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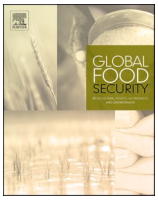

What does the agri-food systems transformation agenda mean for agricultural research organisations? Exploring organisational prototypes for uncertain futures

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ABSTRACT

Agricultural Research Organisations (AROs) are being urgently called to provide solutions for agri-food system transformation. However, contrasting visions of how transformation should be achieved create difficult choices for AROs. This paper reviews existing transformation narratives to build four scenarios of future AROs: 1. Industry transition-oriented; 2. Technology mission-oriented; 3. The Community innovation-oriented; and 4. Facilitating transformative innovation-oriented. Their analysis uncovers possible risks and trade-offs, and suggests the need for new hybrid organisational forms that incorporate elements from across the scenarios. Besides, the paper highlights that given the broad industry, policy, and societal interests of AROs, decisions about transformation pathways cannot be made unilaterally and without broader discussion around the future shape and aims of innovation systems in which these organisations are embedded.

1. Introduction

As the need to transform food systems becomes increasingly central in global sustainability debates, a critical and still largely unanswered question revolves around the present and future roles of Agriculture Research Organisations (AROs) (Klerkx et al., 2022; Körner et al., 2022). These organisations are at a critical point of inflexion as they are called upon to respond to new and pressing demands for solutions to highly systemic and complex challenges that span environmental, economic and social domains (IPES, 2021; Rockstrom et al., 2023).

While it is widely agreed that research and innovation will play a central role in helping design and manage food system transformative processes across the globe (Fazey et al., 2018; Kok et al., 2021), the novel agenda calls for a rethink of how AROs function and their role and responsibilities for supporting – or even enabling – a shift towards more sustainable trajectories of development (Béné et al., 2019). This task of rethinking AROs is made all the more difficult because, in the broader debates about food system transformation, there are different views on how this should be achieved, particularly in terms of the role of technology. Klerkx et al. (2022) highlight two opposing points of view. On the one hand, the "techno-optimists" argue that transformation can be achieved through the right technologies (Carolan, 2020). On the other hand, the "techno-pessimists" argue that technological innovations (e.g. agriculture 4.0, digital value chains etc.) alone will be insufficient to respond to the transformation agenda (Klerkx and Rose, 2020). There is a risk that direction of technological innovation is framed by existing path-dependencies of agri-food systems that perpetuate unsuitability (Conti et al., 2021b). These two opposing views are not mutually exclusive, as many hybrid views exist (Giller et al., 2021; Tittonell et al., 2022). However, they highlight a growing concern for reframing innovation action in a way that not simply incrementally, but systemically restructures the architecture of agri-food systems towards sustainability (Hall and Dijkman, 2019).

These contrasting views play out in the societal and political arena in which AROs operate. On the one side, policymakers are turning to research for silver bullet solutions and technological fixes to meet sustainability targets (e.g. zero net emissions by 2050, the SDGs by 2030) (Costa et al., 2022; Hambloch et al., 2022). On the other, civil society is becoming increasingly involved in the quest for sustainability, urging research organisations to become more open and inclusive of alternative

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and bottom-up forms of innovation that have both technical, social and institutional change dimensions and which target structural and historical inequities of food systems (Berthet et al., 2018; Pereira et al., 2020). For instance, tensions emerged during the United Nations (UN) Food System Summit between powerful alliances (corporations, philanthropies and export-oriented countries) trying to capture the narrative around "food system transformation" as a largely technological task, in contrast to civil society voices advocating for a system reformatting towards food sovereignty and human rights (Canfield et al., 2021).

These tensions generate questions around the possibly novel role of research organisations. Some authors suggest a shift in their traditional role of technology provider to one that is much more proactive in designing and even managing transformative processes (Fazey et al., 2018; Kok et al., 2021). Thus, as research communities start to engage with the transformation agenda and respond to its novel demands a diverse set of "research for sustainability and transformation" practices have started to emerge, guided by principles of experimentation, transdisciplinarity and plurality (Caniglia et al., 2021). Examples of these practices include sustainability science, human-centred design and mission-oriented innovation (Bason, 2017; Carolan, 2020; Horcea-Milcu et al., 2020; Kok and Klerkx, 2023). These practices would need to play out in a diversity of ARO organisational settings, each with different drivers, mandates, and constituencies and where the transformation agenda is eliciting different sorts of responses. These range from international research organisations with an international public good mandate serving small holder farmers to national research organisations that exercise their public good mandate by servicing the needs of nationally important agricultural industries and business interest (see box 1). Given the diversity of views on how different forms of innovations should be bundled and harnessed for food system transformation (Barrett et al., 2020), AROs face a difficult set of choices on the ways forward.

This paper aims to contribute to the debate on the relative merits of different choices and approaches by structuring a discussion of the benefits and trade-offs of four hypothetical ARO organisational prototypes or scenarios: an industry transition-oriented scenario; a technology mission oriented-scenario; a community innovation-oriented scenario; and a facilitating transformative innovation scenario. The purpose of the scenarios is not to predict or prescribe what AROs will look like in the coming years: rather, these are used to highlight implications and adaptation considerations that need to be made and the benefits, trade-offs and risks that AROs will need to navigate. Such considerations concurrently prompt a deeper reflection on how different organisational visions (and their underpinning assumptions) might need systemic innovation within research institutes themselves (Hall et al., 2001; Hall and Dijkman, 2019).

In conclusion, we highlight two issues. Firstly, choices about adapting the role and focus of AROs need to be carefully considered by these organisations as these decisions cannot be made unilaterally and will require ongoing consultation and reflexivity as part of a process of continuous organisational refinement. Second, the issue of reimagining AROs cannot be done in isolation from a complimentary process of reimagining the wider agricultural innovation system in which these organisations are situated. As with the first point, broad consultation and reflexivity will be required to reform and redirect the innovation system towards sustainability. Moving forward, we believe that the organisational prototypes represented by our scenarios could be a valuable boundary object to stimulate this consultation and to explore the perspectives of a range of interested and affected actors within the research and innovation system.

2. Constructing ARO scenarios for agri-food system transformation

The AROs scenarios were constructed through a two-stage process. The first stage involved a literature review to identify four narratives illustrating key perspectives on the role and organisation of resarch and innovation in relation to agri-food system transformation (see further explanation below). The analysis of these narratives was then used by the authors to identify core themes about which there were contrasting propositions – referred to as core dialectics - that needed to be represented in the development of scenarios. Following the review and identification of contrasting dialectics, the highly interdisciplinary group of authors collectively and iteratively worked towards the conceptual elaboration of the scenarios. All authors provided insights and raised different discussion points based on their expertise and visions. Thus, both the development of the narratives and of the scenarios is based on the authors' (a group of researchers working in AROs for decades) own experiences in AROs.

2.1. Narrative concept and literature review methods

Since the foundational work of Boje (1995, 1991), the idea of innovation narratives has represented a critical way of understanding how research and innovation practices can become institutionalised and be reproduced between individuals and through time (Feix and Philippe, 2018; Maclean et al., 2020).[1] The idea of "narratives" is specifically used in this paper to indicate the constructed nature that each view on the role of research and innovation has in terms of certain issues, how they are problematised, the associated socio-technical solutions and the implied role of key actors in the process (Anderson and Rivera-Ferre, 2021; Thompson et al., 2007). To explore narratives, we conducted a targeted literature review (Grant and Booth, 2009) to capture dominant theories and conceptual positions on the role of research and innovation in transformation. The search was conducted on Google Scholar, ScienceDirect, and Scopus and was not restricted to any particular geography. However, the search was not exhaustive or systematic, as its purpose was not to represent *all* literature on the role of research and innovation for transformation. Instead, publications were selected based on their potential to illustrate critical points of debate emerging from a broad literature landscape. The authors then collectively elaborated four research and innovation narratives. These are not fully comprehensive or entirely discrete categories. Rather, they have purposefully been made distinct by the authors for analytical and illustrative purposes, and do not aim to represent specific AROs or specific geographies. They are thus used in a broad sense to highlight fundamentally different visions for research and innovation in relation to food system transformation (see a summary in Table 1).

3. The research and innovation narratives

In presenting the narratives below, emphasis is given to their core propositions about the role of research and innovation (and technology) in transformation, the major research debates and research approaches used, how change for sustainability is understood to take place (impact logic), who are the principal actors, and what success looks like. Key references for each narrative are organised in Table 1.

3.1. The "silver-bullet technologies for transformation" narrative

The most long-standing narrative is "technology for transformation".

[1] Narratives can be considered as series of "texts", authored by organisational participants, where the "tellings of strategy fundamentally influence strategic choice and action" (Barry and Elmes, 1997). These texts enable and constrain the ongoing activities of actors because they encode lessons for success as well as their ongoing justification for future-oriented action (Fenton and Langley, 2011). Narratives are rarely codified, but have normative dimensions that persist and evolve in organisational cultures and practices through written and oral artefacts that reinforce the dominant narrative by legitimising certain forms of practice and behaviour (Moezzi et al., 2017).

Box 1
AROs at a glance.

The AROs discussed in this paper refer specifically to national and international public agencies established to conduct biophysical, social and economic analysis to resolving agriculture and food-related challenges.

At the national level ARO, take a number of forms, and articulate their public good role in different way, for instance:

In India, this takes the form of Indian Council for Agricultural Research comprising of 65 research Institutes and 14 National research centres. This is largest ARO in the world, is entirely public funded with a mission of "technology development and policy guidance for vibrant and resilient agriculture, which should be productive, eco-friendly, sustainable, economically profitable and socially equitable" (https://www.iari.res.in/en/mission.php).

The Brazilian ARO Embrapa (https://www.embrapa.br/en/sobre-a-embrapa) is styled as a is a state-owned research corporation affiliated with the Ministry of Agriculture to develop research, development and innovation solutions for the sustainability of agriculture, for the benefit of Brazilian society. Embrapa is largely state funded with additional funding from private foundations.

Different again is the ARO of Australia that sits as a business unit (division) within the Australian national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Framed by a mandate of "assisting Australian industry and furthering the interests of the Australian community", agriculture research is largely funded by a co-investment arrangement that matches public funds with funding from 15 commodity (industry) levy-funded research and development corporations (https://www.csiro.au/en/work-with-us/industries/agriculture).

In the Netherlands, the main ARO is centred around Wageningen University and its affiliated with a privately registered-company, Wageningen University and Research, that supports industry research needs within a strong social and environmental framing.

Many of these organisation express food systems transformation ambitions and established food systems transformation centres (for example, in CSIRO https://www.csiro.au/en/work-with-us/industries/agriculture/food-system-horizons). However, as a cross commodity and cross disciplinary research area, food system transformation challenges the way these organisations have historically organised their capability. In the case of AROs with co-investment arrangements with industry, this agenda sets up new tensions between public good impact aspiration associated with transitions and the revenue models of these organisations that are closely linked to delivering industry scale solutions and commercialising research results.

The international AROs are largely comprised of the OneCGIAR (https://www.cgiar.org/), an integrated network of 15 commodity and eco-regionally focused research organisation mandated to deliver international public goods to underpin food and nutritional security, poverty reduction, gender equity and environmental sustainability goals. These organisations have historically been funded by bi-lateral and multi-lateral development assistance funding, but are now increasingly funded by philanthropic funding, notably by the Gates Foundation. Like their national counterparts, the strategic plans of the OneCGIAR have expressed food system transformation ambitions and establish Food Systems Transformation programmes (for example, in the International Centre for Crops Research Institute for the Semi-Arid Tropics, ICRISAT, https://www.icrisat.org/). These ambitions have surfaced the challenge of how to reconfigure expertise around this new agenda and revealed capability gaps needed to enact it. As long-term systemic change agenda it has also created tension with existing project funding cycles where funder expect impact to be achieved in three years. The on-going reform of the OneCGIAR has also raised questions about organisational identify, the appropriate balance between international public good research and scaling development solutions and need to accommodate multiple organisational identifies with different goals and modus operandi (Banerjee et al., 2019).

The core proposition of this narrative is that novel technologies can deliver economic growth *and* sustainability. AROs' role is critical in delivering these technological breakthroughs and propel (technological) change for sustainability. This narrative has historically conceptualised food system transformation as a process of using research and innovation to substantially increase agricultural productivity, in what has been defined as the productivist/modernisation of agriculture-type approach (Cabral and Sumberg, 2022) – or, according to Schot and Steinmueller (2018) the "innovation for growth" framing of research and innovation. This has played out in the development of food systems around the world driven by both public R&D and agri-business R&D.

The origin of the narrative can be traced back to post-World War II concerns over the need for production increases, particularly in Low and Middle-Income Countries (LMICs), to feed a growing world population (Thompson and Scoones, 2009). A core approach has been to identify isolatable technical problems, such as pests and diseases or low yields, and develop technological fixes to resolve them. The approach is typified by the success of the high-yield cereal varieties that revolutionised food production in South Asia in the last quarter of the 20th century (FAO, 2009). The so-called Green Revolution (GR) was and continues to be closely associated with many of the CGIAR centres (see box 1) which developed these varieties (Greenland, 1997; Pingali, 2001). Poverty and hunger were reduced, but there were significant environmental externalities, and often, new technologies exacerbated inequities. As the GR example suggests, this narrative sees technological and scientific discovery (and its delivery to farmers) as a motor for economic growth (Schot and Steinmueller, 2018).

This long-standing narrative has recently responded to the transformation agenda by once again presenting technological breakthroughs as not simple accelerators for economic prosperity, but as a way to succeed in delivering sustainability (Davis et al., 2019). This has justified renewed R&D investments from the public and private sectors in R&D to provide technologies with better environmental performance (e.g. digitally enabled precision agriculture (Oliver et al., 2013)), and improve food availability and nutrition worldwide, (e.g. foods with functional properties (Conti et al., 2021a; Regis, 2020). The narrative legitimises the idea that stand-alone technology can solve societal problems, and is aligned with current business models of AROs and the private sector.

3.2. *The "directing innovation for tackling grand challenges" narrative*

Unlike the previous narrative that saw technologies' contribution to transformation through a general economic growth lens, this narrative explicitly articulates the need to purposefully direct innovation toward sustainability, greener economic growth, and social inclusion. Often, this proposition is accompanied by a mandate to disrupt the direction and structure of existing innovation systems (Klerkx and Begemann,

Table 1
Narratives emerging from the literature, theory of innovation for transformation, school of thought, core research and innovation practices and key references.

Narrative	Theory of innovation for transformation	School of thought	Core Research and innovation practices	References
Technology for transformation	Technological innovations can be the way to achieve both economic growth and address sustainability concerns.	Innovation for growth	High investments on promising scientific discoveries that can have economic returns and, especially in recent years, address sustainability concerns.	(Bongiovanni and Lowenberg-Deboer, 2004; Cabral and Sumberg, 2022; Davis et al., 2019; Di Vaio et al., 2020; FAO, 2009; Fleming et al., 2021; Fredenburg, 2011; Goh and Vinuesa, 2021; Greenland, 1997; Lajoie-O'Malley et al., 2020; Maclean et al., 2020; Maru et al., 2018; Oliver et al., 2013; Palazzi et al., 2019; Patrício and Rieder, 2018; Pingali, 2001; Potrykus, 2010b; Scrinis and Lyons, 2007; Shepherd et al., 2020; Smith and Smith, 2018; Sreewongcha and Nakasathien, 2015; Voytovych et al., 2020; World Economic Forum, 2018; Zhang et al., 2021)
Technologies directed to the public good	Technological innovations are essential for meeting sustainability target, but they need to be carefully directed to avoid adverse outcomes	RRI	Targeted efforts to ensure stakeholder involvement and openly discuss ethical issues and social desirability of technologies	(Bellon-Maurel et al., 2022; Bronson, 2019, 2018; Craigon et al., 2023; Eastwood et al., 2019, 2021; European Commission, 2011; Gremmen et al., 2019; Kuzma, 2022; Owen et al., 2013, 2021; Rose and Chilvers, 2018; Schomberg, 2011; Simelton and McCampbell, 2021; Tabarés et al., 2022; von Schomberg, 2012; Von Schomberg, 2019, 2011; Wakunuma et al., 2021)
		Missions	Time bound efforts that can drive markets and innovation systems to tackle grand challenges	(Björk et al., 2022; Boorman et al., 2023; Brown, 2020; Bugge et al., 2021; Cappellano and Kurowska-Pysz, 2020; Eastwood et al., 2023; Hekkert et al., 2020; Kattel and Mazzucato, 2018; Klerkx and Begemann, 2020; Mazzucato, 2016, 2018a, 2018b; Mendonça et al., 2018; Mowery, 2009; Nylén et al., 2023; Wanzenböck et al., 2020)
Diversity for transformation from the margins	It is necessary to shift to much more plural, bottom up, participatory forms of research for addressing equity and inclusion concerns.	Agroecology and regenerative agriculture	Substitutive system to the industrial agriculture one, rooted on human rights, social justice, food sovereignty and diversity	(Anderson et al., 2019; Anderson and Maughan, 2021; Borras, 2023; Breier et al., 2023; Cook et al., 2013; De Schutter, 2010; Domptail et al., 2023; Francis et al., 2003; Gahman et al., 2022; Gliessman, 2013, 2023; Gosnell et al., 2019; Guerrero Lara et al., 2023; IPES, 2021; Lacoste et al., 2021; Martínez-Torres and Rosset, 2010; Pimbert, 2022, 2017; Pimbert et al., 2001; Putnam et al., 2014; Quintas-Soriano et al., 2022; Ryschawy et al., 2019; Tornaghi and Dehaene, 2020)
		Sustainability science	Importance of knowledge co-production, need to include plural, tacit and until-now marginalised knowledge(s) into an anti-elitist, inclusive and transdisciplinary quest for sustainability	(Clark, 2007; Clark and Harley, 2020; Jerneck et al., 2011; Kajikawa, 2008; Kates, 2011; Messerli et al., 2019; Schneider et al., 2019; Smith et al., 2018; Whyte et al., 2016)
		Citizen science	Public participation in scientific research, in particular, with members of the public partnering with professional scientists	(Beza et al., 2017, 2018; Bonney et al., 2016; Dehnen-Schmutz et al., 2016; Ebitu et al., 2021; Irwin, 1995; Mourad et al., 2020; Pollard et al., 2017; Ryan et al., 2018; Steinke et al., 2017; van de Gevel et al., 2020)
		Plural knowledge systems	Need to address historical issues such as colonisation, and de-westernize/decolonise science to include indigenous and traditional knowledge	(Chakraborty et al., 2021; Delgado et al., 2022; Díaz et al., 2018; Hill et al., 2020; Hoppers, 2002; Jacobs et al., 2020; Leventon et al., 2021; Pimbert, 2017; Rarai et al., 2022; Reid et al., 2021; Steinke et al., 2017; Suarez et al., 2022; Zafra-Calvo et al., 2020; Zanotti et al., 2020)
Transforming innovation	Transformation requires system level innovation to deliver broad outcomes of social, environmental and economic viability	Transformative innovation	Search for transformative opportunities, under uncertain and unpredictable conditions (no established end)	(Beck et al., 2021; Diercks et al., 2019; Fagerberg, 2018; Ghosh et al., 2021; Grillitsch et al., 2019; Haddad et al., 2022; OECD, 2015; Ojha and Hall, 2021; Parks, 2022; Schot and Steinmueller, 2018, 2019; Scoones et al., 2020; Scrase et al., 2009; Stirling, 2014; Stirling et al., 2008; Weber and Rohracher, 2012)
		Pathways and transformative spaces	New more plural and democratic approaches to development and/or sustainability. Sustainability highly context specific and political.	(Baret, 2017; Bui et al., 2016, 2019; Bui, 2021; Darnhofer, 2014; De Herde et al., 2019, 2020; Della Rossa et al., 2020; El Bilali, 2019a, 2019b; Fares et al., 2012; Farstad et al., 2020; Feyereisen et al., 2017; Geels, 2011; Hinrichs, 2014; Magrini et al., 2018;

(*continued on next page*)

Table 1 (*continued*)

Narrative	Theory of innovation for transformation	School of thought	Core Research and innovation practices	References
				Meynard et al., 2016; Pereira and Drimie, 2016; Pereira et al., 2018a; Truffer et al., 2022)
		Sustainability transitions	Science and innovation to support socio-technical reconfigurations toward more sustainable systems.	(Baret, 2017; Bui, 2021; Bui et al., 2016, 2019; Darnhofer, 2014; De Herde et al., 2019, 2020; Della Rossa et al., 2020; El Bilali, 2019a, 2019b; Fares et al., 2012; Farstad et al., 2020; Feyereisen et al., 2017; Gamache et al., 2020; Geels, 2011; Hinrichs, 2014; Magrini et al., 2018; Meynard et al., 2016; Pereira and Drimie, 2016; Truffer et al., 2022)

2020). This narrative is underpinned by the understanding that innovation has both a pace and a direction (the purposes to which it is deployed) (Stirling, 2014). While AROs have a critical role in stimulating innovation through R&D that can meet these objectives, public policy is also a key player in de-risking uncertain innovation ventures and safeguarding the preservation of the established directionality (Schot and Steinmueller, 2016).

Over the years, two major approaches have emerged in the literature as a way forward for this. Responsible Research and Innovation (RRI) recognises that technological innovations are key to addressing societal challenges but can have adverse societal consequences (Gremmen et al., 2019). To balance the economic, sociocultural and environmental aspects of innovation processes, RRI encourages stakeholder involvement from an early stage (Bronson, 2018; European Commission, 2011). The logic is that multiple actors can be accountable and mutually responsive and account for the acceptability, sustainability and societal desirability of the innovation process and its marketable products (Rose and Chilvers, 2018). However, others argue that RRI approaches may reinforce perceptions that novel technology will be the main driver for transformation, excluding other forms of innovation that may also be required (Eastwood et al., 2019).

The second approach is Mission-Oriented innovation policy. Mission approaches are premised on the idea that time-bound public investments to tackle tightly specified societal challenges can act as a way of marshalling and redirecting research and innovation across the innovation system, establishing new innovation capacities and trajectories (Mazzucato, 2018a). It is argued that, once established, these innovation trajectories de-risk private investment in products, services and business value propositions aligned with sustainable development objectives. (Klerkx and Begemann, 2020). Explicit in this prospect is the desire to catalyse disruption in the innovation system, creating new capacities for directed innovation (Boorman et al., 2023). Mission approaches are at a relatively early stage of development (Wanzenböck et al., 2019). However, there are already concerns emerging that the path dependency of incumbent systems (for policy and sector silos, entrenched research practices etc.) may yet frustrate a potentially powerful approach (Björk et al., 2022).

3.3. The "system replacement from the margins" narrative

This narrative originates in concerns that the current global food system is driven by, and result of a capitalist logic which consolidates injustices and unsustainability (Gahman et al., 2022). This narrative suggests that the only way towards justice and sustainability is to develop entirely new systems. To do this, it is suggested that previously marginalised players (e.g. civil society, people) reconfigure food systems from the bottom-up (Gliessman, 2023). These players breach industrial food systems and replace them with transformed and place-specific ones that are embedded in re- (locally envisioned) principles of equity, justice, and democracy (Pimbert, 2017, 2022). This narrative has manifested itself through the emergence of a number of "alternative" food system visions founded on ecological and social justice principles (Breier et al., 2023). For example, regenerative agriculture and agroecology perspectives advocate for a shift to fundamentally re-designed food systems governed by principles of human rights and food sovereignty (De Schutter, 2010).

However, the way that AROs should engage with the system replacement narrative is less clear (Sumberg and Giller, 2022). Transdisciplinary sustainability science and co-production research and innovation approaches are emerging as a suite of practices that enable the inclusion of a diversity of knowledges, values and beliefs into research and innovation practice (Wibeck et al., 2022). Prominent in such approaches is the recognition that this is not simply "assimilating" local and indigenous knowledge systems into western science but rather be considered as equally valuable for opening sustainable development pathways (Reid et al., 2021). On-farm experimentation is another example of developing ways to support farmers in engaging with "alternative" farming systems practices to frame and undertake experiments driven by their own values and physical and temporal scales (Lacoste et al., 2021). Differently, citizen science challenges "traditional" science structure and research by stressing the need for public participation for a more democratic research process (Bonney et al., 2016). With all the research and innovation approaches associated with this narrative, there is a recognition that significant capability and capacity development efforts are going to be needed to equip ARO to effectively engage in these more bottom-up and democratic innovation processes (Hall and Nahdy, 1999; Lacoste et al., 2021).

3.4. The "system innovation for transformation" narrative

This narrative recognises that all elements of current food systems - existing behaviours, skillsets, consumer practices and markets, as well as infrastructure, institutions and policies-are not only unfit to meet sustainability objectives. They also act as mutually-reinforcing factors of unsustainability (Conti et al., 2021b). The narrative thus frames transformation as a process of system-level innovation that fundamentally redesigns the system, orienting it towards delivering outcomes valued by society (Weber and Rohracher, 2012). It recognises such system-level innovation will be not only costly and politically onerous, undermining incumbents' interests (Kennedy et al., 2021), but also highly uncertain, with the quest for sustainable pathways possibly leading to unknown ends (Stirling, 2014). Besides, transformation will likely be both bottom-up and top-down. For instance, flourishing research debates on sustainability transitions have stressed the role of niches to challenge the existing system (Bui, 2021), while others have emphasized how transformation will be a negotiated process between all food system actors and largely driven by policy and regulation (Hebinck et al., 2021).

One research and innovation approach suggested to engage with this understanding of transformation is the "pathway" approach, which understands that achieving sustainability will entail broad consultations that acknowledge the existence of "diverse sustainability goals and tackle the associated trade-offs" (Leach et al., 2007, 2010). Similarly,

debates around transformative innovation policy and approaches (Haddad et al., 2022), such as working in transformative spaces (Pereira et al., 2018b), propose collaborative environments that promote dialogue and reflexive learning among multiple stakeholders for elaborating solutions and strategies for achieving sustainability (Pereira et al., 2020). The emphasis in both is experimentation and learning in both policy and practice and fostering the learning connections between these two domains. The role of AROs in this process has yet to be definitively defined. One role could in supporting niche-level experimentation (Gamache et al., 2020). This could imply convening and facilitating collective visioning, learning and innovation processes among stakeholders. It could also involve brokering between contending interests and opposing values and creating broader coalitions needed to prompt a transformation at scale towards collectively agreed visions of sustainability (Klerkx et al., 2017). Different again, it could be about undertaking analysis to alter policy to unintended consequences of transformation or alternatively analysis that supports learning about how transformation can be accelerated to achieve societal goals (Turner et al., 2017a). The narrative stresses the importance of highly experimental, transdisciplinary, and reflexive approaches that can embrace the complexity and uncertainty of agri-food system transformation (Beck et al., 2021).

4. Key dialectics that inform the development of ARO scenarios

The narratives demonstrate the existence of sometimes very different, sometimes overlapping perspectives regarding the role and organisation of research and innovation in agri-food system transformation. This in turn implies contrasting roles and practice for ARO. To structure the development of scenarios, four dialectic propositions from the narratives are identified.

Dialectic 1. Technology optimism, technology pessimism and technology ambivalence. The first axis revolves around the role of technology in transformation. In some narratives, the development of new technologies plays a central role in achieving a sustainability shift, whereas in others, this role is more marginal. The "silver-bullet technologies for transformation" and the "directing innovation for tackling grand challenges" rely heavily on the potential of technological innovation for responding to present challenges, and believe AROs have a critical role in this in terms of producing and, particularly in the "directing innovation for tackling grand challenges" narrative, help to harness these technologies. Whereas these two narratives are technology "optimists" (Klerkx et al., 2022) the other two do not put particular emphasis on this, instead advocating for a much broader system reframing to ensure all elements (not only technologies, but also behaviours, institutions, political and power patterns) are redesigned to deliver sustainability, and technology will only be one part of this.

Dialectic 2. Servicing narrow or broad societal needs. The "silver-bullet technologies for transformation" and, ironically, the "system replacement from the margins" are premised on serving a narrow set of societal interest. In the first, transformation is seen as a process where AROs mainly deliver technological breakthroughs that, while contributing to sustainability, largely profit powerful food system players (e.g., industries) deploying (and generating economic returns) from them. This leaves power relations undisturbed, with many actors (such as civil society) left out of the "sustainability" debates. The other narrative takes a seemingly diametrically opposite position, advocating for the primacy of marginalised actors in the sustainability debates. However, while underpinned by good intentions, this narrative, in truth, equally excludes incumbent actors from the debates in favour of the interests of communities wanting to replace the current systems. Instead, the "directing innovation for tackling grand challenges" and the "system innovation for transformation" understand that transformation will be a collective effort that by necessity will involve large coalitions working together towards the realisation of a common sustainability vision.

Dialectic 3. Bottom-up versus top-down pathways. Both the silver-bullet technologies for transformation and directing innovation for tackling grand challenges narratives see transformation as a mainly top-down process. For the first narrative, this is driven by incumbents investing in research and innovation activities for producing new technologies; for the second, this is driven by a public sector which de-risks "risky" innovation venues and ensures the directionality of the process. On the contrary, for the system replacement from the margins narrative, transformation is largely bottom-up, with communities and marginal actors actively disrupting power structures, and AROs focusing on nurturing niches willing to experiment with novel and largely local alternative pathways that can challenge the status quo. The system innovation for transformation narrative takes a middle-way on this, recognising both the importance of bottom-up disruption and the need for top-down support for transforming food systems.

Dialectic 4. Transformation within systems or transformation through systems reconfiguration. The degree of system reconfiguration is implicit and explicit in each narrative. The silver-bullet technologies for transformation narrative has ambitions to change the performance of specific parts of the system (productivity, farming system sustainability) without fundamentally altering the system's overall configuration. Differently, the directing innovation for tackling grand challenges understands the need to alter the system direction through some form of coordinated changes across different elements. System reconfiguration is even more explicit in the system replacement from the margins and system innovation for transformation narratives.

We now use these dialectics to build scenarios for AROs of the future.

5. Scenarios

The narratives help to highlight fundamentally different worldviews on the visions of future AROs, underpinned by fundamentally different priorities, types of action, actor involvement and visions of success for AROs. Based on the analysis above, we now describe four distinct scenarios, each presenting its own stance on the four dialectics above (Table 2). As with any scenario exercise, these scenarios, while informed by an analysis of the narratives, are "imagined" and polarised to allow the interrogation of issues and not intended to represent existing AROs. This has been done to facilitate discussion of key issues that ARO will need to face in their responses to the transformation agenda.

5.1. Scenario one: industry transition-oriented

In this scenario, transformation is understood as a process by which existing industries transition to more sustainable pathways through the adoption of new technology. AROs are thus embedded in an R&D-centric agricultural innovation system that is geared towards market mechanisms allocating R&D resources and setting innovation directions in a neo-liberal political framing.

The central role of AROs in this scenario is as an R&D agency that develops and supplies technology. AROs have a strong partnership with industries, which co-invest in R&D and provide demand signals for research and innovation. Public policy is focused on allowing the market to allocate R&D funding and drive innovation aligned to sustainability objectives. The main role of public policy is to address market failures in funding allocation. Impact planning and technology choice mechanisms are articulated in strategic plans developed by AROs. However, impact ambitions of AROs are ultimately influenced by funding relationships with industries. In some cases, this might be powerful philanthropic funding bodies associated with major global industry players. While AROs track their impact performance, metrics around technology commercialisation and revenue achieved are prominent. Core features of the organisational culture include entrepreneurship, customer focus and IP capture, although there may be tensions in these organisations with more traditional public science values and culture. Capability mixes for this type of AROs include applied science and technology, engineering and economics. Economists and social scientists have a less

Table 2
Key points of difference across the scenarios, based on the dialectics identified in the previous section.

		Scenarios			
		Scenario One: Silver-bullet technologies for transformation	Scenario 2: Directing innovation for tackling grand challenges	Scenario 3: System replacement from the margins	Scenario 4: System innovation for transformation
Dialectics emerging from the narratives	Role of technologies	Optimist	Optimist	Pessimist	Pessimist
	Scope of interests	Narrow	Broad	Narrow	Broad
	Approaches	Top-down	Top-down	Bottom-up	Top-down & Bottom-up
	Level of reconfiguration	Low	Medium	High	High

prominent role and focus on ex ante and ex-post impact appraisal of technology options. These are attractive to entrepreneurially spirited scientists who believe in industry-led pathways to societies problems.

5.2. Scenario two: technology mission-oriented

This scenario shares the belief of the above in terms of the importance of technologies for delivering sustainability but recognises that this will be part of a process of disrupting existing industries and creating new industries. Public policy has a strong public good framing and is proactive in ensuring that innovation is directed towards sustainability by giving high priority to novel technological solutions for societal challenges such as emissions reduction, waste reduction, food security and so forth. AROs are embedded in an R&D-centric innovation system that integrates agricultural innovation with innovation in allied sectors. The system is geared towards the deployment and use of novel sustainability technologies through regulation and incentives, including investment in technological capability in incumbent and new industries.

The central role of AROs in this scenario is as an R&D agency that develops technology. AROs are mainly publicly funded with priorities purposefully aligned with national and international sustainability goals. Public funding is justified not just on market failure arguments, but also on innovation systems failure arguments and the value of shaping innovation trajectories towards new social goals. AROs establish networks and collaborations with the national and international scientific communities to access frontier knowledge to drive novel technology development. The focus is on the intersection of agriculture and food challenges, with scientists drawing on science and technology in other sectors and disciplinary fields (energy, transport, artificial intelligence and so forth). Technology missions are a key approach for focusing and accelerating research and innovation in defined challenge spaces. Responsible research and innovation approaches are routinely used to build social licence for contentious or disruptive technological solutions. The culture of the organisation is problem solving spurred by scientific curiosity. The fast-paced production of these new technologies is aims to respond to society's grand challenges rather than serving the interest of individual industries or stakeholder groups. The main accountability and performance measures include science metrics and science reviews, combined with public value impact assessments, for example, contributions to emissions reduction or improvements in food security. Capability mixes include applied science, technology, engineering, and economic and social sciences, but often clustered in multidisciplinary groups. Economics and social sciences undertake ex-ante and ex-post impact assessment. Particular attention is given to brokering partnerships and diagnosing and designing effective innovation processes. This is a much more collaborative approach that is attractive to public-spirited scientists who seek to achieve just scientific outputs and deliver real world impact.

5.3. Scenario three: community innovation-oriented

In this scenario, the transformation agenda is framed specifically to achieve more democratic and just agri-food systems. The focus is on addressing complex societal and often place-based issues such as inequality, injustice, decolonisation, just transitions and food sovereignty. AROs are embedded in a co-design and people-centred innovation system, geared towards supporting highly decentralised innovation processes with a strong role of local actors in governance arrangements.

The central role of AROs is to provide research support to civil society and grassroots movements in their efforts to develop solutions to local sustainability and inclusion issues. With public policy focusing on regional social development outcomes, publicly-funded AROs structure themselves as a geographically decentralised network of local research centres, as part of a wider strategy of strengthening local innovation capacities. Working from the bottom-up, AROs establish novel partnerships with civil society organisations and networks, as well as universities and other research centres, to co-develop context-relevant, applied science advances. Research priorities are demand-led by local communities and are often funded through regional development initiatives. Research approaches are highly applied and use co-innovation and co-production methods to build inclusive innovation processes to address structural and often cross-sectoral challenges (e.g., agriculture, food, nutrition, energy, health etc.). A highly democratised research culture applies sustainability science in place-based research to generate local solutions, and the innovation system becomes a mosaic of local/regional networks with strong community governance and leadership. Innovation performance is measured in terms of impacts on community-level issues. Research organisations are highly accountable to the community and associated governance mechanisms. Capability mixes are weighted towards the social and ecological sciences and organised in transdisciplinary teams and are often focused on bridging local and scientific knowledge systems and values. This research environment attracts community-spirited scientists, including researchers advancing indigenous methods and knowledge systems, willing to work in remote rural or regional areas and interested in bottom-up, place-based innovation solutions.

5.4. Scenario 4: Facilitating transformative innovation-oriented

In this scenario, the transformation agenda is framed by the recognition that transformation will be complex, highly uncertain, and politically challenging and as such will need to be approached experimentally. Innovation is likely to be social rather than purely technical involving brokering and negotiation of contending interests in society, as well as facilitation of the development and testing of solutions along uncertain innovation pathways. In this scenario, AROs are embedded in experimentation-centric innovation systems geared towards plurality of innovation pathways, with a diversity of sources of innovation including, but beyond, R&D and with collaborative and top-down/bottom-up governance.

The role of AROs is as transformative innovation facilitation agencies highly networked into the broader innovation system, where they play an intermediary function. This function involves stimulating the reflexivity, evaluation, learning, and adaptive management processes

that support innovation. AROs have core public funding to maintain critical research infrastructure and capability where everybody likes an innovation broker, but nobody wants to pay for one. This is part of a wider public value justification premised on system failure arguments. However, AROs rely on a consulting business model advising and facilitating innovation and change processes that industry and civil society groups are navigating and experimenting with. ARO priorities emerge from their interaction with their broad network and in part are driven by demands from a market for sustainability innovation facilitation services. AROs support both top-down and bottom-up approaches to experiment with sustainability solutions. An important part of AROs' role is supporting innovation connections between agriculture and other sectors to address cross-sectoral challenges. AROs' culture centres around the value of collaborative approaches as well as reflexivity and experimentation, what works where how and for whom, rather than emphasising specific technological solutions or disciplinary approaches. AROs' mandate is focused on the reconfiguration of food systems and part of this mandate is providing evidence and advising public policy on sustainability. Key performance measures include both public value impacts (e.g. emissions reduction and food security), and outcomes related to the emergence of more democratic and inclusive approaches that better encompass more recent concerns (e.g., around social justice and equity), which explicitly tackle the directionality of the system towards shared and negotiated sustainability visions. Capability mixes are weighted towards the social and ecological sciences that are organised in transdisciplinary teams, and use facilitation and complexity-aware innovation process design approaches that can tackle the systemic and uncertain nature of today's challenges. This research environment attracts transdisciplinary researchers – as well as non-research actors such as brokers, communication engagement specialists, facilitators– who are committed to co-constructing sustainable futures with a range of long-term, research and non-research partnerships.

6. Discussion: what issues do the scenarios reveal for further consideration

All the scenarios envision how AROs could contribute to agri-food system transformation towards more environmentally and socially inclusive pathways. Each scenario encapsulate a worldview of how this could be achieved (Reilly and Willenbockel, 2010). The paper does not present any of these as an ideal option, as each has its own strengths, drawbacks and trade-offs. Rather, the paper helps to reveal the issues to be considered in deliberations about the role and modus operandi of AROs going forward, and the underlying assumptions that underpin them. This is why the authors have, to some extent, artificially polarised the scenarios to emphasize key concerns and issues that need to be considered, articulating them in four key themes: i) core strengths, contradictions, and trade-offs, ii) alignment with existing capabilities; iii) alignment with existing roles and mandates, and iv) risks for AROs under different scenarios. These discussion categories are chosen as these are live debates in the ARO in which the authors work and have experience and in related literature (Banerjee et al., 2019; Hall and Dijkman, 2019; Reardon et al., 2019; Rijswijk et al., 2019; Turner et al., 2017a, 2017b).

6.1. Core strengths, contradictions, and trade-offs

The first scenario, industry transition oriented, places technology at the centre of the transformation agenda, exploiting the traditional strength of AROs in leveraging science and technology to solve pressing problems (Schot and Steinmueller, 2018). However, this scenario would leave the responsibility for tackling other non-technical dimensions of the transformation process to other players. This would mean, for instance, that new capabilities and regulations to enable the use of new technology would need considerable industry and policy attention (Ptak et al., 2023). The need to break path dependency and navigate the contested nature of change would need additional and purposeful governance arrangements that specifically address this dimension (Dobermann et al., 2022; Fesenfeld et al., 2020). This would need to be handled outside the scope of what AROs traditionally are responsible for. Organisations in the One CGIAR have faced this challenge of need to expand their mandate beyond technology development when additional dimension need to create impact are lacking in the broader innovation system (Banerjee et al., 2019).

The second scenario equally plays on the traditional strengths of AROs by placing technology at the centre of the transformation process (Maru et al., 2018; Shepherd et al., 2020). The scenario exploits public policy's power to set new directions for innovation through missions and similar ways of targeting innovation towards transformation (Mazzucato, 2018a). It also exploits existing relationships AROs may have with industry (Hannon, 2016). The scenario's focus on top-down efforts to redirect innovation towards sustainability may however overlook the potential of bottom-up and community-led innovation for sustainability, such as food movements, ecologically sensitive farming approaches and so forth (Diercks et al., 2019). Recently, more "informal" missions, where innovation emerge as spontaneous and collective social process (Fielke et al., 2023), have started to emerge. Yet, more consideration should be given to those as a way to avoid overlooking opportunities for AROs to leverage and scale promising and often unconventional forms of innovation emerging from the margins (Leeuwis and Aarts, 2021). The scenario could advance the "naïve belief" that governments and public AROs "know best" in terms of what can enable transformation (Kirchherr et al., 2023).

The third scenario, community innovation-oriented, is an altogether new territory for AROs that exploits the power of human-centred innovation processes (Biggeri and Ferrannini, 2014). While this could help with much-needed place-based solutions (Pereira et al., 2020), other research and innovation mechanisms would need to be implemented to tackle issues at regional, sector or national scales. The fourth scenario, facilitating transformative innovation-oriented, presents a yet more radical vision of AROs. It does, however, exploit the neutrality and legitimacy of AROs for broking and negotiating different visions and pathways to sustainability across multiple food systems actors (Klerkx et al., 2022). The risk, common perhaps with the third scenario, is that this type of ARO might undervalue traditional skills and comparative advantage in research and technology that have served well in the past (Schot and Steinmueller, 2018). These research and technology capabilities might need to be housed elsewhere.

6.2. Alignment with existing capability

As already discussed, scenarios one and two are highly aligned with AROs existing capability in science and technology development and would require complementary capability in topics such as responsible innovation or missions (Bugge et al., 2021; Espig et al., 2022), instead of proposing fundamental overhauls of AROs (Wojtynia et al., 2021). In contrast, scenarios three and four will require the development of radically new capabilities (Fazey et al., 2017; Ministry of Business, 2021). In the case of scenario three, this will be capability in community engagement, sustainability science and related forms for human-centred design approaches, on-farm experimentation, co-production and other approaches (discussed earlier in and in Table 1). In scenario four, new capabilities will be needed in areas such as visioning, foresight and coalition building (Den Boer et al., 2021; Leeuwis et al., 2021). While these types of skills are starting to appear in AROs, scenarios three and four suggest that these would need to become core areas of expertise, rather than areas of capability that support core research and technology development capability (Caniglia et al., 2021; Körner et al., 2022).

6.3. Alignment with existing roles and mandate of ARO

As illustrated above, the four scenarios present progressively more

radical visions of AROs roles and mandates, and it has been argued that fulfilling the wide-spanning objectives of the transformation agenda will require wide-ranging technical, institutional and policy change in current research priorities (Thornton et al., 2022). This might entail critical shifts in the organisational identity of AROs in terms of capabilities, services, partnerships, purposes and values (Rijswijk et al., 2019). This alerts us to the level of disruption and legitimation of AROs' (new) roles, that would need to be negotiated with stakeholders, policy and perhaps society as a whole. Scenario one is highly aligned with AROs existing role of supporting agriculture and food production and the industry players associated with this agenda. As such it presents the path of least resistance in terms of social and political acceptance. In scenario two, the sector focus on agriculture and food industries remains, but the transformation agenda will demand more boundary work with allied sectors such as, for example, in the case of emissions reduction, energy, transport and manufacturing (Ghodsvali et al., 2019). In scenario three, the role and mandate of AROs will need to broaden out considerably to address a range of community issues in the rural sector that include agriculture and food industry, and go beyond these to include, for instance, dimensions regarding indigenous people, minorities, and food sovereignty (Kropp et al., 2020). This presents a considerable reframing of the role and mandate for most AROs, challenging existing relationships and legitimacy to operate. Scenario four reframes the domain, mandate and impact aspirations of AROs from agri-food industry to agri-food system, as this scenario will inevitably encompass a much broader set of interests and pathways and will imply a fundamentally different way of engaging with sustainability challenges (Grillitsch et al., 2019). As with scenario three, challenging existing relationships and legitimacy to operate might call for new alliances with both industries and the civil society (Herrero et al., 2021). In this context, it is important to highlight that power struggles are likely in case of a fundamental shift in AROs mandate and role. If AROs have, in the past 50 years, largely been oriented towards the commercialisation of scientific discovery novel arrangements that prioritise, for instance, sustainability concerns over profits are likely to encounter resistance from powerful players that have interests in preserving the status quo (Conti et al., 2021b; Williams et al., 2023).

A further issue for consideration is the way the scenarios align with the existing mandate of AROs of balancing more immediate, demand-led, but often incremental research, with long term and discovery research focused on creating more radical venues of innovation (IPES, 2021). This is, for instance, an ongoing struggle within OneCGIAR debates and priority-setting (Leeuwis et al., 2017; Orr et al., 2022). Each of the scenarios implies dealing with this in different ways. Scenario two explicitly shifts the balance of research and technology development focus towards the radical or transformative end of the spectrum. In contrast, scenario three, with its focus on serving the needs of local communities, would seem to imply shifting the balance to the more demand-led and incremental end of the spectrum. Ways of achieving this balance between serving todays sustainability needs and being prepared for the unpredictable research and innovation challenges that lay ahead is going to need careful consideration (Glover et al., 2021).

6.4. Risks and trade-offs for AROs under different scenarios

Many general risks associated with the scenarios have started to reveal themselves in the discussion above. However, each scenario is associated with specific risks. In the case of scenario one, existing relationships with major agricultural industry players may make it difficult to pursue new and disruptive pathways to sustainability in cases where these threaten incumbent interests (Anderson and Maughan, 2021; Kalvelage et al., 2023). This will be particularly so for AROs that rely heavily on public-private co-investment funding arrangements. This may also be a consideration in scenario two. Another risk consideration for scenario two is that it might alienate existing and long-standing partnerships, particularly with industry players vulnerable to disruption (Hall and Dijkman, 2019). This might result in loss of political support and revenue from industry. Scenarios three and four may well encounter similar political and revenue loss risks. However, specific risks for scenario three and four is the hollowing out of core capability in research and technology development. This could undermine the ability of a sector or country to absorb new science and technology from other countries and sources (Breznitz et al., 2008), and even hamper a sector or country's ability to collaborate in international research and innovation networks and influence the international agenda (e.g. on climate change).

There are of course ways of mitigating these risks through adaptations in the broader innovation system to ensure capability gaps are filled, suitable funding mechanisms are in place, direction setting mechanisms are strong, and coordination is effective (Dinesh et al., 2021; Körner et al., 2022). However, just as the scenarios present progressively more radical interpretations of the role, mandate and modus operandi of AROs, each scenario will require an innovation system that is progressively going to embrace minor to major adaptions (Koerner et al., 2023). This raises a further risk associated with the urgency of the transformation agenda and need for AROs to respond to it in a timely fashion – while also raising questions on the emergent responsibility of AROs to ensure broader and more inclusive discussion around novel priorities, and possibly more ambitious and riskier actions to address those (Mazzucato, 2018b). The major overhaul of the innovation system implied by scenarios three and four, even if they were politically feasible, could be a decades-long organisational and institutional reform project, as would the development of associated capabilities in the ARO themselves. This temporal dimension will need to be given serious consideration (Conti et al., 2021b), especially for enabling AROs to explicitly and strategically address not only capability issues (Turner et al., 2017b), but also for finding a balance in responding to short-term versus long-term needs and demands (Glover et al., 2021).

7. Where do we go from here?

The scenarios of AROs developed in this paper reflect a reality that there are divergent views on the role, modus operandi and contribution of research and innovation in the agri-food system transformation agenda (Klerkx et al., 2022). None of these differences can be resolved by expert analysis as there are divergent yet legitimate political and philosophical viewpoints amongst stakeholders, that will have to be navigated. As Foran et al. (2014) points out in respect to the notion of agri-food systems, not only can such differences not be reconciled, it also may not be useful to try and, instead, it would be better to embrace the diversity that these represent. A key consideration will also be the nature of the country context, its historical pattern of institutional development associated with AROs and the constrains and opportunities this imposes in any particular country. In practice, AROs will need to find ways to incorporate different elements of practice and organisational roles from across these scenarios. The result may well be new hybrid organisational forms that are comfortable in accommodating a variety of perspectives on how transformation can be achieved and the different roles that AROs may play in this process (Banerjee et al., 2019; Schut et al., 2014). This might mean a fluidity of organisational practice across the four scenarios, with hybrid configurations that combine features of different scenarios. These configurations might respond both to necessary geographical adaptations that ARO will need to consider (e.g. what is feasible where) and mirror likely overlaps and possible parallel narratives to the ones illustrated in the paper. The question remains, however, as to how this diversity of ideas can be harnessed in practice and how the inevitable power dynamics in innovation systems can be navigated to ensure public good outcomes (Kenter et al., 2019; Scoones, 2016). For AROs, difficult and potentially contested choices lay ahead.

Given the broad industry, policy, and societal interests (and stakeholding) of AROs, decisions about future pathways and organisational roles should not be made unilaterally and are likely to encounter

opposition if they are. This suggest that discussions and consultations will need to be inclusive of a variety of different perspectives and interests, with much more consideration given to the undeniably contrasting interests and views that stakeholders hold around AROs. Different AROs configurations are expected to benefit different sets of players, and losses will need to be compensated. In reality, consensus is unlikely to be reached, but compromise on priority pathways for AROs will be essential (de Cleene, 2019; Eakin et al., 2017).

The role of the scenarios presented in this paper could be as a boundary object[2] to support reflection on what features of AROs would be valued, and where, in relation to the agri-food system transformation agenda (Morris et al., 2021). The analysis of the scenarios has flagged several issues in reflection around valued features of different ARO prototypes, highlighting different strengths, weaknesses, trade-offs, risks, and political challenges. This could be a starting point to help structure broader discussion around the scenarios.

A final point opened by the analysis of the different scenarios is that any discussion of the reframing and reorganisation of AROs cannot be separated from a discussion about the nature of the agricultural innovation system and how this can be better aligned to the transformation agenda (Koerner et al., 2023; Kok and Klerkx, 2023). The ability of AROs to prosecute their role and mandate is always going to be mediated by the nature of the innovation systems in which they are embedded. In other words, is the nature of the innovation system adequately adapted to the contingencies of the agri-food systems transformation agenda? In most countries, the purpose for which the agricultural innovation systems is being developed (economic growth and or social inclusion and or food security) remains ambiguous. The policy question of "innovation systems for what" is becoming increasingly urgent in relation to enacting the transformation agenda, for instance in relation to mission-oriented approaches (Frost et al., 2019; Kok and Klerkx, 2023; Pigford et al., 2018). This suggests that if AROs are going to start a reflection with their stakeholders on possible organisational reforms and priorities, this cannot be done in isolation from broader discussion of the future shape and aims of agricultural and even national innovation systems. Connecting these discussions and opening them to as broad a participation that is practically possible is going to be critical in charting new research and innovation pathways towards agri-food system transformation.

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Declaration of competing interest

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Data availability

No data was used for the research described in the article.

[2] Boundary objects can be described as external *representations* of reality that simplify an issue to be more easily communicated, creating understanding among actors with different values and views. Thus, they can prompt discussion and deeper exploration of issues that might be understood differently or incompletely by different actors, until a shared understanding is reached (Morris et al., 2021).

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