scientific methods to work holistically and at larger scales. Participant 3 pondered, 'The kind of conundrum of—how do we conduct experimental research in highly controlled environments with multiple replications, etc. that is relevant for producers at large scales?' Here, the research leader expresses their concerns about how to retain the acceptable reductionistic scientific rigor while working on larger, more complex (i.e., messier) scales that directly benefit LTAR's stakeholders and end users.

At the institutional level, perceived lock-ins included available funding, human capacity and skillset, and institutional inertia. The formation of LTAR and site selection itself created a lock-in that perpetuates efficiency and eco-technological paradigms. One criterion for inclusion in the LTAR was pre-existing long-term data sets on management practices. This criterion for inclusion has become a lock-in to changing the alternative practice treatment to embody the transformative R&I paradigm characteristics. Long-term research has its own challenges. LTAR's value of long-term data has led site scientists to hesitate to change their Altnerative Practices. 'Over the years, we've worked on residue management, tillage management, crop production, and now we're refocusing that project on our LTAR activities' said Participant 2. Participant 11 said, 'We had to start our alternative practice treatment on something that we were working on already because we didn't have any money from LTAR to do this work.' Here the participant notes how the institutional inertia lock-in was further perpetuated by lack of funding.

At the research site level, several participants perceived the following barriers that perpetuated lock-ins: reliance on external collaborators for stakeholder engagement, lack of formal processes for stakeholder engagement, and land access and tenure. Five participants explicitly mentioned land tenure as a lock-in for implementing their alternative practice treatment over a long-term basis as originally envisioned. Some sites lost their land access or relied on on-farm research for their alternative practice treatment, which limited their control and consistent long-term experimentation of management practices.

> We don't own land. So we can't control the studies… An elderly lady was managing the estate of her husband but she died. Once the heirs of the estate stop squabbling over to sell or to continue, if they sell it and then we've got to go somewhere else, then I've lost continuity of my experiment. (Participant 16)

Most site leaders reported that the alternative practices were influenced by organizations creating demand for agricultural innovations (e.g., producers and commodity boards, federal and regional boundary organizations, environmental NGOs, agricultural input industries, and food value chain conglomerates), and institutions that could provide the data, skillsets, or resources (e.g., state and federal agencies, university collaborations). 'It's those people whose farms I'm working on because they're the ones I talked to more, and it's their problems I hear more, and it's their problems that I think about solutions to, and that may or may not be representative of the broader stakeholder,' said Participant 16. The participant articulated how a limited capacity to interact with multiple stakeholders narrows what innovations they pursue with their R&I. Of the 18 sites, only two sites actively worked with stakeholders that could provide them multiple ways of knowing about the agroecosystem, such as tribal nations or 1890s land grant institutions. Various forms of stakeholder engagement arose from the interviews during the second round of coding (Table 4). These various forms of perceived stakeholder engagement demonstrate the breadth of the R&I paradigm expressed across the LTAR network with some stakeholder engagement types being perceived as more desirable, beneficial, and influential than others.

Finally, perceived individual cognitive barriers created lock-ins that limited the ability to conduct transformative aspirational innovations. These barriers included scientific identity, career trajectories, fear of failure, perception of systems-level influences as subjective, and functional fixedness. Participant 18 expressed the compounding cognitive and human capacity perceived barriers. 'We could go out with an organic system out there and just fail miserably because we don't know how to do organic agriculture very well, quite frankly.' Participants reported that their food

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

systems-level knowledge, compared to their alternative practice treatment, was mostly influenced by subjective factors (e.g., personal identity, personal values, media, life experiences, and personal connections) or secondary demand influences (e.g., producer's perception of market demands, and environmental NGO perception of market demands). This meant that participants felt like they did not have primary stakeholders who could inform them of how to incorporate systems-level knowledge into their alternative practice treatment. However, three sites did work directly with primary stakeholders (that is, the processing and distribution industries). Functional fixedness, a cognitive bias, led to sites taking incremental and pragmatic steps toward changing their alternative practice innovation and focusing on field-level management changes instead of holistic systems-level change.

> I guess that's not my research area. We look at the natural resources in general. That is the mission of our research and so, within a given direction/system, how can we sustain our resources, such as water and soil? We don't try to change what is being grown here or look at necessarily different things. (Participant 4)

Participants feared that researching radical innovations could fail and negatively affect their career. A lack of expertise to effectively carry out the innovation could result in no or poor data, an inability to publish the results, and failure.

Perceived hierarchical barriers at multiple scales within the R&I systems led to lock-ins when conducting the alternative practice treatment that would support transformative research. An increase in research innovation capacity within agroecosystems may allow agroecosystems research to keep pace with the rapid development of technology, access information, and expand social learning and multidimensional global change. 'Challenges may be the same, but the groups attacking them at the different sites hopefully bring different perspectives and solutions,' said one participant during a member check. This statement indicates the participant saw the potential of the LTAR network to tackle sustainable large-scale innovations.

Discussion

This research provides a novel case study of an R&I research network adopting a multidimensional mission to address complex systems and global change within a North American, publicly funded research context. These empirical results characteristics align with the ideal characteristics of transformative R&I identified by Fazey et al. (2018), Kok and Klerkx (2023), and Schot and Steinmueller (2018). However, perceived barriers to the alternative practice treatment occurred at various R&I hierarchical levels and compounded upon one another to create lock-ins that limited the ability of the research sites to effectively establish alternative practice innovations. In the following sections, we discuss the potential of stakeholder engagement as a leverage point to support transformative R&I. We also address lock-ins within the R&I system and how stakeholder engagement can broaden influences at the systems level to facilitate co-innovation (Fig. 3.)

What potential does stakeholder engagement provide to support a transformative paradigm?

Paradigms act as a lens for each level (research network, research site, and individual) of the R&I, influencing how R&I is conducted. In this study, we initially started by trying to categorize the paradigm of each participant. What we found was that participants did not discretely fit within a paradigm category as they were transitioning and shifting to a new paradigm—transformative. In the following section, we discuss how stakeholder engagement may facilitate each of the four identified characteristics of transformative R&I.

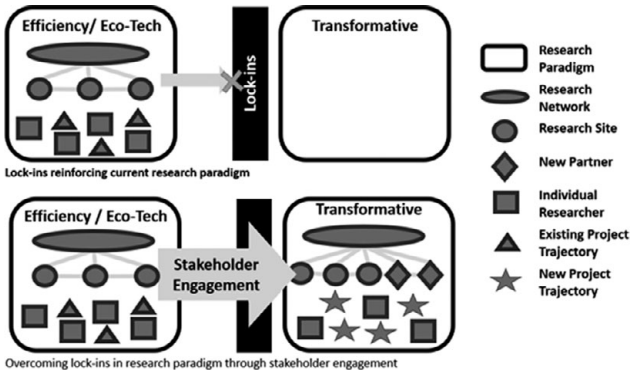


Figure 3. The top model shows how lock-ins prevent the research network from transitioning to a transformative research paradigm. The bottom model shows how stakeholder engagement can be a leverage point for overcoming research paradigm lock-ins. With the incorporation of new partners at the research site level, a new project trajectory will develop that fits within the transformative paradigm.

Resources need to be focused on capacity building and supporting R&I, where various collaborators can come together to innovate and support the integration of knowledge of social drivers and the outcomes of agricultural systems within a transformative paradigm (Busse et al., 2015). Representation of stakeholders across multiple scales and activities of agroecosystems could fill knowledge and expertise gaps in systems level and social outcomes of the agroecosystem (Elzen et al., 2012; Schlaile et al., 2017; Pigford, Hickey and Klerkx, 2018). Increasing partnerships with external boundary organizations such as extension specialists are important as they can connect stakeholders across the agricultural system (Hall and Clark, 2010; Klerkx, Aarts and Leeuwis, 2010; Lubell, Niles and Hoffman, 2014).

Learning and adaptive R&I processes could foster co-innovation with stakeholders. Extension can serve as a boundary organization where they are able to create meaningful, collaborative learning environments across food system stakeholders, catalyzing knowledge exchange (Lubell, Niles and Hoffman, 2014). Story visioning is one collaborative tool to spur interest in innovations that are outside of the current research trajectory (Klerkx, Aarts and Leeuwis, 2010). The R&I ability to support co-innovation is dependent upon stakeholders; their influence on the system; an effectively supported process with sufficient financial, cultural, and resource capital, as well as the support of the involved stakeholders (Turner et al., 2016).

Including stakeholders and their multiple worldviews within the innovation process is essential for improving innovation effectiveness (Busse et al., 2015; De Herde, Maréchal and Baret, 2019). Table 2 provides multiple ways to incorporate multiple worldviews within R&I. This research shows that if researchers interact with stakeholders with similar worldviews then there is a self-reinforcing vision, and the R&I process may limit the ability to integrate multiple ways of knowing within the R&I process (Meynard et al., 2017; Rotz, 2018). Sites that collaborated with tribal nations and land-grant institutions indicated that stakeholder engagement can facilitate the integration of multiple ways of knowing throughout the R&I process.

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

Additionally, stakeholder engagement could increase knowledge and exposure to alternative agricultural systems. For example, participant 18 expressed interest in organic agriculture but they had limited knowledge to implement it. Increasing resources to support multiple ways of knowing through stakeholder engagement may help spur effective innovation (Busse et al., 2015; De Herde, Maréchal and Baret, 2019).

Finally, stakeholder engagement may increase perceived agency to create systems-level change to supportive transformative R&I. The transformative characteristic of perceived agency to make change is a contribution of the study. It suggests that more research needs to examine behavioral change variables and theories to understand R&I evolution over time. Systems-level stakeholders provide primary information about how the agroecosystem functions and how stakeholders with power to create change may help spread the adoption of the innovation. Stakeholder engagement can be a leverage point for transformation, as they may be a pivotal gate keeper or have power within the agriculture system (Klerkx, Aarts and Leeuwis, 2010).

Shifting toward transformative R&I requires a conscious stakeholder engagement strategy. Reflecting upon what categories of stakeholders are represented and who is missing can be facilitated through the list of the categories presented in Table 2. Additionally, Table 4 provides a resource for reflection on choosing what methods and types of stakeholder engagement to pursue within R&I. The 4D reflectivity strategy (Directionality, Diversity, Distribution, and Democracy) can help evaluate the power dynamics impacting the R&I process (Kok and Klerkx, 2023). Additionally, Fazey et al. (2018) identifies 10 essential characteristics of transformative R&I: focus on transformation, focus on solution processes, focus on 'how to' practical knowledge, approach research as occurring from within, work with normative aspects, seek to transcend current thinking and approaches, take a multifaceted approach to change, acknowledge the value of alternative roles of researchers, encourage second-order experimentation and change, and be reflexive.

These resources can be used to reflect on current and future representation of stakeholders. For example, are consumption stakeholders represented within your stakeholder engagement strategy? Are stakeholders who represent diverse dietary preferences included within your stakeholder engagement? A diversity of stakeholder sectors and types are necessary to spur R&I to system-level innovation and social outcomes (Schlaile et al., 2017).

Stakeholder engagement may foster a transformative R&I paradigm by broadening the representation of knowledge across the agroecosystem, facilitating learning and adaptive R&I, incorporating multiple ways of knowing of the agroecosystem, and increasing agency for the alternative practice innovations to create transformative agroecosystems (Fazey et al., 2018).

Potential of stakeholder engagement to address hierarchical lock-ins

Because the participants were facing the challenge of shifting paradigms, they were able to easily articulate barriers to implementing innovations. Stakeholder involvement may help address several barriers at the research paradigm, institutional, research site, and individual cognitive level. These barriers may be hierarchical in scale across the research network, and thus the impact from different lock-ins may not be equal.

At the research network institutional level, stakeholder engagement could address institutional inertia, increase human capacity and skillset, and integrate multiple ways of knowing. For example, integrating and collaborating with diverse stakeholders across agroecosystems could increase the human skillset of an institution. Or inclusion of diverse stakeholders previously excluded from the R&I could break the institutional inertia and support new radical innovations that may provide new pathways to work toward its mission. However, it would be necessary to prioritize effective stakeholder involvement as a value within the research network with appropriate allocation of financial, cultural, and resource capital (Turner et al., 2016). Additionally, leveraging the research network governance to prioritize and devote resources to stakeholder engagement may cause a larger impact than addressing scientific level barriers that limit transdisciplinary R&I. Creating an institutional norm that stakeholder engagement occurs in different forms with specific outcomes is necessary for supporting behavioral change at the individual cognitive level (Turner et al., 2016).

Stakeholder engagement may occur at various points during the R&I process (Busse et al., 2015), involving a diversity of stakeholders depending upon their ability to lead transformative change in sustainable food systems (Schlaile et al., 2017) at each stage (Eastwood et al., 2019). Stakeholder involvement is not a panacea for overcoming lock-ins but a potential leverage point toward shifting paradigms and must occur at multiple levels of the research network hierarchy to cause a shift in research paradigms.

Advancing R&I within networked science

This research begins to fill knowledge gaps on methodology for studying agroecosystem research networks, the effect of stakeholders on their research paradigm, and how to facilitate a research network to implement a multidimensional mission that includes environmental, production, and well-being outcomes (Klerkx and Begemann, 2020). The conceptualization has typically been one dominant paradigm present within an organization or field of research (Vanloqueren and Baret, 2009), or that paradigms are layered upon each other within an institution (Schot and Steinmueller, 2018). The findings of this study demonstrate that such conceptualizations may be an oversimplification, particularly concerning networked science. A research network may have multiple research paradigms and research trajectories to diversify the breadth of innovations being pursued. It might be better to view paradigms along a continuum rather than in discrete categories.

There is limited knowledge about a methodology for studying R&I within a networked science context. However, this cross-sectional comparison of research sites across a research network provides an understanding of a shift in research paradigms across a research network mission. Qualitative interviews provided a useful methodology for providing a snapshot in time of the spectrum of research paradigms across a network, science context, and barriers to conducting transformative R&I.

Limitations

Limitations to this study include the sampling structure of one snapshot of the current research leader at each site as the representative for the entire research site. A longitudinal effort of data collection may help improve our understanding of how the network of research sites evolve and shift their research paradigm to advance one common mission. Additionally, snowball sampling to capture other researchers at each site who may have more direct or varied stakeholder engagement activities, and expanding the sample to

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

include stakeholders to understand their perspective would provide a holistic perspective of effective stakeholder engagement.

Additionally, this case study evolved from existing established long-term research plots and therefore their evolution in R&I paradigm may be different from research networks that are newly established without perceived lock-ins.

Conclusion

A transformative research paradigm is one that has systems-level innovation and social outcomes, a learning and adaptive R&I process, includes multiple ways of knowing, and supports perceived agency to create systems-level change. Stakeholder engagement is one method for supporting the transition to a transformative research paradigm. Additionally, stakeholder engagement builds trust, capacity, and adoption of innovations. For an effective R&I transformation, stakeholder engagement must incorporate the beliefs, values, and worldviews of stakeholders from across the agricultural system. There is no one bullet proof stakeholder engagement strategy. The context, stakeholder type, preference, and research site will determine what type of stakeholder engagement is most effective. Stakeholder engagement ranges from passive networks to customer focus groups to community action research. The main goal of stakeholder engagement should not be a specific method but instead should focus on the desired outcomes of incorporating multiple worldviews within the research process to support transformative R&I and overcome barriers and lock-ins.

Data availability statement. Due to the nature of the research, due to human ethics, supporting data are not available.

Acknowledgements. No generative AI tools were used during the entire research process, analysis, and writing.

Author contribution. C.N.F., G.M., and Z.H. formulated the research question, designed the research study, carried out the study, analyzed the data, interpreted findings, writing, and editing. A.D. interpreted findings and was involved in writing and editing. J.D.W. secured funding, interpreted findings, and was involved in writing and editing.

References

Ashley, C. and Carney, D. (1999) *Sustainable livelihoods: lessons from early experience*. London: Department for International Development.

Bentley Brymer, A.L., Toledo, D., Spiegal, S., Pierson, F., Clark, P.E. and Wulfhorst, J.D. (2020) 'Social-ecological processes and impacts affect individual and social well-being in a rural western U.S. landscape', *Frontiers in Sustainable Food Systems*, **4**. https://doi.org/10.3389/fsufs.2020.00038.

Bernard, H.R. (2002) *Research methods in anthropology: qualitative and quantitative approaches*. 3rd edn. Walnut Creek: Altamira Press.

Bernard, H.R. (2011) *Research methods in anthropology: qualitative and quantitative approaches*. 5th edn. Lanham, MD: AltaMira.

Bernard, H.R. and Ryan, G.W. (2009) *Analyzing qualitative data: systematic approaches*. Thousand Oaks, CA: SAGE Publications.

Busse, M., Schwerdtner, W., Siebert, R., Doernberg, A., Kuntosch, A., König, B. and Bokelmann, W. (2015) 'Analysis of animal monitoring technologies in Germany from an innovation system perspective', *Agricultural Systems*, **138**, pp. 55–65. https://doi.org/10.1016/j.agsy.2015.05.009.

Charmaz, K. (2014) *Constructing grounded theory*. 2nd edn. Los Angeles: SAGE.

Cowan, R. and Gunby, P. (1996) 'Sprayed to death: path dependency lock-in and pest control strategies', *The Economic Journal*, **106**, pp. 521–542.

Darnhofer,I. (2015) Socio-technical transitions in farming: Key concepts. In: Sutherland, L., Darnhofer, I., Wilson, G.A., and Zagata L., editors, *Transition pathways towards sustainability in European agriculture*. Case studies from Europe. CABI, Wallingford, UK. p. 17–31. eISBN: 978-1-78064-220-8

De Herde, V., Maréchal, K. and Baret, P.V. (2019) 'Lock-ins and agency: towards an embedded approach of individual pathways in the Walloon Dairy sector', *Sustainability*, **11**(16), p. 4405. https://doi.org/10.3390/su11164405.

Donovan, M., Spiegal, S., Kaplan, N., Archer, D., Bean, A., Beebout, S.E.J., Bestelmeyer, B.T., Clark, P., DeLong, A., Fortuna, A.M., Friedrichsen, C. N., Hoover, D.L., Huggins, D., Kleinman, P.J.A., McIntosh, M., Renschler, C.S., Ritten, J., Smith, D.R., Webb, N.P. and Wulfhorst, J.D. (2025) 'Selecting performance indicators for farms and ranches engaged in collaborative agroecosystem research', *Journal of Environmental Quality* **54**, 6, pp. 1500–1514. https://doi.org/10.1002/jeq2.70051.

Eastwood, C., Klerkx, L., Ayre, M. and Dela Rue, B. (2019) 'Managing socio-ethical challenges in the development of smart farming: from a fragmented to a comprehensive approach for responsible research and innovation', *Journal of Agricultural and Environmental Ethics*, **32**(5), pp. 741–768. https://doi.org/10.1007/s10806-017-9704-5.

Eaton, W.M., Burnham, M., Robertson, T., Arbuckle, J.G., Brasier, K.J., Burbach, M.E., Church, S.P., Hart-Fredeluces, G., Jackson-Smith, D., Wildermuth, G., Canfield, K.N., Córdova, S.C., Chatelain, C.D., Fowler, L.B., Hendawy, M.M.Z.E., Kirchhoff, C.J., Manheim, M.K., Martinez, R. O., Mook, A., Mullin, C.A., Murrah-Hanson, A.L., Onabola, C.O., Parker, L.E., Redd, E.A., Schelly, C., Schoon, M.L., Sigler, W.A., Smit, E., van Huysen, T., Worosz, M.R., Eberly, C. and Rogers, A. (2022) 'Advancing the scholarship and practice of stakeholder engagement in working landscapes: a co-produced research agenda', *Socio-Ecological Practice Research*, **4**(4), pp. 283–304. https://doi.org/10.1007/s42532-022-00132-8.

El Bilali, H. (2018) 'Transition heuristic frameworks in research on agro-food sustainability transitions', *Environment, Development and Sustainability*, **22** (3), pp. 1693–1728. https://doi.org/10.1007/s10668-018-0290-0.

El Bilali, H. (2019) 'The multi-level perspective in research on sustainability transitions in agriculture and food systems: a systematic review', *Agriculture*, **9**(4), p. 74. https://doi.org/10.3390/agriculture9040074.

Elzen, B., Barbier, M., Cerf, M. and Grin, J. (2012) 'Stimulating transitions towards sustainable farming systems' in Darnhofer I., Gibbon D. and Dedieu B. (eds.) *Farming systems research into the 21st century: the new dynamic*. Netherlands: Springer, pp. 431–455.

Fazey, I., Schäpke, N., Caniglia, G., Patterson, J., Hultman, J., van Mierlo, B., Säwe,F., Wiek, A., Wittmayer, J., Aldunce, P., Al Waer, H., Battacharya, N., Bradbury, H., Carmen, E., Colvin, J., Cvitanovic, C., D'Souza, M., Gopel, M., Goldstein, B., Hämäläinen, T., Harper, G., Henfry. T., Hodgson, A., Howden, M.S., Kerr, A., Klaes, M., Lyon, C., Midgley, G., Moser, S., Mukherjee, N., Müller, K., O'Brien, K., O'Connell, D.A., Olsson, P., Page, G., Reed, M.S., Searle, B., Silvestri, G., Spaiser, V., Strasser, T., Tschakert, P., Uribe-Valvo, N., Waddell, S., Rao-Williams, J., Wise, R., Wolstenholme, R., Woods, M. and Wyborn, C. (2018) 'Ten essentials for action-oriented and second order energy transitions, transformations and climate change research', *Energy Research & Social Science*, **40**, pp. 54–70. https://doi.org/10.1016/j.erss.2017.11.026.

Hall, A. and Clark, N. (2010) 'What do complex adaptive systems look like and what are the implications for innovation policy?' *Journal of International Development*, **22**(3), pp. 308–324. https://doi.org/10.1002/jid.1690.

Hall, A., Janssen, W.G., Pehu, E. and Rajalahti, R. (2006) *Enhancing agricultural innovation: how to go beyond the strengthening of research systems*. Washington, DC: World Bank.

Holt-Gimenez, E. (2010) *Food Security, Food Justice or Food sovereignty*. Institute for Food and Development Policy.

Jacquet, F., Jeuffroy, M.-H., Jouan, J., Le Cadre, E., Litrico, I., Malausa, T., Reboud, X. and Huyghe, C. (2022) 'Pesticide-free agriculture as a new paradigm for research', *Agronomy for Sustainable Development*, **42**(1), p. 8. https://doi.org/10.1007/s13593-021-00742-8.

Johnson, D.B. and Macy, G. (2001) 'Using environmental paradigms to understand and change an organization's response to stakeholders', *Journal of Organizational Change Management*, **14**(4), pp. 314–335. https://doi.org/10.1108/EUM0000000005516.

Johnson-Laird, P.N. (2013) 'Mental models and cognitive change', *Journal of Cognitive Psychology*, **25**(2), pp. 131–138. https://doi.org/10.1080/20445911.2012.759935.

Kemp, R., Schot, J. and Hoogma, R. (1998) 'Regime shifts to sustainability through processes of niche formation: the approach of strategic niche

management', *Technology Analysis & Strategic Management*, **10**(2), pp. 175–198. https://doi.org/10.1080/09537329808524310.

Khan, N., Ray, R.L., Kassem, H.S., Hussain, S., Zhang, S., Khayyam, M., Ihtisham, M. and Asongu, S.A. (2021) 'Potential role of technology innovation in transformation of sustainable food systems: a review', *Agriculture*, **11** (10), p. 984. https://doi.org/10.3390/agriculture11100984.

Klerkx, L., Aarts, N. and Leeuwis, C. (2010) 'Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment', *Agricultural Systems*, **103**(6), pp. 390–400. https://doi.org/10.1016/j.agsy.2010.03.012.

Klerkx, L. and Begemann, S. (2020) 'Supporting food systems transformation: the what, why, who, where and how of mission-oriented agricultural innovation systems', *Agricultural Systems*, **184**, p. 102901. https://doi.org/10.1016/j.agsy.2020.102901.

Klerkx, L., van Mierlo, B. and Leeuwis, C. (2012) 'Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions' in Darnhofer I., Gibbon D. and Dedieu B. (eds.) *Farming systems research into the 21st century: the new dynamic*. Netherlands: Springer, pp. 457–483.

Kok, K.P.W., den Boer, A.C.L., Cesuroglu, T., van der Meij, M.G., de Wildt-Liesveld, R., Regeer, B.J. and Broerse, J.E.W. (2019) 'Transforming research and innovation for sustainable food systems—a coupled-systems perspective', *Sustainability*, **11**(24), p. 7176. https://doi.org/10.3390/su11247176.

Kok, K.P.W. and Klerkx, L. (2023) 'Addressing the politics of mission-oriented agricultural innovation systems', *Agricultural Systems*, **211**, p. 103747. https://doi.org/10.1016/j.agsy.2023.103747.

Liebig, M.A., Abendroth, L.J., Robertson, G.P., Augustine, D., Boughton, E. H., Bagley, G., Busch, D.L., Clark, P., Coffin, A.W., Dalzell, B.J., Dell, C.J., Fortuna, A.M., Freidenreich, A., Heilman, P., Helseth, C., Huggins, D.R., Johnson, J.M.F., Khorchani, M., King, K., Kovar, J.L., Locke, M.A., Mirsky, S.B., Schantz, M.C., Schmer, M.R., Silveira, M.L., Smith, D.R., Soder, K.J., Spiegal, S., Stinner, J., Toledo, D., Williams, M. and Yost, J. (2024) 'The LTAR common experiment: facilitating improved agricultural sustainability through coordinated cross-site research', *Journal of Environmental Quality*, **53**(6), pp. 787–801. https://doi.org/10.1002/jeq2.20636.

LTAR Research Network Home. (2023) *LTAR network* [Online]. Available at: https://ltar.ars.usda.gov/ (Accessed: 27 December 2023).

Lubell, M., Niles, M. and Hoffman, M. (2014) 'Extension 3.0: managing agricultural knowledge systems in the network age', *Society and Natural Resources*, **27**(10), pp. 1089–1103. https://doi.org/10.1080/08941920.2014.933496.

Meredith, G., Bean, A., Brymer, A.B., Friedrichsen, C. and Hurst, Z. (2021) 'Integrating human dimensions within the LTAR Network to achieve agroecological system transformation', *Rangelands*, **44**. https://doi.org/10.1016/j.rala.2021.05.002.

Meynard, J.-M., Charrier, F., Fares, M., Le Bail, M., Magrini, M.-B., Charlier, A. and Messéan, A. (2018) 'Socio-technical lock-in hinders crop diversification in France', *Agronomy for Sustainable Development*, **38**(5), p. 54. https://doi.org/10.1007/s13593-018-0535-1.

Meynard, J.-M., Jeuffroy, M.-H., Le Bail, M., Lefèvre, A., Magrini, M.-B. and Michon, C. (2017) 'Designing coupled innovations for the sustainability transition of agrifood systems', *Agricultural Systems*, **157**, pp. 330–339. https://doi.org/10.1016/j.agsy.2016.08.002.

Pigford, A.-A.E., Hickey, G.M. and Klerkx, L. (2018) 'Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions', *Agricultural Systems*, **164**, pp. 116–121. https://doi.org/10.1016/j.agsy.2018.04.007.

Reimer, A., Doll, J.E., Boring, T.J. and Zimnicki, T. (2023) 'Scaling up conservation agriculture: an exploration of challenges and opportunities through a stakeholder engagement process', *Journal of Environmental Quality*, **52**(3), pp. 465–475. https://doi.org/10.1002/jeq2.20317.

Robertson, G.P., Allen, V.G., Boody, G., Boose, E.R., Creamer, N.G., Drinkwater, L.E., Gosz, J.R., Lynch, L., Havlin, J.L., Jackson, L.E., Pickett, S.T.A., Pitelka, L., Randall, A., Reed, A.S., Seastedt, T.R., Waide, R.B. and Wall, D. H. (2008) 'Long-term agricultural research: a research, education, and extension imperative', *Bioscience*, **58**(7), pp. 640–645. https://doi.org/10.1641/B580711.

Rotz, S. (2018) 'Drawing lines in the cornfield: an analysis of discourse and identity relations across agri-food networks', *Agriculture and Human Values*, **35**(2), pp. 441–456. https://doi.org/10.1007/s10460-017-9838-0.

Schlaile, M.P., Urmetzer, S., Blok, V., Andersen, A.D., Timmermans, J., Mueller, M., Fagerberg, J. and Pyka, A. (2017) 'Innovation systems for transformations towards sustainability? Taking the normative dimension seriously', *Sustainability*, **9**(12), p. 2253. https://doi.org/10.3390/su9122253.

Schmidt, L., Falk, T., Siegmund-Schultze, M. and Spangenberg, J.H. (2020) 'The objectives of stakeholder involvement in transdisciplinary research. A conceptual framework for a reflective and reflexive practise', *Ecological Economics*, **176**, p. 106751. https://doi.org/10.1016/j.ecolecon.2020.106751.

Schot, J. and Steinmueller, W.E. (2018) 'Three frames for innovation policy: R&D, systems of innovation and transformative change', *Research Policy*, **47** (9), pp. 1554–1567. https://doi.org/10.1016/j.respol.2018.08.011.

Schulser, T.M., Decker, D.J. and Pfeffer, M.J. (2003) 'Social learning for collaborative natural resource management', *Society & Natural Resources*, **16**(4), pp. 309–326. https://doi.org/10.1080/08941920390178874.

Spiegal, S., Bestelmeyer, B.T., Archer, D.W., Augustine, D.J., Boughton, E. H., Boughton, R.K., Cavigelli, M.A., Clark, P.E., Derner, J.D., Duncan, E. W., Hapeman, C.J., Harmel, R.D., Heilman, P., Holly, M.A., Huggins, D. R., King, K., Kleinman, P.J.A., Liebig, M.A., Locke, M.A., McCarty G.W., Millar N., Mirsky, S.B., Moorman, T.B., Pierson, F.B., Rigby, J.R., Robertson, G.P., Steiner, J.L., Strickland, T.C., Swain, H.M., Wienhold, B.J., Wulfhorst, J.D., Yose, M.A. and Walthall, C.L. (2018) 'Evaluating strategies for sustainable intensification of US agriculture through the long-term agroecosystem research network', *Environmental Research Letters*, **13**(3), p. 034031. https://doi.org/10.1088/1748-9326/aaa779.

Spiegal, S., Webb, N.P., Boughton, E.H., Boughton, R.K., Brymer, A.L.B., Clark, P.E., Collins, C.H., Hoover, D.L., Kaplan, N., McCord, S.E., Meredith, G., Porensky, L.M., Toledo, D., Wilmer, H., Wulfhorst, J.D. and Bestelmeyer, B.T. (2022) 'Measuring the social and ecological performance of agricultural innovations on rangelands: progress and plans for an indicator framework in the LTAR network', *Rangelands*, **44**(5), pp. 334–344. https://doi.org/10.1016/j.rala.2021.12.005.

Spielman, D.J. and Birner, R. (2008) *How innovative is your agriculture? Using innovation indicators and benchmarks to strengthen national agricultural innovation systems*. Washing, DC: World Bank.

Tilman, D., Balzer, C., Hill, J. and Befort, B.L. (2011) 'Global food demand and the sustainable intensification of agriculture', *Proceedings of the National Academy of Sciences*, **108**(50), pp. 20260–20264. https://doi.org/10.1073/pnas.1116437108.

Tong, A., Sainsbury, P. and Craig, J. (2007) 'Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups', *International Journal for Quality in Health Care*, **19**(6), pp. 349–357. https://doi.org/10.1093/intqhc/mzm042.

Tsegaye, T., Eve, M., Hapeman, C.J., Kleinman, P.J.A., Baffaut, C., Browning, D.M., Coffin, A.W. and Spiegal, S.A. (2024) 'The long-term agroecosystem research (LTAR) network: cross-site transdisciplinary science to support a sustainable and resilient agriculture', *Journal of Environmental Quality*, **53** (6), pp. 777–786. https://doi.org/10.1002/jeq2.20649.

Turner, J.A., Klerkx, L., Rijswijk, K., Williams, T. and Barnard, T. (2016) 'Systemic problems affecting co-innovation in the New Zealand agricultural innovation system: identification of blocking mechanisms and underlying institutional logics', *NJAS - Wageningen Journal of Life Sciences*, **76**, pp. 99–112. https://doi.org/10.1016/j.njas.2015.12.001.

Turnhout, E., Metze, T., Wyborn, C., Klenk, N. and Louder, E. (2020) 'The politics of co-production: participation, power, and transformation', *Current Opinion in Environmental Sustainability*, **42**, pp. 15–21. https://doi.org/10.1016/j.cosust.2019.11.009.

Vanloqueren, G. and Baret, P.V. (2009) 'How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations', *Research Policy*, **38**(6), pp. 971–983. https://doi.org/10.1016/j.respol.2009.02.008.

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press

Vuillot, C., **Coron, N.**, **Calatayud, F.**, **Sirami, C.**, **Mathevet, R. and Gibon, A.** (2016) 'Ways of farming and ways of thinking: do farmers' mental models of the landscape relate to their land management practices?' *Ecology and Society*, **21**(1). https://doi.org/10.5751/ES-08281-210135.

Wilmer, H., **Derner, J.**, **Fernandez-Gimenez, M.**, **Briske, D.**, **Augustine, D. and Porensky, L.M.**, **The CARM Stakeholder Group** (2017) 'Collaborative adaptive rangeland management fosters management-science partnerships', *Rangeland Ecology & Management* **71**. https://doi.org/10.1016/j.rama.2017.07.008.

Worldlink. (2026) *Food system map* [Online]. Available at: https://www.nourishlife.org/teach/food-system-tools/ (Accessed: 23 January 2026).

https://doi.org/10.1017/S1742170526100441 Published online by Cambridge University Press