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Digital and sustainable agricultural futures: sociotechnical imaginaries of twin transitions and emerging roles for science

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Introduction: Recently, the concept of twin transitions gained momentum in policy and scientific discourse about agrifood systems. In twin transitional processes, digital tools are leveraged to drive sustainability transformations, while sustainability thinking guides the development, diffusion, and use of digital technology. However, these transitions are characterized by high uncertainty about the futures they will lead agriculture into.
Methods: In the present study, following a sociotechnical imaginaries perspective and using data from a workshop attended by Greek researchers, farmers, and farm advisors, we pursued two objectives. First, to delineate the futures that these transitions might shape for agriculture. Second, to identify the roles that science has to play in these futures.
Results: Our results reveal the multiplicity of agri-digital and sustainable transitions, picturing futures that range from idealized states, where digital technology continuously supports the achievement of sustainability targets, to less optimistic scenarios, in which digitalization fails to improve agricultural sustainability or even to deliver on its promise to provide tangible benefits at the farm level.
Discussion: Science is called to respond to these futures by contributing to technology upgrading, developing low-end digital tools, monitoring and assessing the sustainability performance of agricultural digitalization, informing policy-making, and co-shaping problematizations about digitalization with societal actors.

KEYWORDS
Agriculture 4.0, agrifood systems, digital agriculture, farming, future, sociotechnical imaginaries, sustainability, twin transitions

1 Introduction

As digitalization proceeds apace, expectations and hopes about the ability of digital agricultural technology to address grand challenges are high. Policy frameworks view the digitalization of agriculture as a means to reinvent farming and achieve sustainability goals, thereby supporting a twin (digital and sustainability) transition (Barabanova and Krzysztofowicz, 2023). Nevertheless, recent research suggests that the potential impacts of digital technological advancements on agriculture and society are mixed (Jakku et al., 2022; Duncan et al., 2021; Eastwood et al., 2021; Fleming et al., 2021), drawing attention to the futures that digitalization will bring for agriculture and its contribution to sustainability.

In this study, we aim to outline these futures by relying on sociotechnical imaginaries (Jasanoff and Kim, 2009), i.e., shared visions of the (always entangled) social and technological futures that agricultural digitalization shapes. Additionally, we seek to explore the roles that science should play in shaping these agri-digital futures and supporting societally desirable twin transitions.

In the following sections, we provide an overview of twin transitions and situate the concept of sociotechnical imaginaries within the context of agricultural transitions. We then describe our methodological approach and present the results of our analysis. The article closes with a discussion of our findings and a list of open questions that highlight areas for future inquiry.

2 Twin transitions

2.1 An overview

The word "transitions" is today a keyword in policy documents and several research disciplines. Generally speaking, transitions are change processes or passages from one state to another (Cambridge University Press, 2009). The discussion about energy (Gatto, 2022), circular (Campbell-Johnston et al., 2019), urban (Hughes and Hoffmann, 2020), or mobility transitions (Ruhrort and Allert, 2021) is vivid and growing, pursuing different targets related to the sustainability of sociotechnical systems. The concept of twin transitions emerged after 2020 to denote a simultaneous shift toward a green and digitalized future. Muench et al., 2022, in a landmark report of the European Union's Joint Research Centre, stress the need to promote and successfully manage a twin green and digital transition to move toward a "sustainable, fair, and competitive future."

Today, despite its increased use, the term "twin transitions" still lacks a commonly accepted definition (Aloisi, 2025). Some scholars describe twin transitions as the digitally enabled shift of current techno-socio-economic systems toward a more sustainable future. Such a consideration highlights the potential contribution of digital technologies to achieving sustainability targets (Mäkitie et al., 2023) and to pursuing a greener future (Mehmood et al., 2025). Viewing twin transitions through this angle, digital technologies are conceived of as tools facilitating the attainment of environmental objectives (Aiello et al., 2025; Brueck et al., 2025), such as the reduction of resource and energy consumption (Chen et al., 2023) or carbon footprint (Rehman et al., 2023). In this line of thinking, twin transitions are "digitalizing-for-greening" processes, in which the digital transformation of a system boosts sustainability transitions.

Another strand of the relevant literature emphasizes the complementary relationship between sustainability and digital transitional processes (Husain et al., 2022) and their synergistic evolution (Colapinto and Masé, 2025; Fazio et al., 2025; Tabares et al., 2025). Looking beyond the "greening" of socio-economic sectors or society, this clade of the literature embraces the importance of pursuing social and economic sustainability goals (Torrent-Sellens et al., 2025).

Both strands presented above emphasize the potential of digitalization to initiate sustainability transitions. However, digitalization may have substantial negative externalities. As Meijer (2024) argues, the overemphasis on the ability of digital technologies to drive sustainability transformation may blur our capacity to recognize all the potential threats associated with digitalization, and, hence, it may be dangerous. The experience of previous technological transitions, such as the Green Revolution, confirms this contention (John and Babu, 2021).

Following this train of thought, several policy documents point out the need to focus on the environmental externalities of digital transitions, like the extremely high energy consumption required to produce and utilize digital technologies (Daehlen, 2023; Muench et al., 2022), and the not-so-obvious impacts associated with the raw materials used to produce these technologies or the potential environmental costs at the end-of-life stage (e.g., soil contamination and water pollution) (FAO, 2024a). Scholarly work acknowledges the environmental risks of digital transitions (Szalkowski et al., 2024; Chen et al., 2020), also exposing many social and economic perils of digitalization, such as the polarization of income, potential loss of jobs for unskilled or low skilled employees due to automation, social exclusion due to lack of digital literacy (Grybauskas et al., 2022), negative impacts on adopters' mental health, new forms of cybercrime, worsening of working conditions due to digital fatigue (Szalkowski and Johansen, 2024).

The realization that digitalization can jeopardize the environmental, social, and economic sustainability calls for a holistic view of twin transitions. Therefore, twin transitions can be defined as processes in which digitalization paves the way for a sustainable future and, in parallel, sustainability thinking is applied to and governs the process of producing and exploiting digital technologies (Charatsari, 2024). In this view, the emphasis shifts from how digitalization spurs the sustainability transition to how the two transitions are interlinked and interdependent, serving societal interests without producing adverse effects.

2.2 Characteristics of twin agricultural transitions

Not surprisingly, a significant share of scholarly and policy attention is directed to the twin transitions of agrifood systems. Current systems of agricultural and food production account for approximately one-third of anthropogenic global greenhouse gas emissions (FAO, 2024b), while they contribute to – and are heavily impacted by – climate change (Chataut et al., 2023). Agricultural production is under extreme pressure due to the climate crisis, and the estimates of the future societal and economic impacts of yield decrease are not optimistic (Carleton and Hsiang, 2016).

However, science might face difficulties in supporting agricultural twin transitions due to their multifaceted and convoluted nature. These transitions are systemic processes that take place within complex systems, i.e., interwoven webs involving interdependent components (Broska et al., 2020): social actors (farmers, farm advisors, AgTech companies, policy bodies, and scientists), natural elements (including the agroecosystem, natural resources, and phenomena far beyond the control of social actors), technologies, and various non-technical artifacts (finance and institutions). These systemic elements continuously interact in a disorderly manner, producing novel (facilitating, inhibiting, or neutral) structures (Ladyman et al., 2013). The high complexity and interactivity characterizing these systems increase the levels of uncertainty (Meijer et al., 2007) and hinder any effort to predict future states (Rotmans and Kemp, 2003) or the emerging trajectories of agricultural transitions (Eastwood et al., 2025).

Notably, these transitions represent attempts to initiate purposeful shifts, guided by specific goals. As Casañas and Kovacic (2025) note, innovation – the guiding force of twin transitions – is developed and directed toward achieving (more or less) specific purposes. In this vein, they argue, these transitions possess the qualities of mission-oriented innovation (see Mazzucato, 2018). This approach to innovation requires and facilitates the engagement of stakeholders from diverse socio-economic realms, including science actors, in transitional processes (Wiarda et al., 2023), as well as the collaborative development and exploration of innovation (Hekkert et al., 2020). Nevertheless, being directed by policy, twin transitions of agricultural systems often have to cope with several misfits, since missions are not always well-tailored to the social, cultural, and innovation contexts that they aspire to transform (Uyarra et al., 2025).

Finally, although the focus of relevant work primarily lies in digital technologies, agricultural twin transitions are catalyzed by different types of innovation that are combined to achieve the desired results. Following the typology used by Klerkx and Leeuwis (2009), the innovation mix applied may involve a “hard” component referring to technological artifacts, a “soft” part that concerns the knowledge that the hard innovation encompasses (and the tacit knowledge of the social actors who utilize it), and the “orgware” dimension, which includes institutional and organizational factors. Although actors operating in agricultural systems can and do engage in organizational innovation to fit the purposes of digital (Charatsari et al., 2020) and sustainability transitions (Martin-Rios, 2025), they might face considerable difficulties in dealing with the soft innovation component, due to the highly transformative nature of digital transitions, which require new skillsets to be built (Da Silveira et al., 2025; Nettle et al., 2025; Michailidis et al., 2024).

3 Sociotechnical imaginaries

3.1 Imagination as the foundation of imaginaries

Before delving into the concept of sociotechnical imaginaries, it is helpful to devote some lines to explaining its links and differences with imagination. The latter term, a widely used word in our everyday lives, describes the process of creating images and forms based on actual representations and knowledge (Lennon, 2015). For psychologists, it is a mental process that gives people the power to transform their world into a new, possibly better, one (Barron, 1958); for sociologists a social practice serving as a guiding force for coordinating possible futures (Fuist, 2021); and for philosophers a primary function of human existence that gives birth to the creation of new realities (Castoriadis, 1987).

Regardless of the varying viewpoints through which one can approach imagination, one thing is clear: imagination produces. When focusing on technology, imagination is the first essential step in developing novel artifacts, methods of working, and approaches to reforming current operational models. Technology design always entails an imagination phase (Turner, 2020). What drives this imagination is a gap between an actual and a desired state; the purpose is always to produce an artifact that can, and hopefully will, solve existing or future problems, leading to an ideal (or nearly ideal) state. Developers of future technological systems imagine potential uses – some of which are unforeseen by users of current technologies – long before they begin producing alpha versions of an innovative artifact. For instance, as far back as the 1960s, scholars and the tech industry had begun to imagine and then work on the development of a new and multi-interpretable at their time technological block, in which machines would have thinking capabilities, thus being able to perform tasks that require human reasoning: Artificial Intelligence (Hamming, 1965; Feigenbaum, 1963).

However, when technologies exit the lab and enter the market, new forms of imagination emerge. Potential users envision possible fields of application and the changes that new technologies will bring to their lives, while tech companies imagine relevant, complementary, or supplementary artifacts. New fields of technology development and application are therefore arising. Scholars, especially those working on the social end of science, use imagination to picture how new technologies will impact social structures, existing economic systems, or the natural environment before developing research designs to uncover hidden opportunities and, most importantly, risks. Policymakers also partially rely on imagination to develop legislative frameworks for regulating these risks.

3.2 Sociotechnical imaginaries: what they are and what they do

When several individual imaginings of the new social realities that technology creates (and of the future technology development trajectories) converge, they unite members of a society or social group through shared perceptions of the futures that lie ahead (Jasanoff, 2015). This way, new forms of sociotechnical imaginaries emerge through enmeshing the imaginative work of various social actors “in performing and producing diverse visions of the collective good,” or collective fears (Jasanoff, 2015, p. 11).

Coined by Jasanoff and Kim (2009) and later adapted by Jasanoff (2015), the term “sociotechnical imaginaries” refers to socially shared visions of worth pursuing or troubled futures. These visions, which can be endowed with hope or fear (Rahm, 2023b), are animated by shared beliefs about the new forms of social life and order that can emerge through scientific and technological developments (Jasanoff, 2015).

Sociotechnical imaginaries partially carry the characteristics, norms, and values that prevail within specific social groups or time periods. Hence, they are not stable but dynamic and context-related. They can change over time (Chateau et al., 2021) while they may differ between socio-spatial contexts (Smith and Tidwell, 2016), often producing various contested or parallel forms of conceiving sociotechnical futures (Mager and Katzenbach, 2021). This characteristic should not be viewed as a shortcoming of the theoretical foundation behind sociotechnical imaginaries research. Instead, it opens up several opportunities to understand the future.

Although they do not – or even attempt to – precisely describe a single sociotechnical future, these imaginaries can help capturing the significance of the many possible futures (Lennon, 2015). Additionally, they shape expectations that, in turn, reform social actors’ priorities and plans (Rudek, 2022) and support the development of lines of thinking, the construction of choice canvases, and the establishment of courses of action (Sismondo, 2020). If, as we noted above, imagination produces positive outcomes, sociotechnical imaginaries lend meaning to the products of imagining by loading them with expectations and embedding them in future projections of social life. Importantly, the shared visions of sociotechnical futures largely determine what resources would be mobilized (Chung, 2025), what practices would be enacted (Martinez, 2022), and what technologies should be developed to achieve (or avoid) desirable (or undesirable) futures (Linderoth et al., 2024; Preininger, 2024).

In this respect, sociotechnical imaginaries play a pivotal role in informing policy-making and un-making (Levidow and Raman, 2020; Levenda et al., 2019; Jasanoff and Kim, 2013). Additionally, they serve another critical purpose. They can offer a solution to the long-standing question of how to achieve at least a baseline level of social control over (or, at least, societal actors' involvement in) technology development. Reflecting the ideals, hopes, fears, and ideas of societal actors, sociotechnical imaginaries construct a rich picture of how societies view the futures that (might) come, thus offering science a series of problematizations and problem framings.

3.3 Sociotechnical imaginaries of a sustainable agri-digital future

The high level of performativity characterizing sociotechnical imaginaries (Rudek, 2022; Jasanoff and Kim, 2013), and their contribution to future-making (Mager and Katzenbach, 2021) fed the popularity of the concept beyond its birthplace – energy research (e.g., Kuchler and Stigson, 2024; Carvalho et al., 2022; Rudek, 2022; Longhurst and Chilvers, 2019) – as a tool for studying transitions in mobility (Martin, 2021) and educational systems (Webster, 2025), or to a digitalized (Hassan, 2020) and environmentally sustainable future (Beck et al., 2021), to mention only a few areas of application. In agricultural systems research, the concept also witnessed growing interest. For example, Polzin (2024) examined how dominant sociotechnical imaginaries influence the trajectories of German agrifood systems, undermining novel visions of sustainable agriculture. Omar and Thorsøe (2025), analyzing calls of the Horizon Europe Program related to the "Farm to fork" strategy (2021–2024), uncovered that they reflect three principal imaginaries: the need to leverage nature-based solutions to reduce the environmental pressure caused by agriculture, the production of proteins from alternative (non-animal) sources as a means to ensure a healthy diet for citizens, and the utilization of digital technologies by medium- and small-scale farmers as a vehicle for promoting justice in agrifood systems.

In the strand of literature exploring the futures of digital agriculture, imagination and imaginaries are key concepts. Even the terms "smart farming" and "Agriculture 4.0," which are often used interchangeably with digital agriculture, encompass imaginaries of an intelligent and revolutionary type of farming. Imagination is, thus, an essential practice for understanding the futures that digital technologies can forge (Fielke et al., 2022).

Led by a group of Australian scholars working on the Digiscape project (an Australian nation-wide initiative aiming to generate a palette of agri-digital technological products), a new subfield employing imagination as a practice for building future scenarios and technologies that match societal and policy goals emerged (Fielke et al., 2021; Fleming et al., 2021; Fielke et al., 2019). Others contributed to the field, offering critical insights into how media and policy construct positive imaginaries of digital and/or sustainable futures. For instance, Preininger (2024) showed that imaginaries cultivated by popular media, though not always free of corporate interests, pave the way for a transition to a digital agricultural future. Focusing on influential international organizations, such as the Food and Agriculture Organization, the World Bank, and the Organization for Economic Cooperation and Development, Lajoie-O'Malley et al. (2020) concluded that these institutions promote the idea of digital technologies as tools for addressing critical sustainability challenges. Therefore, it is not surprising that a new culture of "techno-optimism" prevails, weaving positive sociotechnical imaginaries (Stroparo, 2025; Foster et al., 2023).

Such a culture can create a cluster of imaginaries colored by utopian visions of a future in which digitalization is a panacea that addresses grand challenges and opens up new windows of opportunity, blurring its risks and uncertainties. Bain et al. (2020), in a study analyzing the imaginaries of gene editing proponents in the USA, uncovered a relevant pattern: gene editing is portrayed as a scientific progress assimilating traditional plant breeding techniques and, thus, leading to "nature identical" products, which can help address food security concerns and democratize biotechnology development and application.

Nevertheless, in societies, the existence of multiple contradictory or conflicting imaginaries is the norm. In a study involving 1,000 Canadian farmers, Ruder et al. (2025) uncovered that positive, negative, and neutral imaginaries co-exist: power imbalances and divides between winners and losers of the digitalization race go hand-in-hand with imaginings of a more sustainable future, where the environmental footprint of agriculture will be decreased, while farming will continue to be human-centric despite the emergence of technologies like farmbots and Artificial Intelligence.

4 Methods

The data for this study were derived from a workshop attended by 14 Greek experts. Five of them were researchers working in the field of agricultural digitalization and sustainability (two conducting social science research and three performing technology research), five were farm advisors, and four were farmers who had adopted digital technologies (Table 1). Participants provided informed consent. Involving these three groups of participants we attempted to merge different imaginaries of agri-digital and sustainable futures, through integrating the visions of digital technology and sustainability-related innovation developers (researchers), field-level actors (farmers who adopted digital technologies and are requested by policy to follow sustainability paths), and intermediaries (farm advisors), who act as agents facilitating the transition process and the extraction of value from it (Nettle et al., 2025).

Potential participants were selected from a list of actors involved in previously held research projects that had as a central purpose to support sustainable agricultural digitalization: the first aimed to leverage digital innovation to increase the competitiveness and sustainability of farmers and supply chains in the Mediterranean area, and the second to promote responsible digitalization in short food supply chains. We adopted this strategy to ensure that all participants are familiar with agricultural digitalization and sustainability. The list of people involved in workshops conducted within these projects included more than 120 actors (farmers, researchers, and farm

TABLE 1 Characteristics of the experts participating in the workshop.

Participant	Professional position and characteristics	Contribution to scenarios	
		Co-developer	Contributor
1	Researcher (Woman, 44 years old)	2	3, 4
2	Researcher (Man, 51 years old)	1	2, 3
3	Researcher (Man, 33 years old)	1	2, 3
4	Researcher (Man, 46 years old)	4	2, 3
5	Researcher (Woman, 52 years old)	3	2, 4
6	Farm advisor (Man, 39 years old)	2	3, 4
7	Farm advisor (Woman, 52 years old)	3	2, 4
8	Farm advisor (Woman, 37 years old)	1	2
9	Farm advisor (Man, 58 years old)	2	
10	Farm advisor (Woman, 53 years old)	4	2, 3
11	Farmer (Man, 29 years old)	1	3
12	Farmer (Man, 36 years old)	2	3, 4
13	Farmer (Woman, 47 years old)	2	1, 3, 4
14	Farmer (Man, 38 years old)	3	1, 4

The title "co-developer" has been attributed to those participants who initially described the scenario. The column "contributor" indicates the scenarios for which participants provided input.

advisors). Among them, we randomly selected and invited five individuals from each group (forming a total of 15 potential attendees). We did not increase the number of invitations to keep the final group manageable. One farmer was unable to attend the workshop. As a result, the final number of participants was 14. To surface participants' sociotechnical imaginaries of agricultural twin transitions, we asked them to envision the evolution of digital agricultural technologies over the next 20 years and their potential impacts on society, and share their visions with the group. The key features of each imagination were written on a whiteboard. Then, we invited experts to collectively develop views on the potential futures that these technologies create, using these notes as a guide. Two facilitators encouraged the engagement of all participants in this process and stimulated conversation among workshop members. This way, four scenarios were developed by experts. Based on the premise that individuals may hold multiple visions of the future (Seligman et al., 2013), we invited participants to optionally add to these scenarios (even if they did not contribute to their initial development), unless they consider them unlikely to occur. We followed this strategy to enrich data.

To help experts frame their thinking and identify imaginaries that reflect not only technology-induced social changes but also describe how these changes will emerge and what actors will be affected, we built our data collection process on Rahm's (2023b) sociotechnical imaginaries model. In her study, Rahm conceptualizes sociotechnical imaginaries as webs of four interlinked constructs (Figure 1). Technology refers to the set of existing and expected artifacts that may produce significant social change. The subsequent social transformations (and the technologies behind them) generate new problematizations, i.e., conceptualizations of what constitutes a problem, the impacts this problem will have, and the types of solutions that exist or should be developed to address it. Moreover, a critical problematization is who will be impacted by sociotechnical changes. Although agricultural production concerns and affects all members of society, some groups (target populations) might bear a disproportionately high share of the expected impacts of digitalization. Notably, these problematizations do not emerge out of nowhere. Societal actors – such as the scientific community, policy actors, governmental organizations, corporations, and other entities from the private sector, social movements, activists, the media community, organizations operating in the third sector – produce and guide problematizations, individually or collectively, synergistically or antagonistically.

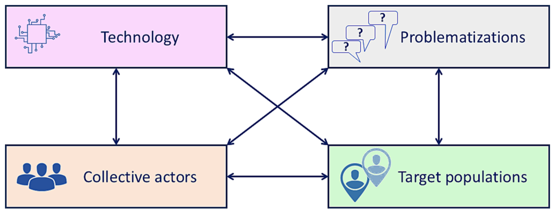

FIGURE 1
The four components included in Rahm's (2023b) sociotechnical imaginaries model.

During the workshop, we motivated participants to imagine and reflect on these four points (technology, problematizations, collective actors, and target populations), asking a series of questions concerning the next 20 years (Table 2). Extra probes (like "tell me about" or "let us discuss more about it") were used to elicit details about the scenarios built. Then, we asked workshop members to describe the roles and competencies of science actors in the futures they envision.

Given that imagination is based on connections between the (known) past and expected future (Bazzani, 2023), we asked experts to parallel the scenarios they create for the future with past evolutionary lines of technology and associated social changes, generating historical analogies. The term refers to the cognitive schemes emerging when comparing a past event, phenomenon, or trajectory with another that evolves in the present (Spellman and Holyoak, 1996). In these analogies, knowledge of past events, phenomena, or their

TABLE 2 Questions used to elicit data on technology, problematizations, collective actors, and target populations.

Domain	Questions
Technology	How will digital agricultural technologies evolve? Do you expect new digital agricultural technologies to emerge? What will these technologies look like? What will they do?
Problematizations	What problematizations will digitalization generate? What types of problems do you imagine? What is the possibility of these problems emerging? Do you envision any solution to these problems?
Target populations	What impacts do you think digitalization will have on society? Are there any indirect societal impacts (e.g., through the effects of technology on the natural environment)? Who will be affected by agricultural digitalization? How?
Collective actors	Do you expect that the societal impacts of agricultural digitalization will lead social groups to raise problematizations? What actors will raise problematizations and how? Will these actors collaborate to produce problematizations? Who will lead the process?
Roles of science	What science must do? What roles scientists must play in this scenario?

evolutionary paths serves as the foundation for people's efforts to understand the current or future trajectories of target events or phenomena (Gentner, 1983). This way, narratives about the future and the roles of various actors in it are constructed by drawing lines from the past (Ghilani et al., 2017).

5 Results

5.1 Scenario 1: future perfect – twin transition as a technological fix

The first imaginary emphasizes the enormous growth of digitalization, which is expected to continue progressing rapidly. According to this view, new tools and applications will be developed and integrated into existing technology building blocks. Second or even third generations of technologies or evolutionary shifts in the ways Artificial Intelligence is used will emerge over the next two decades, opening new opportunities to increase productivity and reduce the environmental impacts of farming.

Participants expressed the belief that digital tools used on the farm, such as farmbots, drones, and sensor networks, will be refined so that they gradually enable advanced functionalities, "just like smartphones gradually became what they are today," as mentioned by an advisor. As an example, a participant described the envisioned evolution of wearable sensors for trees:

> "I believe in the future these sensors will be more accurate in their measurements, and the materials used for their production will endure harsh conditions."

Moreover, the competition among AgTech companies will provide impetus for producing more sophisticated, intelligent, and cost-effective technologies. The anticipated reduction in the prices of digital technologies over the coming years is likely to increase adoption rates, thus opening up opportunities to digitalize not only large-scale but also smaller (yet intensive) farms.

So, what will happen with small-scale farmers? This question yielded mixed answers. For some, the adoption process will gradually span across all farmers. Hence, the inclusion of these farmers in the digitalization process will naturally arise as a result of the technology diffusion process. A pivotal task for scientists is to expedite adoption by helping farmers understand the potential and applicability of digital technologies and by improving the user interface design of future technologies.

From a second viewpoint, farmers lacking the financial resources to afford digital technologies will continue doing business as usual, but will take advantage of some simple and/or open applications that can help them improve their efficiency and environmental performance, thus engaging in a form of "semi-digitalized agriculture," as said by an expert. In this sub-scenario, scientists should work on creating parallel digitalization lines: a more intensive one, which will involve advanced technologies capable of transforming farming, and a less advanced one that, nonetheless, can bring several benefits to users.

In this imaginary, nature will continue to offer its resources to farming. However, the evolution of data science, along with the continued advancement of decision support systems, is expected to create new opportunities for more efficient use of resources (e.g., irrigation water, soil nutrients). Notably, technologies that produce energy from clean sources are anticipated to be developed and applied in agriculture. It is worth noting that this scenario involves cross-sectoral cooperation, in which energy and agricultural technologies are created collaboratively, and on-farm technologies are developed by AgTech corporations based on insights emerging from the experiences of other sectors. The following quote summarizes this perception:

> "Supply chain tracking systems can be used to monitor the inputs and outputs in an animal farm, or implantable sensors like those used in medicine can be adapted and used to monitor the health of cows. The lessons learned from other industries can inform and transform agriculture."

In this perspective, the main problematization is how to achieve an efficient collaboration among actors operating in different industries. According to the advocates of this imaginary, this is a challenging endeavor for policy. Current policy frameworks and initiatives, such as Horizon Europe, have a somewhat unclear focus on promoting cross-sectoral innovation, as they place limited emphasis on the sustainability of the networks they create. An interesting view expressed during the workshop was that these initiatives exclude big players of the technology industry from (or do not offer sufficient incentives to these actors to be included in) their efforts to boost research and innovation.

Key actors in shaping problematizations in this imaginary include AgTech developers, companies from sectors that have been and will continue to be transformed by digitalization, researchers, policy-makers, and farmers. The latter group is expected to experience a significant increase in status and well-being, absorbing the majority of the benefits of digitalization. Concerning consumers and society, supporters of this scenario foresee multiple benefits: access to better, healthier, and more affordable products, as well as a higher quality of the natural environment due to the reduced the negative environmental impacts from farming.

5.2 Scenario 2: future as continuation of the present – twin transition as scientific fiction

In the second imaginary, the twin transition is viewed as a hard, if not impossible, target. That is not to say that digital technologies will not continue to evolve. As in the first scenario, participants envision an advancement of technology in the years to come, without parallel progress toward sustainability goals. In this vein, to use a farmer's words, twin transition is:

> "Scientific fiction. Sustainability is more like a dream that cannot be realized, a scientist's dream, than a real target."

Drawing lines with past sociotechnical transitions, experts parallelized this scenario with the waves of agricultural mechanization and the Green Revolution, describing it as a scene where technologies continue to mature and be adopted by farmers, making farming easier but without meeting societal expectations for a fairer and more sustainable agrifood system, or even producing more environmental problems than those anticipated to solve. Proponents of this vision agreed that the technology advancements would not lead to a reduction in the environmental burden produced by agricultural activities. "Not if we consider the footprint of technology development," as noted by a participant. The increased production of technologies will consume vast amounts of energy, while data storage and maintenance will also contribute to the depletion of resources. Interestingly, some participants discussed the reliance of digital technology on rare earths and scarce metals, which makes its production unsustainable.

At the farm level, it is also questionable whether digitalization will lead to positive environmental and social outcomes. Despite their potential for "correcting errors associated with the environmental management of a farm" (according to an advisor), only minor improvements are expected in terms of contributing to the fight against climate change or increasing biodiversity. As one of the proponents of this imaginary commented:

> "Honestly, it is difficult to find any connection between the use of digital technologies and biodiversity conservation. It is more like a hope than a claim that holds some truth."

In general, some of the participants do not seem to trust technology providers. In this scenario, AgTech companies are seen as actors pursuing a single agenda: to promote technology and increase their returns. Sustainability promises are, in this vein, a form of advertising technologies; a part of the antagonistic game played in a highly competitive industry, or even a form of greenwashing.

Collective actors, such as environmental activists, citizen organizations, and the media, are expected to raise concerns about the actual capacity of digital technologies to support the pursuit of sustainability, as well as questions about the legitimacy of high public investment in digital technology development. According to this imaginary, in response to societal concerns over the funding of digitalization, science should continuously assess the sustainability performance of digital agriculture, seek ways to improve the sustainability outcomes of going digital, and inform policy about the risks entailed in the digitalization process.

Interestingly, in this scenario, citizens with low incomes are expected to bear the bulk of the impacts of an unbalanced twin transition, as they are anticipated to see their purchasing power decrease due to the envisioned increase in food prices, which is considered a likely outcome of digitalization. Nevertheless, other groups not directly linked to agricultural production may also be affected by the direction of state and private funds to the development of digital agricultural technologies. "That money could be used to support health research, public care services, or education," said a farmer to defend this contention.

5.3 Scenario 3: future perfect (after continuous corrections) – twin transition as a scientific refinement

The third imaginary lies between the two that have been presented above. As in the previous scenarios, digital technology development is expected to continue, leading to new artifacts that are marketed with the promise of accelerating the sustainability transition of agrifood systems. However, what makes this narrative different is the emphasis put on the corrective actions that will follow possible failures to meet sustainability-related expectations.

Interestingly, participants who developed this scenario agreed that digitalization will proceed faster than the achievement or even the setting of sustainability goals, as a result of market pressures. The competition among AgTech actors, the cultivation of high hopes for the bright prospects of digitalization by popular media, and investors' interest in digital agriculture will attract new actors to the field. Hence, companies with no previous involvement in agricultural technology development will enter the market, thereby boosting innovation and increasing the variety of available digital tools. However, according to this imaginary, these tools will focus more on increasing farming efficiency and reducing the burden of farm work than on greening the agrifood sector.

"It is a logical evolution," said a researcher. "Farmers care more about increasing their production and making work easier than reducing their impact on the environment, and, much more, about social sustainability. Companies [that produce digital agricultural technologies] are always interested in meeting consumers' demands. If policies do not *enforce* [emphasis added] the achievement of sustainable goals in some way, then the development of these technologies will follow market rules, as it always happens."

Commenting on the above, a farmer mentioned that "it is difficult for a producer to estimate the environmental impacts of their activity. Farmers purchase technologies to enhance productivity and save time and effort. Calculating their impacts is not a job for farmers."

From these two comments, a critical question emerged: Who will take the responsibility for ensuring that digital technologies really contribute to sustainability transitions? Participants left little room for doubt: science and policy are the realms that will oversee the trajectory of digitalization and direct it toward achieving sustainability-related targets. This process of continuous supervision of digitalization will be based on consecutive assessments of the positive and negative impacts of digital technology production and implementation at the farm level and beyond (in food processing, storage, and distribution).

The historical analogy used was that of automobile technology, where the initial aims of facilitating fast, convenient, and safe mobility were expanded to include sustainability considerations, and new products were developed to achieve relevant objectives. However, a significant difference between the two evolutionary lines is that this scenario views twin transition as a transparent process, where societal actors like citizen organizations, governmental and non-governmental organizations, and funding schemes (especially those representing policy initiatives) collaborate with science and policy actors to detect problems in time, analyze them, and propose solutions.

Science actors, in this respect, are charged with the task of co-constructing problematizations with societal actors. Beyond the sustainability performance of digital technologies, problematizations concern the social impacts of agricultural digitalization (effects on farmers' well-being and workers' rights), and its ability to increase the economic returns of adopters without compromising the affordability of food. Hence, target populations include farmers, farm workers, and the financially vulnerable consumer segments.

The co-shaping of problematizations is expected to initiate science-led initiatives aimed at producing positive transformations. New technologies will therefore emerge as customized solutions to the problematizations arising, promoting sustainability transitions. However, as noted by experts, this will not be a one-stop process. Given that the AgTech industry will continue to prioritize economic growth, sustainability objectives will remain secondary to financial goals. To respond to this challenge, science must continuously monitor twin transition paths, redefine problematizations, and refine technology development, while, in parallel, guiding relevant policy actions.

5.4 Scenario 4: error 404 – expected future not found

The fourth imaginary radically differs from the other three. As in the previous scenarios, digital technologies will continue to evolve, and new AgTech players (startups and invaders from other technology sectors) will enter the scene. However, central to this imaginary is the emphasis on the capacity of technology to achieve the desired aims not only by meeting sustainability expectations, but also by improving farming performance. The imaginary describes a future where farmers and other actors face significant difficulties in fully extracting value from digital technologies.

For those who contributed to this scenario, a primary source of concern is the quality of digital technologies. "All technologies present problems in their first phases of development," commented a farm advisor, explaining that "to believe that digital technologies are an exception to this rule is illusory." Being the outcome of rushed development procedures, where testing periods and processes do not provide sufficient time and space for validation, technologies are likely to suffer from functional problems, ranging from minor glitches to major failures, such as crashing, data loss, or even complete system failures. As a researcher noted, software bugs, incompatibilities between subsequent generations of the same technology or between technologies produced by different designers, design flaws, or the use of unreliable materials in their production can lead to these failures. "As the competition in the industry is extremely high, and everybody runs to produce new technologies, design errors are quite likely to occur."

Moreover, participants foresee misfits between digital and analog technologies, or issues associated with the performance of digital tools in harsh agroclimatic and unfavorable geological conditions, such as high levels of humidity and extreme heat, which can reduce the efficiency of sensor networks, or non-flat farm terrains and slopes that can pose difficulties in the use of agricultural robots. Hence, this imaginary conceives of digitalization as a process that may be hindered by the inability of technologies to perform effectively, thus breaking the promise of bringing significant benefits to farmers.

Such a situation might lead to disappointment among adopters and limit further diffusion of digitalization. However, experts added a new element to the discussion: social opposition to digital agricultural technologies. As they stated, the low performance of digitalization may lead some social groups to reject the digital modernization of agriculture, advocating instead for an "anti-smart" or "analog" farming style. Although those who adhere to this scenario did not describe opposition as an offensive stance (e.g., sabotaging technologies), they believe that anti-smart activism can delay agricultural digitalization, especially when opponents build their claims upon social and ethical concerns, like the replacement of farm workers from technologies, farmers' loss of control over their data, and the environmental burden caused by the production of digital tools. Notably, half of the participants who contributed to this scenario view the emergence of conspiracy theories as a potential outcome of opposition to agricultural digitalization. Fed by misinformation spread through social media and misinterpretation of scientific findings, concerns over the dark purposes of technology giants, the fear of surveillance through technologies, and the relation of digital agriculture with technologies already surrounded by misleading claims, like 5G, these theories can erode trust in digital technologies and discourage farmers from following digitalization.

This imaginary presents a future in which agricultural digitalization progresses at a similar pace to that of wind farm technologies, which was the historical analog mentioned by participants. Technology evolves, but failures, design errors, and decreasing social acceptance, reduce its potential to fulfill its purposes. Policy actors, along with academia and research institutes, legislative bodies, farm advisors and farmers' organizations are those who will raise problematizations related to the feasibility of shifting to digital agriculture, the ability of digital technologies to achieve sustainability targets, the standards that technology providers should meet, and the potential impacts of technology failure on adopters and people working in AgTech industry, who represent the populations that will absorb the negative consequences in this scenario.

Beyond expressing problematizations and collaborating with other actors to refine them, science in this scenario is called to undertake a series of duties, spanning from the more technical to the social end of agricultural digitalization. On the technical end of the spectrum, scientific actors should establish robust protocols for technology development, ensure that digital technologies are compatible with varying ecoclimatic conditions, and conduct sustainability assessments. On the social end, they are required to coordinate plans for the responsible diffusion of technology, monitor societal acceptance of digitalization, and promote public dialog on the prospects and externalities of digitalization in agriculture.

5.5 Differences between the supporters of each scenario

Although participants collaboratively created the four scenarios, a closer look at who supports each imaginary is worth doing. As the data presented in Table 1 reveal, the first, optimistic, scenario was developed by two researchers (51 and 53 years old), a farm advisor (37 years old), and a young farmer (29 years old). The co-developers of the second scenario, which is characterized by less idealistic expectations about the ability of technology to address sustainability challenges were two male farm advisors (aged 39 and 58), two farmers (a 47 years old woman, and a 36 years old man) who manage farm enterprises that have adopted digital technologies, and a social science researcher (44 years old). Although quantifying the results was beyond the scope of our analysis, this scenario was the most popular among participants, as Table 1 highlights. The third scenario was formulated by a researcher (52 years old), a farm advisor (52 years old), and a farmer (38 years old), and the less optimistic fourth scenario was conceptualized by a social science researcher and a farm advisor (46 and 53 years old).

Interestingly, the above-mentioned observations do not reveal any robust pattern of social influence in the formation of imaginaries. Notably, all farmers participating in the workshop operate intensive farms with arable crops and orchards, and have adopted digital technologies in recent years. Hence, drawing any conclusions about the influence of farm intensification on shaping future visions is risky. However, it is worth noting that two researchers who initially mapped out the first imaginary conduct technology-oriented research, while the two social scientists hold modest perceptions of the futures that digitalization creates, as evidenced by their contributions to the second and fourth scenarios. This finding may indicate a level of techno-optimism in technology-oriented research, also exposing the skepticism that characterizes social science regarding the ability of digitalization to promote agricultural sustainability.

6 Discussion and conclusion

In the present study, we aimed to depict sociotechnical imaginaries surrounding the agricultural twin transitions and, through these imaginaries, to portray the roles that science should play as a catalyst of desirable twin transitions. Instead of attempting to draw a picture of a unified future, our sociotechnical imaginaries perspective offers the opportunity to see the plurality of futures (Mager and Katzenbach, 2021), thus helping to depict more accurately the many possibilities and uncertainties that follow transitional processes. Moreover, even when they seemingly counter each other, imaginaries of sociotechnical futures allow for the uncovering of new areas in which science can or should intervene, developing new designs and building and sharing new values (Sadowski and Bendor, 2019). Perhaps more importantly, these shared visions, despite their positive or negative coloring, open up spaces of commoning in the process of designing desirable futures (Sardao and Silva, 2024), suggesting joint actions that should be taken in the present to ensure (or avoid) wished (or dystopian) futures.

Framing our analysis around the four-component model proposed by Rahm (2023b), we attempted to explore the different visions that farmers, farm advisors, and researchers hold on the futures that digital agricultural technologies shape, and the degree to which these futures lead to more sustainable ways of farming and living. Our approach led us to sketch imaginaries ranging from purely optimistic to rarely pessimistic scenarios about agricultural digitalization and the hoped achievement of sustainability goals (Table 3). In the following subsection, we discuss these shared visions and the roles of science in the futures they sketch.

6.1 Sociotechnical imaginaries of twin transitions and the (new) roles of science

The imaginaries that emerged through our workshop share some components but also present significant differences. Although in all four scenarios, agricultural digitalization proceeds at a rapid pace, the ability of digital technology to meet the promise of an easier and more efficient future, and its contribution to sustainability, range from certain to dubious. This diversity in the visions of twin transitions does not represent a shortcoming of sociotechnical imaginaries. Instead, variation in viewpoints and imaginings provides the ground for creating common ideations about the future and the optimal ways to approach it (Ingold, 2017).

Not surprisingly, when considering the promotion of digitalization on the part of media (Mohr and Höhler, 2023) and policy (Gugganig, 2025; Kovacic et al., 2024), three of the identified imaginaries view the future as digital. However, only the first scenario presents agricultural digitalization as an unproblematic process that can undoubtedly facilitate the transition to sustainability. In a sense, this scenario embodies the peril of solutionism: it is based on the presumption that technology can solve existing problems through its revolutionary potential (Sætra and Selinger, 2024), without considering any potential unintended effects on adopters or society. Remarkably, participants who contributed to this scenario conceive of the evolution of digital agricultural technologies as an analog to the progression of mobile phone technology, without discussing its adverse outcomes.

Key problematizations in this imaginary center on the collaborative effort to develop better technologies and increase technology adoption rates. Beyond factors like financial (Kitole et al., 2024) and advisory support to potential adopters (Suresh et al., 2025), the diffusion of digital technologies appears to be influenced by the formation of social structures that enable the exchange of institutional support and flow of knowledge among actors, as Da Silveira et al. (2025) conclude in their study. That is a critical role that science must play, while, in parallel, upgrading technologies and developing low-end technological solutions that open up digitalization spaces for farmers who cannot afford high-tech solutions.

The second and third scenarios present more modest views on the potential of digitalization to address sustainability challenges, either because digital technologies have a significant environmental and social footprint (Scenario 2) or because the technology industry, which leads the digitalization game, prioritizes farm efficiency over environmental and social sustainability (Scenario 3). What is common

TABLE 3 Summary of the four sociotechnical imaginaries.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Plot	Twin transitions evolve. Digital technologies address critical challenges in agrifood systems, paving the way for a sustainable future.	Digital technologies evolve and are adopted, but they fail to spur sustainability transitions.	Digitalization proceeds, but it is often marked by failures to achieve sustainability targets. Science and policy surveil twin transitions, steering digitalization in directions that help meet sustainability expectations.	The race of competition spurs technology development. However, technologies fail to meet their promises. Social opposition (along with conspiracy theories) emerges, reducing the pace of adoption.
Technology	Technologies are continuously improved. New technological blocks are developed through merging the knowledge of different sectors. Parallel lines of "softest" technologies evolve as solutions targeted to small-scale farmers.	Technologies are continuously advancing, encompassing new functions that make farming easier. Their production consumes high amounts of energy and limited resources. Their contribution to addressing grand challenges is limited.	Technology development evolves fast. The tools produced improve farm efficiency and performance, but their contribution to pursuing sustainability is limited. However, a social supervision process ensures the early detection of deviations from twin transition targets and the implementation of corrective actions.	Technologies are produced and adopted, but they suffer from frequent failures, misfits, and incompatibilities. Agricultural digitalization cannot achieve sustainability targets or meet the expectations for an easier and improved farm life.
Problematizations	How to promote cross-sectoral collaboration? How to boost technology adoption?	What is the contribution of digitalization to the achievement of sustainability goals? Is the investment in digital technology worth making?	What is the environmental sustainability performance of digitalization? What are the social and economic impacts of digital transitions?	Is transitioning to digital agriculture feasible? How to ensure that digital technologies will meet sustainability objectives? What rules and protocols should digital technology development follow? What are the impacts of technology failure (and for whom)?
Collective actors	Technology developers, industry actors, researchers, policy-makers, farmers.	Environmental activists, citizen organizations, media, science actors.	Science and policy actors, citizen organizations, governmental and non-governmental organizations, funding schemes.	Science and policy actors, legislative organizations, farmers' organizations, farm advisors.
Target populations	Farmers and consumers.	Consumers facing economic barriers, sectors of social life competing with AgTech for the same economic resources.	Farmers, farm workers, financially vulnerable consumers.	Digital technology adopters, workers in the technology industry.
Historical analog	Evolution of mobile phones.	Farm mechanization and Green Revolution technologies.	Automobile technology.	Evolution and acceptance of wind energy technology.
Roles for science	Promoting technology adoption, improving technologies, developing low-end digital technologies.	Assessing the sustainability of digital agriculture, improving the sustainability performance of digitalization, communicating the risks of digitalization to policy-makers.	Co-shaping problematizations with non-science actors, developing tailor-made solutions, continuously monitoring twin transition paths and setting forth new problematizations, informing policy actors and guiding policy action	Defining technology development protocols, improving the fit of digital technologies with varying conditions, assessing the sustainability performance of digitalization, collaborating with non-science actors, coordinating responsible technology diffusion, monitoring social beliefs of digitalization.

to these two narratives is that they echo the concerns of scholars (Hackfort, 2023; Lioutas and Charatsari, 2020; Bronson, 2019; Rotz et al., 2019) about the power that AgTech companies have to direct agricultural digitalization toward serving their agendas. However, one can find silver linings in both imaginaries, as they involve the individual or collective effort of social actors to identify problems and take action. Environmentalists, actors from the media system and the civic sector (in Scenario 2), and governmental organizations, entities acting in the third sector, and funding schemes (in Scenario 3), are those who will co-create problematizations about the sustainability performance of digitalization.

The difference between the two imaginaries lies in the ways these problems are approached and translated into understandings of what should be done to solve them. Although in the second scenario societal actors seem to accept the inability of digitalization to spur sustainability transitions, the third imaginary includes remedial actions on the part of science and policy actors, thus adding a social supervision component in the process of transitioning toward digital and sustainable futures, as the frameworks of Responsible Innovation (Stilgoe et al., 2013) and Responsible Research and Innovation (Von Schomberg, 2013) advocate. Hence, beyond continuously assessing the sustainability of digital agriculture, science has the challenging duty to guide the process of co-constructing problematizations, inform policy-making, and rectifying twin transition trajectories.

Finally, the fourth imaginary poses an intriguing question: what if digital technologies fail to deliver their promises, not only for addressing grand challenges but even for making farming easier? Science is called to take both preventive and remedial actions to address potential technology failures. The former requires the establishment of robust protocols for technological innovation. The latter can be achieved by ensuring that there is no technology performance gap between the laboratory proof-of-concept and implementation in field conditions. To the best of our knowledge, the relevant literature provides limited evidence on the transferability of experimental results to confirm the efficiency of these technologies in real farm settings (Lioutas et al., 2021). A demanding endeavor for science actors, as emerged through our workshop, is assessing the performance of digital technologies within and beyond the limits of farms. The first strand of this task – validating the potential of digital agricultural technologies – can be particularly challenging, mainly when focusing on aspects of technology performance that depend on human-technology interaction, such as technology-driven decision-making (Shepherd et al., 2020). Creating communication channels that connect science and farmers is critical to appraise the operational efficacy of digital technologies. The second – assessing how digitalization, as it evolves, affects the sustainability of agrifood systems – requires the development and implementation of tools and approaches that, ideally, combine metrics and data with qualitative techniques that look beyond the numbers (Hatanaka et al., 2022).

Nevertheless, before problematizing the technical and sustainability performance of digital technologies, science must first answer whether agricultural digitalization is feasible and worth pursuing, and define the standards that technologies should meet. Participants endorsing the failure imaginary view the intense competition within the AgTech industry as a factor that will likely lead to the development of low-quality technologies, due to the reduction of time and emphasis devoted to technology testing and validation. Hence, another critical problematization centers on the rules and protocols governing technology development.

To propose solutions to these problems, science is called to coordinate responsible technology development and diffusion projects, in which policy-making bodies, legislative organizations, and field-level actors co-construct problematizations and envision and apply possible solutions. Strengthening the links between science and these actors, and engaging other societal stakeholders (e.g., citizen organizations, activists) in the process of directing twin transitions, serves another pivotal purpose: it enables science to continuously monitor the evolution of social perceptions of digitalization.

Although studies inquiring into the societal acceptance of agricultural digitalization do exist (Charatsari et al., 2024; Zeddies et al., 2024; Pfeiffer et al., 2021), our work brought to the fore an issue not yet noted elsewhere: the possibility of social opposition to digital agricultural technology to arise as a result of disappointment with the inability of digitalization to drive the desired transformation of agrifood systems, and the socio-ethical concerns that accompany the modernization of farming. Such a pattern of objection to digitalization resembles that observed in wind energy technologies (the historical analog used in the fourth imaginary), where, despite the strong public support, social opposition delays the expected progress in adoption and the delivery of positive outcomes (Klok et al., 2023). In its more intense form, opposition can be combined with conspiracy beliefs, creating an unfavorable environment for technology adoption (Winter et al., 2025).

6.2 Limitations, contribution and directions for future research

A limitation of our study is its reliance on a small sample of farmers, farm advisors, and researchers. Although the number of people who contributed data to our expert workshop exceeded the minimum recommended by some scholars – e.g., Fofana et al. (2020), and Carlsen and Glenton (2011) suggest that 12 participants can lead to data that reach sufficient saturation – and despite the emphasis attributed in our study on the information power that participants hold, which can be more important than their number (Malterud et al., 2016), increasing the sample size and variety of voices included in future studies could lead to richer results. Involving more participants would allow for a socio-structural analysis that could uncover how existing social structures enhance or surpass visions of twin transitions, or a social network analysis that can map the relationships between actors and their centrality in shaping the imaginaries of digital and sustainable futures. Our study did not include such an analysis, as we aimed to depict imaginaries and, through them, identify new roles for science, without focusing on how social relationships catalyze the formation of these imaginaries. However, future studies might broaden the scope and analytical approach of our work, providing relevant insights.

In addition, other stakeholders may hold different imaginaries than those illustrated through our workshop. Our data were derived solely from participants actively involved in the praxis of digital transition. Engaging other groups in the process of envisioning potential agri-digital futures (e.g., non-adopters, actors from civic society) could yield alternative imaginaries. Furthermore, although all workshop members were familiar with digital agriculture, it is important to acknowledge that understandings of digitalization and/or sustainability may vary among participants. However, this is not necessarily a shortcoming of the approach used, since it opens up possibilities for elucidating diverse dimensions of agrifood futures.

Moreover, following a typical pattern in sociotechnical imaginaries research, we did not quantitatively assess attributes such as the positivity or plausibility of each imaginary, nor did we use advanced data analysis techniques, as Ruder et al. (2025) did. Adding a quantitative component could yield additional results, enabling the identification of measurable differences. However, qualitative analyses continue to form the basis of sociotechnical imaginaries research, due to their ability to provide a comprehensive overview of visions of the future, portraying a diverse array of possibilities. Furthermore, in this study, we did not touch upon the historization of identified imaginaries or their genealogy, as Rahm (2023a) termed it. Future researchers can focus on historization, examining how a series of events, cultural shifts, and evolutionary patterns in both technology and society lead to conceptions of the present and imaginings of the future. The lineage of current imaginaries deserves attention from future researchers, as it can reveal why people develop the visions they hold about twin transitions of agriculture.

Study limitations notwithstanding, our work contributes to the understanding of digital and sustainability transitions in agrifood systems. From a methodological standpoint, integrating Rahm's (2023a) four-component model and using historical analogs represent potentially valuable contributions to the sociotechnical imaginaries literature. Future research in the field can utilize and potentially refine the approach used here.

From a theoretical perspective, our study makes three contributions. First, combining imaginaries of technology and social life with emerging problematizations, actors who collectively produce them, and target populations, it provides a rich mosaic of imaginaries around twin transitions, complementing previous work in the field (Ruder et al., 2025; MacPherson et al., 2022; Eastwood et al., 2021; Fleming et al., 2021). The visions included in these imaginaries challenge dominant policy narratives about the imperative to digitalize current agrifood systems as a means to achieve sustainability targets (Lajoie-O'Malley et al., 2020).

Second, our findings point out the need to broaden our focus beyond farmers and farm workers when studying the impacts of agricultural digitalization. As the analysis revealed, low-income consumers may be negatively affected by an increase in food prices that will likely follow digitalization. Another notable result, which merits further elaboration by future researchers, concerns the feasibility of direct public funding in the pursuit of a twin agricultural transition rather than investing in other sectors that enhance human capital and social well-being, such as health or education.

Third, the less-optimistic scenarios that emerged from the present research allowed us to raise a series of new questions about the roles of science in twin transitions. How can research effectively and objectively appraise the impacts of digitalization on the environmental and social sustainability of agrifood systems? How can science rectify the trajectories of twin transitions when sustainability targets are not achieved? How can societal actors be involved in the monitoring, evaluation, and governance of twin transitions? What are the most efficient strategies for connecting science and non-science actors and enabling the co-shaping of problematizations? How can these problematizations reach policy-making? What are the scientific standards that should be met in the technology development process? What factors can lead to technology failure, and how can failure be avoided? Should we expect a Luddite movement against digital agricultural technologies, and how can science actors identify the routes of such a movement by understanding the reasonable concerns and imaginings held by technology opponents? These questions warrant further research, as their answers can provide key insights into how science can support the twin transitions of agricultural systems.

6.3 Conclusion

In this study, analyzing sociotechnical imaginaries of twin transitions, we found that visions of agri-digital futures may vary significantly, ranging from those that embody an unquestioning faith in the ability of digital technology to spur sustainability transitions to less rosy scenarios. Science is requested to support and guide twin transitions by continuously improving technologies, assessing their sustainability performance, rectifying the trajectories of transitions, and, most importantly, collaborating with societal and policy actors to shape problematizations. These findings underscore the importance of shifting to a more critical and inclusive strand of science (Roeven et al., 2025) and support Ravetz's (1997) call to direct scientific efforts toward answering complex and high-stakes "what if" questions. Viewed from a different angle, our results suggest that science may need to challenge its own assumptions about the role of imagination in research. Sociotechnical imaginaries can be a helpful tool not for depicting futures that *will* come, but for delineating futures that *might* come and the actions that should be taken to deal with their many uncertainties. As research on twin agricultural transitions continues to grow, we hope future studies will shed light on how desirable imagined futures can be realized.

Author's note

The first three authors (Evagelos D. Lioutas, Chrysanthi Charatsari, and Marcello De Rosa) serve as guest editors in the research topic "Future Paths for Local and Alternative Food Systems." This potential conflict was noted upon submission.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving humans because ethical review and approval were waived for this study since the study was conducted in accordance with the Declaration of Helsinki and the EU General Data Protection Regulation. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

EL: Conceptualization, Writing – original draft, Visualization, Investigation, Writing – review & editing, Methodology, Formal analysis, Data curation. CC: Funding acquisition, Writing – review & editing, Formal analysis, Writing – original draft, Data curation, Methodology, Investigation, Conceptualization, Visualization. MR: Writing – review & editing, Methodology, Writing – original draft, Conceptualization, Validation, Formal analysis. TP: Validation, Writing – review & editing, Methodology. DA: Resources, Investigation, Writing – review & editing, Formal analysis, Data curation, Validation. LB: Validation, Writing – review & editing, Methodology. CA: Resources, Investigation, Validation, Writing – review & editing. DF: Resources, Investigation, Writing – review & editing, Validation. AM: Project administration, Data curation, Writing – review & editing, Funding acquisition.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Aiello, F., Cozzucoli, P. C., Mannarino, L., and Pupo, V. (2025). Bayesian insights on digitalization and environmental sustainability practices. Towards the twin transition in the EU. *Bus. Strateg. Environ.* 34, 417–432. doi: 10.1002/bse.3985

Aloisi, A. (2025). Integrating the EU Twin (Green and Digital) Transition Synergies, Tensions and Pathways for the Future of Work, European Commission: Joint Research Centre, Seville, JRC140964. Available online at: https://publications.jrc.ec.europa.eu/repository/handle/JRC140964 (accessed September 27, 2025)

Bain, C., Lindberg, S., and Selfa, T. (2020). Emerging sociotechnical imaginaries for gene edited crops for foods in the United States: implications for governance. *Agric. Hum. Values* 37, 265–279. doi: 10.1007/s10460-019-09980-9

Barabanova, Y., and Krzysztofowicz, M. (2023). *Digital Transition: Long-Term Implications for EU Farmers and Rural Communities*. Luxembourg: Publications Office of the European Union, 1–51.

Barron, F. (1958). The psychology of imagination. *Sci. Am.* 199, 150–169. doi: 10.1038/scientificamerican0958-150

Bazzani, G. (2023). Futures in action: expectations, imaginaries and narratives of the future. *Sociology* 57, 382–397. doi: 10.1177/00380385221138010

Beck, S., Jasanoff, S., Stirling, A., and Polzin, C. (2021). The governance of sociotechnical transformations to sustainability. *Curr. Opin. Environ. Sustain.* 49, 143–152. doi: 10.1016/j.cosust.2021.04.010

Bronson, K. (2019). Looking through a responsible innovation lens at uneven engagements with digital farming. *NJAS-Wageningen J. Life Sci.* 90:100294. doi: 10.1016/j.njas.2019.03.001

Broska, L. H., Poganietz, W. R., and Vögele, S. (2020). Extreme events defined—a conceptual discussion applying a complex systems approach. *Futures* 115:102490. doi: 10.1016/j.futures.2019.102490

Brueck, C., Losacker, S., and Liefner, I. (2025). China’s digital and green (twin) transition: insights from national and regional innovation policies. *Reg. Stud.* 59:2384411. doi: 10.1080/00343404.2024.2384411

Cambridge University Press (2009). *Cambridge Academic Content Dictionary*. New York: Cambridge University Press.

Campbell-Johnston, K., ten Cate, J., Elfering-Petrovic, M., and Gupta, J. (2019). City level circular transitions: barriers and limits in Amsterdam, Utrecht and the Hague. *J. Clean. Prod.* 235, 1232–1239. doi: 10.1016/j.jclepro.2019.06.106

Carleton, T. A., and Hsiang, S. M. (2016). Social and economic impacts of climate. *Science* 353:aad9837. doi: 10.1126/science.aad983

Carlsen, B., and Glenton, C. (2011). What about N? A methodological study of sample-size reporting in focus group studies. *BMC Med. Res. Methodol.* 11:26. doi: 10.1186/1471-2288-11-26

Carvalho, A., Riquito, M., and Ferreira, V. (2022). Sociotechnical imaginaries of energy transition: the case of the Portuguese roadmap for carbon neutrality 2050. *Energy Rep.* 8, 2413–2423. doi: 10.1016/j.egyr.2022.01.138

Casañas, C. G., and Kovacic, Z. (2025). Implementing the twin transitions: a critical perspective from the Spanish energy sector. *Environ. Sci. Pol.* 164:104012. doi: 10.1016/j.envsci.2025.104012

Castoriadis, C. (1987). *The Imaginary Institution of Society*. Cambridge, MA: MIT Press.

Charatsari, C. (2024). Preparing adults for twin transitions through competence development. Electronic Platform for Adult Learning in Europe. Available online at: https://epale.ec.europa.eu/en/blog/preparing-adults-twin-transitions-through-competence-development (accessed December 6, 2024).

Charatsari, C., Lioutas, E. D., and De Rosa, M. (2024). Going short and going digital: how do consumers view the impacts of digitalizing short food supply chains? *Sustainability* 16:11241. doi: 10.3390/su162411241

Charatsari, C., Lioutas, D., De Rosa, M., and Papadaki-Klavdianou, A. (2020). Extension and advisory organizations on the road to the digitalization of animal farming: an organizational learning perspective. *Anim.* 10:2056. doi: 10.3390/ani10112056

Chataut, G., Bhatta, B., Joshi, D., Subedi, K., and Kafle, K. (2023). Greenhouse gases emission from agricultural soil: a review. *J. Agric. Food Res.* 11:100533. doi: 10.1016/j.jafr.2023.100533

Chateau, Z., Devine-Wright, P., and Wills, J. (2021). Integrating sociotechnical and spatial imaginaries in researching energy futures. *Energy Res. Soc. Sci.* 80:102207. doi: 10.1016/j.erss.2021.102207

Chen, X., Despeisse, M., and Johansson, B. (2020). Environmental sustainability of digitalization in manufacturing: a review. *Sustainability* 12:10298. doi: 10.3390/su122410298

Chen, X., Kurdve, M., Johansson, B., and Despeisse, M. (2023). Enabling the twin transitions: digital technologies support environmental sustainability through lean principles. *Sustainable Prod. Consumption* 38, 13–27. doi: 10.1016/j.spc.2023.03.020

Chung, H. F. (2025). Betting on (un)certain futures: sociotechnical imaginaries of ai and varieties of techno-developmentalism in asia. *Inf. Commun. Soc.*, 1–18. doi: 10.1080/1369118X.2025.2535427

Colapinto, C., and Masé, S. (2025). Introducing twin transitions in family businesses: a triple-bottom-line perspective. *Bus. Ethics Environ. Responsib.* 35, 164–176. doi: 10.1111/beer.12786

Da Silveira, F., Corrêa, R. G. D. F., Baierle, I. C., Landaverde, R., and Barbedo, J. G. A. (2025). Behavioral profile of farmers in the adoption of agriculture 4.0 technologies in the Agri-food system: a case study in Brazil. *Front. Sustain. Food Syst.* 9:1624753. doi: 10.3389/fsufs.2025.1624753

Daehlen, M. (2023). The Twin Transition Century: The Role of Digital Research for a Successful Green Transition of Society? (The Guild Insight Paper No. 5); The Guild of European Research-Intensive Universities: Brussels, Belgium; Bern Open Publishing: Bern, Switzerland.

Duncan, E., Glaros, A., Ross, D. Z., and Nost, E. (2021). New but for whom? Discourses of innovation in precision agriculture. *Agric. Hum. Values* 38, 1181–1199. doi: 10.1007/s10460-021-10244-8

Eastwood, C. R., Edwards, J. P., Ingram, J., Ayre, M., Fielke, S., and Renwick, A. (2025). On-farm implementation of transformative technologies and practices for sustainability transitions in agriculture. *Front. Sustain. Food Syst.* 9:1616512. doi: 10.3389/fsufs.2025.1616512

Eastwood, C. R., Edwards, J. P., and Turner, J. A. (2021). Anticipating alternative trajectories for responsible agriculture 4.0 innovation in livestock systems. *Anim.* 15:100296. doi: 10.1016/j.animal.2021.100296

FAO. (2024a). *Digital Economy Report: Shaping an Environmentally Sustainable and Inclusive Digital Future*. New York: United Nations Publications.

FAO. (2024b). Greenhouse gas emissions from Agrifood systems. Global, regional and country trends, 2000–2022. Available online at: https://www.fao.org/statistics/highlights-archive/highlights-detail/greenhouse-gas-emissions-from-agrifood-systems.-global--regional-and-country-trends--2000-2022/en (accessed October 5, 2025).

Fazio, G., Maioli, S., and Rujimora, N. (2025). The twin innovation transitions of European regions. *Reg. Stud.* 59:2309176. doi: 10.1080/00343404.2024.2309176

Feigenbaum, E. A. (1963). Artificial intelligence research. *IEEE Trans. Inf. Theory* 9, 248–253. doi: 10.1109/tit.1963.1057864

Fielke, S., Bronson, K., Carolan, M., Eastwood, C., Higgins, V., Jakku, E., et al. (2022). A call to expand disciplinary boundaries so that social scientific imagination and practice are central to quests for 'responsible' digitalagri-food innovation. *Sociol. Ruralis* 62, 151–161. doi: 10.1111/soru.12376

Fielke, S. J., Garrard, R., Jakku, E., Fleming, A., Wiseman, L., and Taylor, B. M. (2019). Conceptualising the DAIS: implications of the 'digitalisation of agricultural innovation systems' on technology and policy at multiple levels. *NJAS Wageningen J. Life Sci.* 90, 1–11. doi: 10.1016/j.njas.2019.04.002

Fielke, S. J., Taylor, B. M., Jakku, E., Mooij, M., Stitzlein, C., Fleming, A., et al. (2021). Grasping at digitalisation: turning imagination into fact in the sugarcane farming community. *Sustain. Sci.* 16, 677–690. doi: 10.1007/s11625-020-00885-9

Fleming, A., Jakku, E., Fielke, S., Taylor, B. M., Lacey, J., Terhorst, A., et al. (2021). Foresighting Australian digital agricultural futures: applying responsible innovation thinking to anticipate research and development impact under different scenarios. *Agric. Syst.* 190:103120. doi: 10.1016/j.agsy.2021.103120

Fofana, F., Bazeley, P., and Regnault, A. (2020). Applying a mixed methods design to test saturation for qualitative data in health outcomes research. *PLoS One* 15:e0234898. doi: 10.1371/journal.pone.0234898

Foster, L., Szilagyi, K., Wairegi, A., Oguamanam, C., and de Beer, J. (2023). Smart farming and artificial intelligence in East Africa: addressing indigeneity, plants, and gender. *Smart Agricultural Technol.* 3:100132. doi: 10.1016/j.atech.2022.100132

Fuist, T. N. (2021). Towards a sociology of imagination. *Theory Soc.* 50, 357–380. doi: 10.1007/s11186-020-09416-y

Gatto, A. (2022). The energy futures we want: a research and policy agenda for energy transitions. *Energy Res. Soc. Sci.* 89:102639. doi: 10.1016/j.erss.2022.102639

Gentner, D. (1983). Structure-mapping: a theoretical framework for analogy. *Cogn. Sci.* 7, 155–170. doi: 10.1016/S0364-0213(83)80009-3

Ghilani, D., Luminet, O., Erb, H. P., Flassbeck, C., Rosoux, V., Tames, I., et al. (2017). Looking forward to the past: an interdisciplinary discussion on the use of historical analogies and their effects. *Mem. Stud.* 10, 274–285. doi: 10.1177/1750698017701609

Grybauskas, A., Stefanini, A., and Ghobakhloo, M. (2022). Social sustainability in the age of digitalization: a systematic literature review on the social implications of industry 4.0. *Technol. Soc.* 70:101997. doi: 10.1016/j.techsoc.2022.101997

Gugganig, M. (2025). Fixing sustainability through technoscience and diversity: the case of EU agriculture policy. *Environ. Sci. Pol.* 171:104121. doi: 10.1016/j.envsci.2025.104121

Hackfort, S. (2023). Unlocking sustainability? The power of corporate lock-ins and how they shape digital agriculture in Germany. *J. Rural. Stud.* 101:103065. doi: 10.1016/j.jrurstud.2023.103065

Hamming, R. W. (1965). Impact of computers. *Am. Math. Mon.* 72, 1–7. doi: 10.1080/00029890.1965.11970691

Hassan, Y. (2020). The politics of sharing: sociotechnical imaginaries of digital platforms. *Inf. Polity* 25, 159–176. doi: 10.3233/IP-190203

Hatanaka, M., Konefal, J., Strube, J., Glenna, L., and Conner, D. (2022). Data-driven sustainability: metrics, digital technologies, and governance in food and agriculture. *Rural. Sociol.* 87, 206–230. doi: 10.1111/ruso.12415

Hekkert, M. P., Janssen, M. J., Wesseling, J. H., and Negro, S. O. (2020). Mission-oriented innovation systems. *Environ. Innov. Soc. Transit.* 34, 76–79. doi: 10.1016/j.eist.2019.11.011

Hughes, S., and Hoffmann, M. (2020). Just urban transitions: toward a research agenda. *WIREs Clim. Change* 11:e640. doi: 10.1002/wcc.640

Husain, S., Sohag, K., and Wu, Y. (2022). The response of green energy and technology investment to climate policy uncertainty: an application of twin transitions strategy. *Technol. Soc.* 71:102132. doi: 10.1016/j.techsoc.2022.102132

Ingold, T. (2017). On human correspondence. *J. R. Anthropol. Inst.* 23, 9–27. doi: 10.1111/1467-9655.12541

Jakku, E., Fielke, S., Fleming, A., and Stitzlein, C. (2022). Reflecting on opportunities and challenges regarding implementation of responsible digital Agri-technology innovation. *Sociol. Ruralis* 62, 363–388. doi: 10.1111/soru.12366

Jasanoff, S. (2015). "Future imperfect: science, technology, and the imaginations of modernity," in *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*, eds. S. Jasanoff and S. H. Kim (Chicago: The University of Chicago Press), 1–33.

Jasanoff, S., and Kim, S. H. (2009). Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea. *Minerva* 47, 119–146. doi: 10.1007/s11024-009-9124-4

Jasanoff, S., and Kim, S. H. (2013). Sociotechnical imaginaries and national energy policies. *Sci. Cult.* 22, 189–196. doi: 10.1080/09505431.2013.786990

John, D. A., and Babu, G. R. (2021). Lessons from the aftermaths of green revolution on food system and health. *Front. Sustain. Food Syst.* 5:644559. doi: 10.3389/fsufs.2021.644559

Kitole, F. A., Mkuna, E., and Sesabo, J. K. (2024). Digitalization and agricultural transformation in developing countries: empirical evidence from Tanzania agriculture sector. *Smart Agricul. Technol.* 7:100379. doi: 10.1016/j.atech.2023.100379

Klerkx, L., and Leeuwis, C. (2009). Establishment and embedding of innovation brokers at different innovation system levels: insights from the Dutch agricultural sector. *Technol. Forecast. Soc. Change* 76, 849–860. doi: 10.1016/j.techfore.2008.10.001

Klok, C. W., Kirkels, A. F., and Alkemade, F. (2023). Impacts, procedural processes, and local context: rethinking the social acceptance of wind energy projects in the Netherlands. *Energy Res. Soc. Sci.* 99:103044. doi: 10.1016/j.erss.2023.103044

Kovacic, Z., García Casañas, C., Argüelles, L., Yáñez Serrano, P., Ribera-Fumaz, R., Prause, L., et al. (2024). The twin green and digital transition: high-level policy or science fiction? *Environ. Plan. E Nat. Space* 7, 2251–2278. doi: 10.1177/251484862412580

Kuchler, M., and Stigson, G. M. (2024). Unravelling the 'collective' in sociotechnical imaginaries: a literature review. *Energy Res. Soc. Sci.* 110:103422. doi: 10.1016/j.erss.2024.103422

Ladyman, J., Lambert, J., and Wiesner, K. (2013). What is a complex system? *Eur. J. Philos. Sci.* 3, 33–67. doi: 10.1007/s13194-012-0056-8

Lajoie-O'Malley, A., Bronson, K., van der Burg, S., and Klerkx, L. (2020). The future (s) of digital agriculture and sustainable food systems: an analysis of high-level policy documents. *Ecosyst. Serv.* 45:101183. doi: 10.1016/j.ecoser.2020.101183

Lennon, K. (2015). *Imagination and the Imaginary*. London: Routledge.

Levenda, A. M., Richter, J., Miller, T., and Fisher, E. (2019). Regional sociotechnical imaginaries and the governance of energy innovations. *Futures* 109, 181–191. doi: 10.1016/j.futures.2018.03.001

Levidow, L., and Raman, S. (2020). Sociotechnical imaginaries of low-carbon waste-energy futures: UK techno-market fixes displacing public accountability. *Soc. Stud. Sci.* 50, 609–641. doi: 10.1177/0306312720905084

Linderoth, C., Hultén, M., and Stenliden, L. (2024). Competing visions of artificial intelligence in education—a heuristic analysis on sociotechnical imaginaries and problematizations in policy guidelines. *Policy Futures Educ.* 22, 1662–1678. doi: 10.1177/14782103241228900

Lioutas, E. D., and Charatsari, C. (2020). Big data in agriculture: does the new oil lead to sustainability? *Geoforum* 109, 1–3. doi: 10.1016/j.geoforum.2019.12.019

Lioutas, E. D., Charatsari, C., and De Rosa, M. (2021). Digitalization of agriculture: a way to solve the food problem or a trolley dilemma? *Technol. Soc.* 67:101744. doi: 10.1016/j.techsoc.2021.101744

Longhurst, N., and Chilvers, J. (2019). Mapping diverse visions of energy transitions: co-producing sociotechnical imaginaries. *Sustain. Sci.* 14, 973–990. doi: 10.1007/s11625-019-00702-y

MacPherson, J., Voglhuber-Slavinsky, A., Olbrisch, M., Schöbel, P., Dönitz, E., Mouratiadou, I., et al. (2022). Future agricultural systems and the role of digitalization for achieving sustainability goals. A review. *Agron. Sustain. Dev.* 42:70. doi: 10.1007/s13593-022-00792-6

Mager, A., and Katzenbach, C. (2021). Future imaginaries in the making and governing of digital technology: multiple, contested, commodified. *New Media Soc.* 23, 223–236. doi: 10.1177/1461444820929321

Mäkitie, T., Hanson, J., Damman, S., and Wardeberg, M. (2023). Digital innovation's contribution to sustainability transitions. *Technol. Soc.* 73:102255. doi: 10.1016/j.techsoc.2023.102255

Malterud, K., Siersma, V. D., and Guassora, A. D. (2016). Sample size in qualitative interview studies: guided by information power. *Qualitative Health Res.* 26, 1753–1760. doi: 10.1177/1049732315617444

Martin, R. (2021). AV futures or futures with AVs? Bridging sociotechnical imaginaries and a multi-level perspective of autonomous vehicle visualisations in praxis. *Humanit. Soc. Sci. Commun.* 8, 1–15. doi: 10.1057/s41599-021-00739-4

Martinez, N. (2022). Theorizing the devices of sociotechnical governance: systemic practices, visions, and dynamics of change in Mexico's energy transition. *Energy Res. Soc. Sci.* 90:102626. doi: 10.1016/j.erss.2022.102626

Martin-Rios, C. (2025). Sustainability transitions in small, entrepreneurial food services through systems innovation. *J. Int. Counc. Small Bus.* 6, 99–113. doi: 10.1080/26437015.2024.2396077

Mazzucato, M. (2018). Mission-oriented innovation policies: challenges and opportunities. *Ind. Corp. Change* 27, 803–815. doi: 10.1093/icc/dty034

Mehmood, K., Kiani, A., Rehman, H., Alshibani, S. M., and Piccardi, P. (2025). Can platform leadership drive twin transitions in greening SMEs? Exploring the nexus between AI infrastructure flexibility, information effects, and green sustainable practices. *Bus. Ethics Environ. Responsib.* 34, 2274–2292. doi: 10.1111/beer.12761

Meijer, A. (2024). Perspectives on the twin transition: instrumental and institutional linkages between the digital and sustainability transitions. *Inf. Polity* 29, 35–51. doi: 10.3233/IP-230015

Meijer, I. S., Hekkert, M. P., and Koppenjan, J. F. (2007). How perceived uncertainties influence transitions; the case of micro-CHP in the Netherlands. *Technol. Forecast. Soc. Change* 74, 519–537. doi: 10.1016/j.techfore.2006.02.007

Michailidis, A., Charatsari, C., Bournaris, T., Loizou, E., Paltaki, A., Lazaridou, D., et al. (2024). A first view on the competencies and training needs of farmers working with and researchers working on precision agriculture technologies. *Agriculture* 14:99. doi: 10.3390/agriculture14010099

Mohr, S., and Höhler, J. (2023). Media coverage of digitalization in agriculture-an analysis of media content. *Technol. Forecast. Soc. Change* 187:122238. doi: 10.1016/j.techfore.2022.122238

Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M., and Scapolo, F.. (2022). Towards a green and digital future. Publications Office of the European Union, Luxembourg, JRC129319. Available online at: https://data.europa.eu/doi/10.2760/977331 (Accessed June 07, 2024).

Nettle, R., Ingram, J., and Ayre, M. (2025). Digiwork: how agriculture 4.0 is changing work for farm advisers. *Front. Sustain. Food Syst.* 9:1542007. doi: 10.3389/fsufs.2025.1542007

Omar, A., and Thorsøe, M. H. (2025). Fairer, healthier, and more sustainable? Three contested sociotechnical imaginaries for transforming the European Agri-food system. *Environ. Plan. E Nat. Space* 9, 25148486251381335. doi: 10.1177/251484862513813

Pfeiffer, J., Gabriel, A., and Gandorfer, M. (2021). Understanding the public attitudinal acceptance of digital farming technologies: a nationwide survey in Germany. *Agric. Hum. Values* 38, 107–128. doi: 10.1007/s10460-020-10145-2

Polzin, C. (2024). The role of visions in sustainability transformations: exploring tensions between the Agrarwende vanguard vision and an established sociotechnical imaginary of agriculture in Germany. *Glob. Environ. Change* 84:102800. doi: 10.1016/j.gloenvcha.2024.102800

Preininger, E. M. (2024). Is this the future? Image and imagination in visual discourses on digital farming in Austrian media. *Geogr. Ann. Ser. B, Hum. Geogr.* 106, 441–459. doi: 10.1080/04353684.2023.2261132

Rahm, L. (2023a). Education, automation and AI: a genealogy of alternative futures. *Learn. Media Technol.* 48, 6–24. doi: 10.1080/17439884.2021.1977948

Rahm, L. (2023b). Educational imaginaries: governance at the intersection of technology and education. *J. Educ. Policy* 38, 46–68. doi: 10.1080/02680939.2021.1970233

Ravetz, J. R. (1997). The science of 'what-if?'. *Futures* 29, 533–539. doi: 10.1016/S0016-3287(97)00026-8

Rehman, S. U., Giordino, D., Zhang, Q., and Alam, G. M. (2023). Twin transitions and industry 4.0: unpacking the relationship between digital and green factors to determine green competitive advantage. *Technol. Soc.* 73:102227. doi: 10.1016/j.techsoc.2023.102227

Roeven, L., Wolf, S. A., Sengers, P., Liu, J., Rubambiza, G., Persaud, D., et al. (2025). Analyzing abstraction in critical Agri-food studies and computer science: toward interdisciplinary analysis of digital agriculture innovation. *Agric. Hum. Values* 42, 1009–1026. doi: 10.1007/s10460-024-10655-3

Rotmans, J., and Kemp, R. (2003). "Managing societal transitions: dilemmas and uncertainties: the Dutch energy case-study," in *OECD Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers*, vol. 12 (Paris, France: OECD), 1–31.

Rotz, S., Duncan, E., Small, M., Botschner, J., Dara, R., Mosby, I., et al. (2019). The politics of digital agricultural technologies: a preliminary review. *Sociol. Ruralis* 59, 203–229. doi: 10.1111/soru.12233

Rudek, T. J. (2022). Capturing the invisible. Sociotechnical imaginaries of energy. The critical overview. *Sci. Publ. Policy* 49, 219–245. doi: 10.1093/scipol/scab076

Ruder, S. L., Wittman, H., Duncan, E., and Satterfield, T. (2025). Sociotechnical imaginaries for Canadian Agri-food futures: a farmer survey. *Agric. Hum. Values* 42, 1439–1456. doi: 10.1007/s10460-024-10675-z

Ruhrort, L., and Allert, V. (2021). Conceptualizing the role of individual agency in mobility transitions: avenues for the integration of sociological and psychological perspectives. *Front. Psychol.* 12:623652. doi: 10.3389/fpsyg.2021.623652

Sadowski, J., and Bendor, R. (2019). Selling smartness: corporate narratives and the smart city as a sociotechnical imaginary. *Sci. Technol. Hum. Values* 44, 540–563. doi: 10.1177/0162243918806061

Sætra, H. S., and Selinger, E. (2024). Technological remedies for social problems: defining and demarcating techno-fixes and techno-solutionism. *Sci. Eng. Ethics* 30:60. doi: 10.1007/s11948-024-00524-x

Sardao, M., and Silva, P. G. (2024). From the universal to the plural: imagining, building up and obliterating alternative futures. *Futures* 161:103412. doi: 10.1016/j.futures.2024.103412

Seligman, M. E., Railton, P., Baumeister, R. F., and Sripada, C. (2013). Navigating into the future or driven by the past. *Perspect. Psychol. Sci.* 8, 119–141. doi: 10.1177/1745691612474317

Shepherd, M., Turner, J. A., Small, B., and Wheeler, D. (2020). Priorities for science to overcome hurdles thwarting the full promise of the 'digital agriculture' revolution. *J. Sci. Food Agric.* 100, 5083–5092. doi: 10.1002/jsfa.9346

Sismondo, S. (2020). Sociotechnical imaginaries: an accidental themed issue. *Soc. Stud. Sci.* 50, 505–507. doi: 10.1177/0306312720944753

Smith, J. M., and Tidwell, A. S. (2016). The everyday lives of energy transitions: contested sociotechnical imaginaries in the American west. *Soc. Stud. Sci.* 46, 327–350. doi: 10.1177/0306312716644534

Spellman, B. A., and Holyoak, K. J. (1996). Pragmatics in analogical mapping. *Cogn. Psychol.* 31, 307–346. doi: 10.1006/cogp.1996.0019

Stilgoe, J., Owen, R., and Macnaghten, P. (2013). Developing a framework for responsible innovation. *Res. Policy* 42, 1568–1580. doi: 10.1016/j.respol.2013.05.008

Stroparo, T. R. (2025). Socio-technical imaginaries and techno-social territories: connecting sustainability and open innovation in agroecology. *Rev. Gest. Soc. Ambient.* 19, 1–17. doi: 10.24857/rgsa.v19n3-038

Suresh, D., Shaw, R., and Masutomi, Y. (2025). Farmers' perspective on digitalization of climate-smart agricultural practices: a comparative study in Tamil Nadu, India. *Discover Agriculture* 3, 1–21. doi: 10.1007/s44279-025-00176-w

Szalkowski, G. A., and Johansen, C. (2024). Defining and measuring the effects of digital technologies on social sustainability: a systematic literature review. *Sustain. Dev.* 32, 1678–1699. doi: 10.1002/sd.2741

Szalkowski, G. A., Mikalef, P., and Windekilde, I. M. (2024). Systematic literature review on solutions to the negative environmental impacts of ICT. *Telemat. Informat. Report.* 14:100134. doi: 10.1016/j.teler.2024.100134

Tabares, S., Parida, V., and Chirumalla, K. (2025). Twin transition in industrial organizations: conceptualization, implementation framework, and research agenda. *Technol. Forecast. Soc. Change* 213:123995. doi: 10.1016/j.techfore.2025.123995

Torrent-Sellens, J., Enache-Zegheru, M., and Ficapal-Cusí, P. (2025). Twin transitions or a meeting of strangers? Unravelling the effects of AI and innovations on social, economic and environmental MSMEs sustainability. *Technol. Soc.* 81:102866. doi: 10.1016/j.techsoc.2025.102866

Turner, P. (2020). "Imagination and design," in *Imagination + Technology. Human–Computer Interaction Series*, (Cham: Springer).

Uyarra, E., Bugge, M. M., Coenen, L., Flanagan, K., and Wanzenböck, I. (2025). Geographies of mission-oriented innovation policy. *Environ. Innov. Soc. Transit.* 56:100970. doi: 10.1016/j.eist.2025.100970

Von Schomberg, R. (2013). "A vision of responsible research and innovation," in *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*, eds. R. Owen, J. Bessant and M. Heintz (New York: Wiley), 51–74.

Webster, J. (2025). Sociotechnical imaginaries in a postdigital world: teachers'perceptions of digital citizenship education. *Postdigit. Sci. Educ.* 7, 770–787. doi: 10.1007/s42438-025-00557-w

Wiarda, M., Sobota, V. C., Janssen, M. J., van de Kaa, G., Yaghmaei, E., and Doorn, N. (2023). Public participation in mission-oriented innovation projects. *Technol. Forecast. Soc. Change* 191:122538. doi: 10.1016/j.techfore.2023.122538

Winter, K., Pummerer, L., von Oertzen, T., Hornsey, M. J., and Sassenberg, K. (2025). Conspiracy belief and opposition to wind farms: a longitudinal study. *J. Environ. Psychol.* 104:102620. doi: 10.1016/j.jenvp.2025.102620

Zeddies, H. H., Busch, G., and Qaim, M. (2024). Positive public attitudes towards agricultural robots. *Sci. Rep.* 14:15607. doi: 10.1038/s41598-024-66198-4