Agricultural Systems 190 (2021) 103120

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Foresighting Australian digital agricultural futures: Applying responsible innovation thinking to anticipate research and development impact under different scenarios

Aysha Fleming[a,*], Emma Jakku[a], Simon Fielke[a], Bruce M. Taylor[a], Justine Lacey[a], Andrew Terhorst[b], Cara Stitzlein[b]

[a] CSIRO Land and Water, Australia
[b] CSIRO Data61, Australia

A R T I C L E I N F O

Editor: Guillaume Martin

Keywords:
Agricultural trends
Responsible innovation
Anticipation
Sustainable agriculture
Foresighting
Agriculture 4.0
Agtech

A B S T R A C T

CONTEXT: Public and private research institutions are grappling with the challenges and opportunities of embedding dimensions of responsible innovation within their research and development programs, including those seeking to transform agricultural productivity and sustainability through digital technologies. Central to meeting this challenge is building institutional, organisational and professional capacity for anticipation and reflexiveness within multidisciplinary research communities. Foresighting methodologies provide a means by which this might be usefully and practically enabled, whilst also shedding light on the broader social and ethical implications of alternative agricultural technology development pathways under uncertain environmental and industry futures.

OBJECTIVE: This paper presents the results of a participatory foresighting exercise undertaken as part of a large, publicly funded multi-disciplinary research initiative designed to build a common big data infrastructure to harness the benefits of the digital revolution for the Australian agricultural and land sectors. We seek to explore what role digital technology will play in the future of Australian agriculture and to consider the social and ethical implications.

METHODS: We ran a one-day foresighting workshop comprised of four steps – 1) horizon scanning to identify trends 2) selecting two drivers of change 3) producing a matrix to generate scenarios 4) building and refining scenarios. Participants explored different possible futures of farming in Australia, with a focus on scenarios involving socio-technical dimensions of digital agriculture to consider the implications of these futures for research practice and for farming communities.

RESULTS AND CONCLUSIONS: Four scenarios were developed, distinguished by the interplay of two critical but uncertain drivers of change identified by participants, namely: the degree of resource security or insecurity that future agricultural enterprises are likely to experience; and the degree to which farming sectors maintain traditional farm business models and associated value chains or transition to more diverse or innovative business models. The process highlighted the need to increase the capacity and opportunity for more reflexivity in research and development, if positive outcomes were to be achieved.

SIGNIFICANCE: The scenarios we produced provide a catalyst for conversation about the implications of digital technology development in Australia and globally, for industry, policy and research and development. In particular, the scenarios highlight potential changes in farm business models, decision making, and beneficiaries and inequities of new technologies and other components of food value chains. The paper also serves as a guide and prompt for others, by demonstrating one way reflexivity can be achieved in organisations attempting innovation.

* Corresponding author at: CSIRO, Land and Water, University of Tasmania, College Rd, Sandy Bay, TAS 7005, Australia.
E-mail address: Aysha.Fleming@csiro.au (A. Fleming).

https://doi.org/10.1016/j.agsy.2021.103120
Received 14 September 2020; Received in revised form 11 February 2021; Accepted 22 February 2021
Available online 8 March 2021

1. Introduction

Digital agriculture is described as a revolution for Australia (Huberty, 2015), which will create a step change in the economy by improving efficiency and sustainability, and a much-needed boost to regional and social prosperity. Technological innovations are important 'solution-providers' for addressing societal problems from employment to climate change, but they can also have negative consequences, and social and ethical impacts need to be considered (Gremmen et al. 2019; Fielke et al. 2020). As agriculture moves towards a 'roll-out' of the digital revolution, implicit assumptions about impacts on farmers and communities (identities, job roles, labour) and the distribution of benefits must be surfaced (Fleming et al., 2018; Carolan, 2018). Responsible innovation is an emerging area of scholarship that can potentially offer some concrete processes to help the agricultural industry to navigate the future.

Responsible innovation has been adopted around the world as a way of designing research to anticipate and respond more deliberately to current and future states through inclusive and reflective engagement with broader societal issues and concerns (Eastwood et al., 2019b; Rose and Chilvers, 2018; Owen et al., 2013; Ashworth et al., 2019). The concept has both academic and normative origins and while responsibility has always been part of the central narrative of research practice, responsible innovation has taken shape over the last decade as a broader framework based on building the dimensions of anticipation, reflexivity, inclusion and responsiveness into scientific research practice and outcomes (Stilgoe et al., 2013). In this research, anticipation and reflexivity are the key dimensions of responsible innovation that are in focus (Owen et al., 2013; Stilgoe et al., 2013; Eastwood et al., 2019b) because we use these in conjunction with foresighting and scenario planning, which are commonly employed tools to anticipate where the future is heading and reflect on the implications (Voros, 2003). Foresighting, anticipation and scenario planning are all terms to describe similar methods of imagining alternative but probable futures to design responses to changing futures (Hines and Zindato, 2016). These techniques are commonly used in policy settings and are popular for environmental, regional, and landscape planning, where levels of complexity and uncertainty are high (Oteros-Rozas et al., 2015). A scenario is "a coherent, internally consistent and plausible description of a potential future trajectory of a system" (Oteros-Rozas et al., 2015:32). Scenarios produce narratives or storylines which guide planning, decision making and expectations, not by setting up a guarantee of the future, but by generating ideas about potential options and opportunities and the steps that might be taken to work towards more desirable futures and prepare for the unknown (Merrie et al. 2018). Scenarios allow ethical, moral and practical issues around beneficiaries, risks and values to be reflexively surfaced and discussed (Fleming et al., 2018). Foresighting is commonly used in agriculture to analyse high level policy directions (e.g. Rutten et al., 2018; O'Malley et al., 2020) but is rare as a method to aid reflexivity and anticipation in research and development projects *in progress*.

Research and development organisations globally, both public and private, are making major investments in developing digital agriculture technologies for a successful future. However, these organisations and the individuals they employ, face three challenges. The first challenge is the highly heterogenous character of farming businesses, farming systems, and environments, particularly in broadacre cropping systems of countries such as Australia, which are spatially diverse and exposed to variable and distinct climates (Robertson et al., 2016). The second challenge is the high level of uncertainty around how new technologies might fit into the future of farm decision-making in contexts which are experiencing rapid change and are increasingly diverse (Fielke et al., 2019). An example is the proliferation of information sources and advice that farmers now use in their decision-making (Knierim et al., 2017; Phillipson et al., 2016). The third and perhaps greatest of the three challenges are the implicit values and assumptions that research and development providers hold about the normative desirability and expected benefits of these technologies among farmers both in the present and under alternate probable farming futures. These implicit values can create unexpected negative social and ethical implications when technology is broadly adopted such as locking out some groups, or further benefiting those who are already privileged (van der Burg et al., 2019; Klerkx and Begemann, 2020; Klerkx and Rose, 2020). Therefore, it is an important exercise that the agricultural industry, along with associated research organisations and institutions consider some fundamental questions about the technological innovation process. It is no longer enough to reflect on whether new technology is merely viable, but also whether it is fit for the diversity of futures into which it may be deployed, and moreover, ask social and ethical questions about whether its impact will be positive or negative, and for whom.

The type of innovations needed cannot be restricted to designing and evaluating solutions, but must also engage with a process of paradigmatic change…Innovative development pathways should no longer focus just on the techno-economic system that delivers economic growth, but on the whole social-cultural-ecological system (Asveld et al., 2017, p.1–2)

This work requires thinking differently and asking different types of questions as we do research to encourage consideration of responsible innovation dimensions of anticipation and reflexivity, inclusivity and responsiveness (Asveld et al., 2017; Ashworth et al., 2019; Lacey et al., 2020).

The aim of this paper is to encourage reflection by researchers and technology developers on whether current and potential future innovations in digital technology in agriculture are effective and whether or not they result in negative social or ethical consequences. This paper reports on the outcomes of a participatory foresighting process undertaken with a diverse group of scientists and engineers working as part of Digiscape, a nationally significant research and development initiative in digital agriculture in Australia. The foresighting process explored the future of digitalisation in agriculture primarily, but not exclusively, on the production end of agriculture. Impacts on consumers, retailers, distribution and societies, were also broadly considered. Linking foresighting approaches with RI questions alone is not a novel contribution (Wilsdon, 2014; van der Duin, 2018) but documenting an organisational experience of the nexus of foresighting, digital technology, responsible innovation and innovation in agriculture, is a novel contribution. In doing so, the paper demonstrates how critical reflection on, and anticipation of, the trajectories at the intersection of technology and agricultural systems can allow innovators to better anticipate and respond to social and ethical challenges; and generate insights that are more broadly applicable to a wider group of stakeholders with interests in digital agriculture and RI in practice, both in Australia and globally.

The paper is organised as follows. Section 2 provides a brief background to the research and development context of digital agriculture in Australia, and internationally, with attention to the Digiscape Future Science Platform (Digiscape), a multidisciplinary, multi-agricultural sector focused research and development initiative to drive innovation in digital agriculture (CSIRO, 2017). It is from this initiative that participants in the study are drawn, including the authors, who are also funded through this initiative. Second, we provide an overview of recent trends in the broader agricultural knowledge and advice networks in Australia. This provides contextual background for the scenarios and how they were developed. This material was also used to stimulate and frame the thinking of participants as part of the foresighting process itself (described as part of methodology in Section 3). Section 4 presents the results of the participatory foresighting process, including major trends identified; prioritisation of drivers of change and the resultant development of the four scenarios that describe alternative but plausible socio-technical futures for digital agriculture in Australia. Lastly, Section 5 returns to the fundamental questions stated above to reflect critically and broadly on the issues raised for research and development practitioners and their institutions.

2. Background to the study

2.1. Overview of research and development context for digital agriculture and Digiscape

Digiscape is a five year, $7.1 M publicly funded research initiative that brings together traditional agricultural research expertise (e.g. agricultural scientists, agronomists, and rural sociologists) and relatively new skillsets and disciplinary backgrounds to the agricultural research domain (e.g. human centred design, data science, software engineering and development). Digiscape consists of two major elements: (i) developing an underpinning data and analytics platform to support multiple digital and ICT based applications, and (ii) a series of sector and technology-specific 'use cases' in water efficiency in irrigated cropping, nutrient management in sugarcane production, and value generation through carbon market participation among others (see CSIRO, 2017). The main objective for Digiscape is to help Australia realise the potential of agricultural digital innovation to increase productivity and relieve pressure on natural resources (AgResearch Limited, 2017; Digital Agriculture Convergence Lab, 2017; IoF 2020, 2017).

While the push towards digital agricultural systems is gaining momentum, there is also an increasing recognition of the social dimensions of digitalisation and the need to pursue responsible innovation with regards to agricultural technology development (Eastwood et al., 2019a; Gremmen et al., 2019, Klerkx et al., 2019). Of these critical social dimensions, we argue that emerging digital technologies and how they interact with changes in agricultural knowledge and advice networks are likely to significantly affect the degree to which changes will be embedded or not within the everyday decisions and practices of farmers.

2.2. Framing the foresighting process: recent trends in agricultural advice networks

We conducted a review of trends in agricultural information and advice networks as part of the pre-workshop horizon scanning process (Fielke et al., 2020). This review identified that recent trends in agricultural advice networks globally are towards increased privatisation, fragmentation and pluralism (Fielke et al., 2020; Eastwood et al., 2017; Nettle et al., 2018; Paschen et al., 2017). The review focused on how these changes are intersecting with private, non-government organisation, farmer-based, public research and education and public authority agricultural advisory services in Australia, including the roles and functions of these different advisory services (Knierim et al., 2017).

In Australia there are decreasing farm numbers but increasing farm sizes (ABS, 2018). This translates to a professionalisation of agriculture where getting 'big' and getting 'smart' are important to stay in business (Murphy et al., 2013). Moreover, privatisation and deregulation have resulted in private agricultural advisory services becoming the key component of the Australian agricultural knowledge and advice network. Privatisation and deregulation have affected the other advisory provider categories to varying degrees (see Appendix 1 for further details). The review also examined potential implications of digitalisation for agricultural information and advisory networks, especially increasing connectivity and transparency, as well as the diversification and ongoing re-structuring of agricultural governance (Darnell et al., 2018; Nettle et al., 2018; Wiseman et al., 2019). A summary of these trends was presented at the workshop to help guide discussion during the scenario development process, providing background information to help participants reflect on the role of technology, potential social and ethical implications of different pathways, and more specific implications for information and advisory services.

3. The scenario-based foresighting process

There are many methods of foresighting, or anticipating the future, discussed in the literature, especially in relation to technology development (Nordmann, 2014). These methods tend to fall into two main types, either starting from current values and trajectories (bottom-up approaches) or starting from desired end goals and working backwards (top-down approaches). Both have strengths and weaknesses but across the literature it is emphasised that the main purpose of foresighting is not generating perfect knowledge of what is to come, but building greater awareness or reflexivity about how things are now (values, objectives) and capacity for flexibility and responsiveness to change (van der Burg, 2014). The approach we use here is bottom-up, starting from current trajectories, because we wish to build capability in reflexivity and responsiveness of the participants and raise questions for researchers and practitioners to consider (discussed below).

Scenario-building is a fundamental element of foresighting processes. According to De Smedt et al. (2013) future scenarios are "narratives set in the future to explore how the society would change if certain trends were to strengthen or diminish, or various events were to occur" (2013:432). Moreover, the deliberative construction of scenarios can play an important role in helping stakeholders orient innovation systems and research priorities in complex social contexts (De Smedt et al., 2013). There are quite different classes or types of futures that might be described though a scenario-building process. For this exercise we adopted the position of *plausible* futures for our scenarios. Plausible futures include those futures "which 'could happen' and stem from our current understanding of, for example, physical laws, processes, causation, systems of human interaction, ways of knowing…from our more general knowledge of "how things work" (Voros, 2003: 13). These futures differ from other perspectives such as *potential* futures as "all of the futures which lie ahead, including those which we cannot even begin to imagine" or *preferred* futures as normatively desirable states (Voros, 2003).

The foresighting process we employed draws heavily on several of the steps articulated by Hajkowicz and Eady (2015) in their earlier exploration of megatrends impacting on Australian agriculture and related rural industry futures. We selected and adapted steps that could be meaningfully implemented as a predominantly facilitated, deliberative exercise and that could be accomplished within a one-day strategic thinking workshop with 26 researchers from the Digiscape initiative (a subset of just over 100 Digiscape researchers).

There were four steps in the foresighting process (see Fig. 1). Step 1 is about horizon scanning and identifying key trends. For this step, three presentations were given to workshop participants: an overview of responsible innovation (Stilgoe et al., 2013); results from a study on the changing identities of agricultural workers arising from digital agriculture (Rijswijk et al., 2019); and an analysis of trends in agricultural advice networks (Fielke et al., 2020). Ensuing discussion settled on 2030

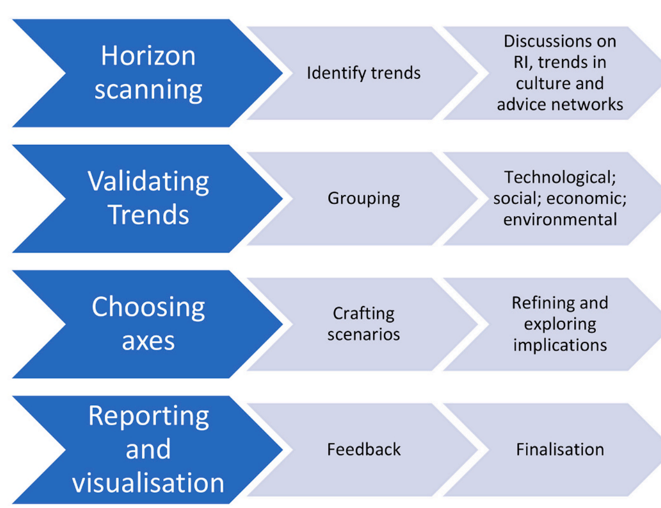

Fig. 1. Workshop process.

as an appropriate timeframe because it is close enough in time to be linked to current trends and trajectories, policies and initiatives (e.g. the UN's Sustainable Development Goals, which also have 2030 as their target). Step 2 is about validating and grouping trends. In this workshop, eight key trends were identified (see Appendix 3) and grouped into four categories: Technological, Social, Economic and Environmental. Step 3 is about developing axes of change and crafting scenarios. Workshop participants selected two axes from the trends to build scenarios: vast or limited resource security (y-axis) and innovative or conservative farm business models and structures (x-axis). Four multi-disciplinary groups of approximately six people discussed the implications of future digital technology and trends. These discussions became the foundation for the scenarios reported to a broader group of Digiscape researchers. Step 4 is about refining scenarios and exploring their implications. Following the workshop, narratives for each scenario were further refined and the implications of these drawn out. Feedback about the workshop and its impact on individual thinking were collected at the end of the workshop as well as through emails, conversations, and debriefs with workshop facilitators. Although the workshop itself was the central process that generated the results we discuss here, the foresighting process involved pre-workshop and post-workshop activities designed to promote deeper thinking. These activities included discussions about digital agriculture broadly, discussions about the projects undertaken in Digiscape, preparations for the workshop, choices about whom to include (see below for more discussion of participants), gathering feedback and reflections post -workshop and identifying connections back to the broader research program.

3.1. Workshop participants

26 participants with key roles and responsibilities in the 'Digiscape Future Science Platform' were invited to a one-day workshop to explore the future of digital agriculture and reflect on the role of responsible innovation and their role as individuals and as members of CSIRO in developing that future. The participants were across all Digiscape projects and had different roles and disciplinary backgrounds (see Table 1), predominantly experts in areas of agronomy, data sciences and environmental information. There were more men than women and the average age was mid 40s. We recognise that the outcomes of the workshop could change if the participants were different but the aim was not to produce a 'perfect' scenario mix, but rather to build reflexivity into the Digiscape program of work, and to contribute these scenarios to stimulate wider scholarly and industry reflection. Thus, the choice of participants was shaped by those who had a leadership role and/or could benefit the most from building reflexivity, both as individuals and in guiding others. Each Digiscape project was represented and had an explicit task to take their learnings back to their teams.

4. Results

The workshop was designed to encourage reflection on whether the technologies Digiscape is developing are likely to be fit for purpose in different futures and indeed in a diversity of futures. The scenarios were developed with this in the background, as a question of whether Digiscape technologies, and other digital innovations in agriculture generally, are adhering to the dimensions of responsible innovation. Each scenario was developed in response to questions of: What role will digital technology play in this plausible future? What are the social and ethical implications that might arise? These are discussed below and summarised in Table 2.

4.1. Four scenarios

The four scenarios produced were called: Struggling, Innovating, Surviving and Thriving (Fig. 2). The scenarios present possible futures for different regions affected by digital agriculture. They are not mutually exclusive and may co-exist across different contexts. In this way they do not necessarily depict a progression from bad to good, as there are positive and negative factors in each, including positive and negative aspects of technology, i.e. more technology is not necessarily better. The scenarios are narratives designed to aid critical reflection, not normative visions of how the future should be. The eight key trends were used to prompt thinking interwoven into the different outcomes associated with the two drivers. Other trends and uncertainties in the future scenarios also became apparent because of this process, including labour shortages, succession planning and the role of trust in people, institutions, technologies and information.

4.2. Scenario 1: Struggling

This scenario describes the top left quadrant of predominantly traditional farming business models operating with insecure resources (Fig. 2).

The Struggling scenario describes farm businesses reacting to their environment and experiencing boom and bust cycles due to high risks and uncertainty. In this future there are fewer, larger farms, with many more marginal farms becoming unviable, leading to monopolisation and nationalisation of farm businesses. Geographic diversification is adopted by farm businesses to manage risk. Risk management and managing uncertainty are core business needs and agricultural derivatives (speculators and hedgers) are driven by the high risk/high return potential. Capital buffers and insurance are important for farm businesses to stay viable and over valuation of agricultural land and optimistic bank loans cause financial stress. Farm businesses have diverse technology use and skill levels, including among their customers (consumers), and there is a high turnover in relationships, both on farm, and between customers and suppliers. The technology sector has also rationalised through acquisitions of start-ups by large companies with contractual arrangements that lock in certain approaches and lead to distrust and accentuate risks. Opportunities for smaller farms and communities to work together become more vital to small farm business survival. Depression and suicide rates continue to be a problem and government support is needed for rural communities to access vital services, for example health care. Margins from traditional markets (e.g. supermarkets, commodity traders) have narrowed and online marketplaces grow, and locally supported agriculture rises as a mechanism to manage risk and reduce costs. Value chains become more agile and diverse.

The risks to producers in this scenario are increased vulnerability of farmers and communities to greater uncertainty and associated risk, increasing inequality between regions and an increasing rural-urban

Table 1
Participant details.

Role	Disciplinary specialisation			Gender		Subtotals
	Agricultural science	Social science	Data science	Male	Female	
Project leader	6	2	1	6	3	*9*
Participant	5	–	4	7	2	*9*
Participant/facilitator	–	7	1	4	4	*8*
Subtotals	*11*	*8*	*6*	*17*	*9*	
Total participants						*26*

Table 2
Summarised descriptions of the role of technology, social and ethical implications and advisory services for each scenario.

	Struggling	Innovating	Surviving	Thriving
Role of technology	Variable and competitive, driven by individuals Costly and biased towards bigger companies Focused on production and distribution	Variable and experimental with sharing of ideas locally and in networks (e.g. social media) New networks and ideas create new types of roles	Important for directly connecting farmer and consumer Important for supply chain	Precision agriculture is widespread Farmers require greater technology skills and training and use technology for all facets of the farm business Technology is fully embedded in the farm business and social life, which changes the traditional values and lifestyle of the farmer and is perceived positively by some and negatively by others
Social and ethical implications	Consumer trust and connection lacking Risk of monopolies and inequity	Risks in data ownership and privacy and legislation gaps Increased connection builds trust	Inequities and variability in levels of social support in different regions facing different threats (flood, drought, etc.) Increased connection builds trust	Monitoring and accountability throughout the supply chain builds trust. Capacity and funding differences limit the ability of some farms to participate
Information and advisory services	Challenge of dealing with many customers with diverse technical backgrounds Boom and bust leading to higher turnover in relationships Rationalisation of the technology sector (locking in/less diversity, dominated by large companies) Risk management and quantification of uncertainty as a business offering Agricultural derivatives become more attractive (speculators and hedgers)	Predictive analytics to manage risk – climate, markets, labour Farmers embedded in information exchange networks Improved data/information availability awareness	The complexity of all this technology creates a lot of noise and confusion There will be a skills gap/lag to enable adoption of technology – it is a likely scenario that farms will not run with less people just people with a different skill set (opportunity in the education sector)	Increased number of internal tech experts on larger farms Small/medium farmers continue to seek external advice Larger farms facing corporate reporting requirements is an opportunity for tech implementation and improvement Increased sensors on farms Trusted advice increasingly valuable
Research questions arising from each scenario	What are the future values that shape the agriculture and food sector? How can science and government prevent society crossing thresholds we wish to avoid (environmental collapse, market failure, social decline)? Is there a role for appropriate technologies in supporting development outcomes or building resilience of farming communities in high risk locations? What opportunities are there for more equitable and appropriate technology development processes in farming that address broader livelihood aspirations and reduce vulnerability of farming communities?	What role does science and RRI play in increasingly diverse and fast-paced industry digital innovation? What policies or practices can be used to encourage bottom-up innovation processes (i.e. supporting niche creation) in diverse settings?	How can publicly funded science promote more equitable outcomes in an increasingly competitive, costly, and constrained environment? What are the human capital requirements (education, advisory services, business skills) required to mitigate potential slide into less desirable states?	Will digital technology result in an agricultural revolution or is it just a continuation of the status quo? Which is more desirable? How has widespread digitalisation of farming, and value chains altered structural and power relationships with the Australian farming sector and globally? What are the immediate and longer-term implications of these changes for food security, market access and sustainability?

	Struggling	Innovating	Surviving	Thriving
Role of technology	Variable and competitive, driven by individuals Costly and biased towards bigger companies Focused on production and distribution	Variable and experimental with sharing of ideas locally and in networks (e.g. social media) New networks and ideas create new types of roles	Important for directly connecting farmer and consumer Important for supply chain	Precision agriculture is widespread Farmers require greater technology skills and training and use technology for all facets of the farm business Technology is fully embedded in the farm business and social life, which changes the traditional values and lifestyle of the farmer and is perceived positively by some and negatively by others
Social and ethical implications	Consumer trust and connection lacking Risk of monopolies and inequity	Risks in data ownership and privacy and legislation gaps Increased connection builds trust	Inequities and variability in levels of social support in different regions facing different threats (flood, drought, etc.) Increased connection builds trust	Monitoring and accountability throughout the supply chain builds trust. Capacity and funding differences limit the ability of some farms to participate
Information and advisory services	Challenge of dealing with many customers with diverse technical backgrounds Boom and bust leading to higher turnover in relationships Rationalisation of the technology sector (locking in/less diversity, dominated by large companies) Risk management and quantification of uncertainty as a business offering Agricultural derivatives become more attractive (speculators and hedgers)	Predictive analytics to manage risk – climate, markets, labour Farmers embedded in information exchange networks Improved data/information availability awareness	The complexity of all this technology creates a lot of noise and confusion There will be a skills gap/lag to enable adoption of technology – it is a likely scenario that farms will not run with less people just people with a different skill set (opportunity in the education sector)	Increased number of internal tech experts on larger farms Small/medium farmers continue to seek external advice Larger farms facing corporate reporting requirements is an opportunity for tech implementation and improvement Increased sensors on farms Trusted advice increasingly valuable

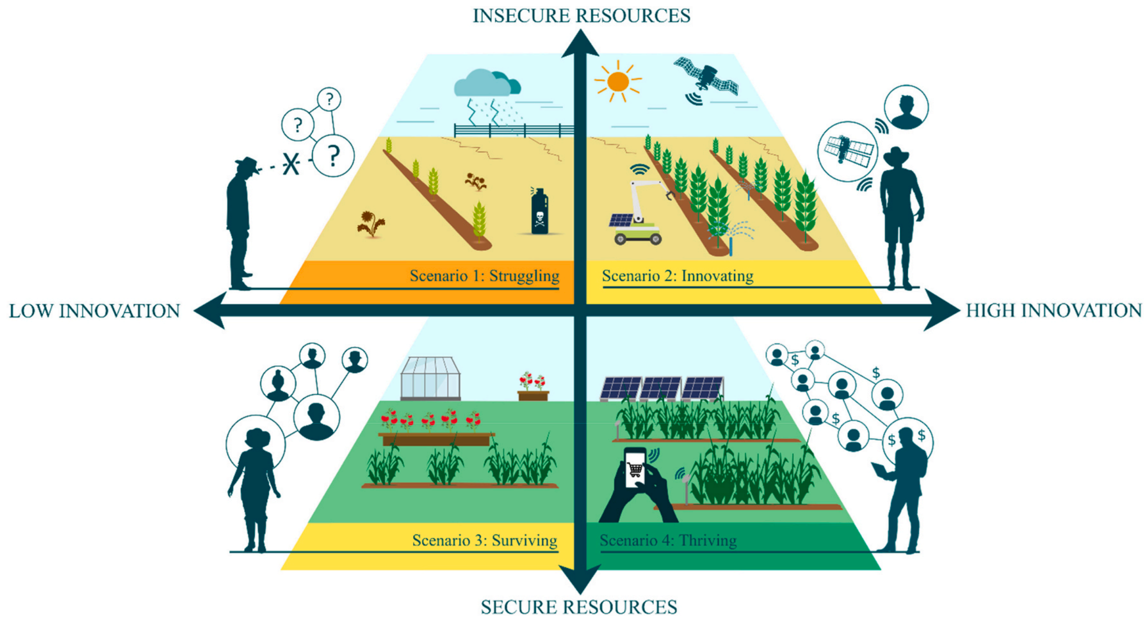

Fig. 2. Four scenarios developed during the workshop.
Note: The x axis represents levels of innovation in farm business models and structures, ranging from conservative on the left to innovative on the right. The y axis represents levels of resource security, ranging from secure at the bottom to insecure at the top. Importantly, the scenarios are not a gradient from bad to good. Scenario 4 is not the 'best' and it is not necessarily a normative target. Each scenario has pros and cons and insights into the digitalisation of agriculture.

divide. Reliance on government interventions is costly and unlikely to improve circumstances over the long term. Increasing exits from farming may promote predatory economic land buying or the increase of foreign ownership. More pressure on agricultural expansion and increased pressure on marginal land may result in further environmental and biosecurity risks. Because of these risks, science outcomes and products need to be directly useful for family farms and need to work in realms of higher uncertainty and increase farmer and value chain stakeholder's capacity to cope. Farmers need to be agile and forward looking and scientists, companies and government agencies need to partner together to deliver useful products. Investment could come from venture capitalists, research initiatives, innovation hubs, insurers and bankers.

4.3. Scenario 2: Innovating

This scenario describes the top right quadrant of novel and diverse farming business models operating with insecure resources (Fig. 2).

The Innovating scenario describes farmers working more flexibly, more embedded within diverse knowledge and advice networks and using high level skills to operate advanced technology, synthesise information from a range of sources in order to adapt to frequently changing conditions and resource availability. Farms appear to be more diverse, in terms of scale, foci and margins and fully autonomous farms are also part of the mix. Land and farming have been decoupled so that properties can be used more creatively and for more enterprises simultaneously (e.g. tourism). Increased use of technology is expensive and demands high skill levels which drives a sharing economy for both labour and equipment. Farmers rely more on digital technology to assess and manage risks, across a range of factors from climate to market. Data is more available and accessible, and farmers are fully embedded in information exchange networks, with a range of others (peers, professionals and service providers). There is improved data availability and analytics to improve information on which decisions are based. Value chains are more integrated and share information. There are more diverse service industries interacting with the value chain and there is a greater choice about where people live and work (as they can work more through technologies).

The risks to farm businesses in this scenario are the significant energy, education and cultural change required to manage and maintain a more diverse and integrated system. Further, there is a risk for maintaining this strategy into the long term. The risk of unemployment in certain labour categories (such as unskilled), or industry displacement (low cost industries might be forced out) bring an associated risk to socio-economic equity. There are also potential issues around debt accrued for expensive capital outlays (for infrastructure or services) and questions about resource use efficiency, technology obsolescence and the ability to problem solve. Therefore, implications include the need for growth in high-tech knowledge and service sectors, innovation in education programs, products, services, and information ecosystems. There needs to be more openness to new ideas and sharing, with broad and high-level skills gaining importance, especially in adaptive capacity. Socially and culturally diverse networks need to make the most of porous boundaries and continual dynamic change needs to be the norm.

4.4. Scenario 3: Surviving

This scenario describes the bottom left quadrant of predominantly traditional farming business models operating with secure resources (Fig. 2).

The Surviving scenario describes a future where farms are contained as single business units or multiple farms. The strong connection to community may lead to development of local co-operatives or farming groups that support each other. The self-sufficiency of the farm could open the possibility for new revenue streams (e.g. payments for services in carbon abatement or natural capital). Digitalisation could be used more readily to create a direct link between the farm and consumer, reducing transaction costs. This would appeal to consumers who want full transparency about production and process. The Surviving scenario describes farmers mainly trying to preserve traditional core values of family farming and self-sustainability and without readily available capital they are unable to invest in technology, at least not without support. There may be a skills gap, with this segment being perceived as technology 'laggards'. The likelihood of investing in technology development was perceived as low (unchanged from present trends) but low-cost solutions based on ingenuity were possible (i.e. farmers introducing their own tech solutions).

As small farms would not be able to compete with corporate farms on commodity prices, they would need a more personal connection or narrative to appeal to consumers or to bring in revenue from additional options. Participants were optimistic that non-traditional investment would support farms in this context. It was also considered plausible that surviving farms had a resilience not found in the other scenarios: by way of containment over their value chain, they may be protected against unforeseen changes that the broader industry might be challenged by, such as questions of social license and transparency. The risks to producers in this scenario were identified as farmer profitability and stability fluctuating because of market forces and only the minority (or the most resilient enterprises) prospering, from opportunities driven by provenance and traceability. This creates socio-economic inequality and high-cost service provisions needing to be tailored to individuals, which furthers the divide between those that can afford support and those that cannot. Implications are that technology needs to be added on through partnerships with existing service providers and offer both information provision and decision support. Successful engagement requires an understanding of previous barriers and individual motivations. Social networks are likely to be more bonded or local and information and technology may need to be disseminated through a range of strategies including trusted advisors, or social media channels that are already in use. Investment may be needed from the government, or internationally through philanthropy, for explicitly important public goods and services and environmental restoration may come to be more important.

4.5. Scenario 4: Thriving

This scenario describes the bottom right quadrant of novel and diverse farming business models operating with secure resources (Fig. 2).

Farmers use technology in all aspects of their business – to monitor the crop and the value chain, engage advice, source information, make decisions and manage the business. Farms are larger and are geographically diversified as a risk management strategy. There are also portfolio farms, with increased specialisation in a commodity and management is outsourced. Farmers deal with more complex information and decisions and rely more heavily on trusted advisors and analytical services (which become more valuable). Ownership structures are diverse and include new arrangements of community and public shares in farms as well as corporate ownership. The size of the farms leads to larger debt and larger investments. There are an increased number of internal technology experts on large farms and external advice becomes more tailored to small and medium farms. Larger farms facing corporate reporting requirements provide an opportunity for technology to be implemented. There are increasing numbers of sensors on farm and an increasing range of information is synthesised in decisions. Value chains have increased use of technology and communication along the chain to increase traceability. Farmers and consumers are more able to directly communicate in a range of ways. Domestic and international, closed and open value chains are more differentiated and specialised.

The risk to farm businesses in this scenario is increased inequity as smaller players are pushed out, unless the price and availability of technology allows everyone access. Powerful monopolies develop and potentially exert increasing influence both nationally and internationally. Size means that inevitably businesses may become less agile. As a result, engagement and collaboration with farmers continues to be important to determine needs and best practice solutions. Information service provision is still an important focus for science (creating/delivering new information) but there is a changing landscape of 'needed information' and how it can be created/delivered. Robots are increasingly common on farms, with both positive and negative implications. Risk management is an increasing issue for farmers, dealing with rising uncertainty and complexity across sectors (environmental, technical, social). Consequently, trust and integrity are increasingly forefront for farmers and multiple agendas and funders may complicate partnerships. Responsible research is increasingly important for science to maintain credibility and trust.

5. Discussion

This foresighting process is not alone in imagining the future of digitalisation and uses a common process of identifying trends towards plausible futures. However, it is unique in its focus on Australian agriculture in connection with targeted digital delivery to that sector (through Digiscape). Our findings echo much of the other literature about future trends and trajectories, including the likely increase of digital technology and the increased pace of change (see below) but also highlight the need for specific thinking about these general issues in the context of what it means to build responsible Australian 'ag-tech' and increase reflexivity in science and digital innovation. In addition, another outcome of these scenarios, which aligns with other foresighting studies, is highlighting the benefit of thinking about these issues for researchers and organisations, and the need to do so at broader and more inclusive scales (Lockie et al., 2020).

5.1. Investing in connectivity and hard and soft infrastructure

Each of the scenarios demonstrated that investment is required to build the capacity for future technology use. The fundamentals of access to internet and infrastructure are a core equity and innovation issue that needs to be addressed (Darnell et al., 2018). In addition to investment in connectivity infrastructure (hard infrastructure) effort needs to be devoted to developing the regulatory environment (Wiseman et al., 2019) and institutional arrangements (soft infrastructure) which govern access to and use of digital technologies and related data in the agriculture sector (Leonard et al., 2017, OECD, 2019). Wiseman et al. (2019) conclude that more open and transparent governance frameworks are needed to better address farmers' concerns over who has access to farm data, who derives the benefits of data sharing as well as privacy concerns.

5.2. Monitoring to understand progress and success

Actively learning from technology use is a key component of Scenario 2 and 4. Digital innovations bring the ability to monitor more on-farm, much more cheaply. There is a significant opportunity for learning (Wolfert et al., 2017). However, the learning needs to be shared in different contexts across industry and society, so that multiple players can benefit, not just those who can more easily capture, aggregate, or analyse data (Evans et al., 2017; van der Burg et al., 2019). Technology may also play a transformative role in how farmers learn, which is strongly peer based (Kernecker et al., 2019).

5.3. Tailoring science and technology outputs to diverse needs and issues

Our scenarios reflect the increase in the availability and affordability of technologies such as sensors is likely to align with monitoring that can be readily tailored to individual farm (and farmer) contexts. However, this will still require support from advisors in many situations (Klerkx and Leeuwis, 2009; Knierim et al., 2017). Knowledge-brokering from advisors will not be separate from considerations of power and access to information, which is unlikely to be evenly distributed (Rose and Chilvers, 2018). Therefore, it is important to consider the politics of access to and control of data and information (Carolan, 2019) and take steps to recognise inequities. There is also opportunity and cause to reflect on power dynamics in terms of linking farm monitoring and progress towards achievement of various national and global targets, such as the SDGs as farmers may play an increasingly important (and scrutinised) role in achieving such targets.

5.4. Supporting innovation and agility in farm business models and value chains

The Innovating scenario highlights how technology provides the potential to allow innovation and agility in farm business models and value chains and thus, increase diversity. Innovative business models may enable the reimagining of value chains, for instance through concepts like the 'circular economy', where waste is converted into different valuable additions to the farm or with further processing into other products (Geissdoerfer et al., 2017). Other studies also foresee considerable change in this area (Scientific Foresight Unit, (STOA), 2016). Experimentation should be encouraged to enable a culture of learning and change, for example allowing flexible policy and financial arrangements that do not regulate the industry unnecessarily before co-innovative opportunities have been explored.

5.5. Investing in human capital and adaptive capacity of farm businesses and rural and regional communities

All of the scenarios highlight the importance of skills and capability development as crucial components of digitalisation. Many farmers are already keen to learn and experiment with new skills (Fielke and Bardsley, 2014). Business training, technological training and a wider range of skills than ever before are now possible in many farm situations. Supporting this trend by updating agricultural education and access to training in a range of ways (not just formal training) is important (Ayre et al., 2019). Similarly, advisors and groups who work with farmers may also need to update their skills and capabilities in order to address the fragmented levels of skills and capabilities to engage with the digital world (Eastwood et al., 2019a). Farmer education is also a key finding of other foresighting groups (EU SCAR, 2015).

5.6. Enhancing new and alternative economic opportunities for farm businesses

The scenarios we explored highlight that demonstration and exploration of potentially novel opportunities for farm businesses will be a core part of many of the scenario narratives described above. This can be supported through technology but as in the recommendation above, will also require dedicated training and development and advisory services to tailor options to farmers needs and objectives (Nettle et al., 2018). Novel job creation is a key factor of other foresighting studies (Scientific Foresight Unit, 2016).

5.7. Responding to societal demand (local and global) for greater transparency, inclusion and accountability

The scenarios each focused on how digital technologies could allow for greater connection between consumers and farmers and greater transparency of product value chains (Jakku et al., 2019) with the potential for both positive (increased trust) and negative (increased competition) responses. This can improve accountability as well as raise awareness in the public about issues, best practices, and more holistic values of the essential services farming provides. This will also feedback into discussion with broader societal perspectives – through NGO agricultural advisory services and social media – that can influence production practices and agricultural policy (OECD, 2019).

5.8. Managing risk and uncertainty

Each of the scenarios explored risk and highlighted how technology might increase risk in some cases (e.g. locked in contracts) and decrease it in others (e.g. data driven decision-making). Technology development creates an environment of change when so much is already uncertain. Techniques to manage risk and uncertainty are necessary to help support decision-making in complex and variable environments (Quigley et al., 2019) and are essential components of technology development, use and training (Kaplan, 2008).

5.9. Supporting collaboration and co-innovation among multiple stakeholders

Trust is increasingly important in each of the future scenarios and one way to increase trust is to be more inclusive. Improved understanding of the implications of trust as agricultural knowledge and advice networks digitalise will be essential (Howells, 2006, Agyekumhene et al., 2018, Klerkx et al., 2019). Collaboration is also a way to share learning. Being aware of changes in knowledge and advice networks and how collaboration partners shift under digitalisation is also important (Jakku et al., 2019; Fielke et al., 2020). A focus on trust (through transparency, inclusivity and appropriate legislation) is also noted in other foresighting processes (e.g. Scientific Foresight Unit, 2016).

5.10. Next steps

Digiscape has made significant attempts to integrate RRI dimensions and while the results are still more at the awareness raising and understanding stages, there have been breakthroughs for different individuals in terms of transformations of thinking in how to develop technology for end users, focusing more on their needs and incorporating their ideas into the process, rather than developing something in isolation and then looking to find a user.

A single workshop is not enough to achieve RRI for a program, but it is the start of a culture shift and the beginning of many more discussions and processes to pause, reflect and critique plausible implications of current work. The scenarios we have developed are stimulants for this type of thinking, and for imagining different futures and desired outcomes with clients and industries in different contexts. Others can use these scenarios to spark similar reflective processes or develop their own. Similarly, the nine points we discuss above are useful prompts for other researchers, advisors and policy makers to guide thinking about social and ethical implications of digital technology, particularly in terms of *who* is being considered and who is excluded, as well as *how* innovation is challenging or reinforcing existing cultural and institutional power arrangements. In the future, foresighting workshops will need to include a broader range of participants, including for example advisors and public and industries themselves and could also be more action oriented, rather than predominantly about building reflexive capacity.

5.11. Reflections and limitations

Foresighting using scenarios linked with Responsible Innovation, or "Responsible foresight" (van der Duin, 2018) has the potential to be an important tool for digital innovation and innovation in agriculture broadly. The workshop led participants to reflect on the innovation process and to acknowledge that certain change is difficult to achieve when embedded within institutions with legacies. Social and ethical considerations still tend to remain on the periphery of what we can directly influence in institutions more focused on products and commercialisation (Glover et al., 2019; Fielke et al., 2018) but the conversations are important to maintain to shift the norms around what is considered and what is able to be influenced.

Based on evaluation feedback collected at the end of the workshop, all the participants thought that the process of thinking about responsible innovation was very important for the organisation and for themselves as individuals and supported the need for increased awareness of the dimensions of responsible innovation in all their work. Some participants were very excited about the process and keen to replicate it with their own teams and industry partners and to continue to reflect on how to shape a more desirable and responsible future.

The participatory foresighting methodology followed here produces different results depending on the participants and the choices they make. For example, the participants here were all researchers, from the same institution, predominantly natural scientists, but also many social scientists. We recognise the limitation of the lack of diversity within our participant group and do not suggest our results are the best or only possible scenarios, but instead aim to encourage others to go through similar reflexive processes to contribute to thinking of plausible future scenarios. We also recognise that due to the rather homogenous group of participants, there may be some views and assumptions that were not challenged, due to the largely similar priorities of the group. This is also in part due to the process we followed building our scenarios from current trajectories, which can entrench certain ideas about continuing rather than challenging the status quo. This was perhaps reflected in the group discussion that more technology and more digitalisation in agriculture is unavoidable, and therefore discussion about whether this trend was 'good' or 'bad' or how it might be averted was limited. The focus of the scenarios was on what unintended impacts likely trends might create and thinking reflexively about how to make innovation more responsible now. Thus, the contribution of our work is to raise awareness, develop capacity and community and begin a cultural shift towards embedding reflexive responsible innovation into organisational research practices.

6. Conclusion

Research organisations should be part of driving socially-responsible and ethical technological change and contributing to more desirable futures. Anticipation of possible futures and thinking about current trajectories are two possible ways to achieve this. This paper presented the steps of preparing for, facilitating, and analysing the results of a foresighting workshop focused on envisioning possible futures for digital agriculture in Australia. Four scenarios based on the axes of resource security and uncertainty and farm business innovation level were worked through by small groups of multi-disciplinary researchers. The four scenarios – named Struggling, Innovating, Surviving and Thriving – described potential futures for Australian agriculture in fifteen years (approximately 2030). The scenarios serve as simple outlines of complex possible realities from which short to medium term inferences relating to digital agriculture can be explored and understood. The different farm business models that were explored in the scenarios highlight opportunities for new and improved decision making at different scales (industry level, business level and individual) and through different methods (new relationships, new technology, new interactions). We believe that agricultural researchers and policy makers need to identify and reflect on the consequences of different trajectories of change and identify ways to work together to influence the future.

The key contribution of this paper was to share insights from a process of foresighting probable digital agriculture futures, with a critical analytic lens, rather than a normative one, in order to reflect on our organisational assumptions and directions. There is an opportunity for other researchers, organisations and the agricultural industry to learn from our approach and to consider 'where we are headed' and how it compares to 'where we want to go'. These questions need to be examined in specific contexts and shared in a global discussion to grow collaboration for socially responsible innovation. Digital technology in agriculture in Australia and around the world has significant and exciting potential to take society in a positive direction, but not without critically and proactively reflecting on how to drive it in a socially desirable and ethical direction. We need to shape the potential of technology by proactively putting people at the centre of design and working together for the best possible outcomes for us all.

Declaration of Competing Interest

The authors received funding from CSIRO Agriculture and Food as part of the Digiscape Future Science Platform and the CSIRO Land and Water as part of the Responsible Innovation Future Science Platform. In the paper we aim to evaluate the work we participated in and to provide insights and recommendations to others working in the space of responsible innovation for the future of agriculture. Reflexivity is a key part of our message.

Acknowledgements

Thanks to all of the participants in the workshop, especially our guest presenter Kelly Rijswijk. Thanks to internal reviewers. Figure 2 developed by Stacey McCormack, McCork Studios.This research was approved by CSIRO's Social Science Human Research Ethics Committee in line with the guideline specified in the (Australian) National Statement on Ethical Conduct in Human Research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2021.103120.

References

ABS, 2018. Agricultural Commodities, Australia - Past and Present Releases. Australian Bureau of Statistics, Canberra. Accessed 25.7.19. http://www.abs.gov.au/AUSSTATS/abs@.nsf/second+level+view?ReadForm&prodno=7121.0&viewtitle=Agricultural%20Commodities,%20Australia~2016-17~Latest~21/05/2018&&tabname=Past%20Future%20Issues&prodno=7121.0&issue=2016a-17&num=&view=&.

AgResearch Limited, 2017. Preparing NZ for shift to digital agriculture. http://www.agresearch.co.nz/news/preparing-nz-for-shift-to-digital-agriculture/.

Agyekumhene, C., de Vries, J.R., van Paassen, A., Macnaghten, P., Schut, M., Bregt, A., 2018. Digital platforms for smallholder credit access: the mediation of trust for cooperation in maize value chain financing. NJAS - Wageningen J. Life Sci. 86–87, 77–88.

Ashworth, P., Lacey, J., Sehic, S., Dowd, A.-M., 2019. Exploring the value proposition for RRI in Australia. J. Respons. Innov. https://doi.org/10.1080/23299460.2019.1603571.

Asveld, L., van Dam-Mieras, R., Swierstra, T., Lavrijssen, S., Linse, K., van den Hoven, J. (Eds.), 2017. Responsible Innovation 3. A European Agenda?. Springer, Switzerland.

Ayre, M., Mc Collum, V., Waters, W., Samson, P., Curro, A., Nettle, R., Paschen, J.A., King, B., Reichelt, N., 2019. Supporting and practising digital innovation with advisers in smart farming. NJAS - Wageningen J. Life Sci., 100302 https://doi.org/10.1016/j.njas.2019.05.001.

Carolan, M., 2018. "Smart" farming techniques as political ontology: access, sovereignty and the performance of neoliberal and not-so-neoliberal worlds. Sociol. Rural. 58 (4), 745–764.

Carolan, M., 2019. Automated agrifood futures: robotics, labor and the distributive politics of digital agriculture. J. Peasant Stud. 1–24.

CSIRO, 2017. The Digiscape Future Science Platform. https://research.csiro.au/digiscape/.

Darnell, R., Robertson, M., Brown, J., Moore, A., Barry, S., Bramley, R., Grundy, M., George, A., 2018. The current and future state of Australian agricultural data. Farm Policy J. 15 (1), 41–50.

De Smedt, P., Borch, K., Fuller, T., 2013. Future scenarios to inspire innovation. Technol. Forecast. Social Change 80, 432–443.

Digital Agriculture Convergence Lab, 2017. #DigitAg. Retrieved from. http://www.hdigitag.fr/en/.

Eastwood, C., Klerkx, L., Nettle, R., 2017. Dynamics and distribution of public and private research and extension roles for technological innovation and diffusion: case studies of the implementation and adaptation of precision farming technologies. J. Rural. Stud. 49, 1–12.

Eastwood, C., Ayre, M., Nettle, R., Dela Rue, B., 2019a. Making sense in the cloud: farm advisory services in a smart farming future. NJAS - Wageningen J. Life Sci. 90–91, 100298 https://doi.org/10.1016/j.njas.2019.04.004.

Eastwood, C., Klerkx, L., Ayre, M., Dela Rue, B.T., 2019b. Managing socio-ethical challenges in the development of smart farming: from a fragmented to a comprehensive approach for responsible research and innovation. J. Agric. Environ. Ethics. https://doi.org/10.1007/s10806-017-9704-5.

EU SCAR, 2015. Agricultural Knowledge and Innovation Systems Towards the Future – A Foresight Paper, Brussels. https://scar-europe.org/images/AKIS/Documents/AKIS_foresight_paper.pdf.

Evans, K., Terhorst, A., Kang, B., 2017. From data to decisions: helping crop producers build their actionable knowledge. Crit. Rev. Plant Sci. 36 (2), 71–88. https://doi.org/10.1080/07352689.2017.1336047.

Fielke, S.J., Bardsley, D.K., 2014. The importance of farmer education in South Australia. Land Use Policy 39, 301–312.

Fielke, S.J., Botha, N., Reid, J., Gray, D., Blackett, P., Park, N., Williams, T., 2018. Lessons for co-innovation in agricultural innovation systems: a multiple case study analysis and a conceptual model. J. Agric. Educ. Ext. 24, 9–27.
Fielke, S., Garrard, R., Jakku, E., Fleming, A., Wiseman, L., Taylor, B., 2019. Conceptualising the DAIS: implications of the 'Digitalisation of Agricultural Innovation Systems' on technology and policy at multiple levels. NJAS - Wageningen J. Life Sci. https://doi.org/10.1016/j.njas.2019.04.002.
Fielke, S., Taylor, B., Jakku, E., 2020. The digitalisation of agricultural knowledge and advice networks: a state-of-the-art review. Agric. Syst. 180, 102763.
Fleming, A., Jakku, E., Lim-Camacho, L., Taylor, B., Thorburn, P., 2018. Is big data for big farming or for everyone? Perceptions in the Australian grains industry. Agron. Sustain. Dev. 38 (24), 23–33. https://doi.org/10.1007/s13593-018-0501-y.
Geissdoerfer, M., Savaget, P., Bocken, N.M., Hultink, E.J., 2017. The circular economy–a new sustainability paradigm? J. Clean. Prod. 143, 757–768.
Glover, D.J., Sumberg, G., Ton, J., Andersson Badstue, L., 2019. Rethinking technological change in smallholder agriculture. Outlook Agric. 48 (3), 169–180.
Gremmen, B., Blok, V., Bovenkerk, B., 2019. Responsible innovation for life: five challenges agriculture offers for responsible innovation in agriculture and food, and the necessity of an ethics of innovation. J. Agric. Environ. Ethics 32 (5–6), 673–679.
Hajkowicz, S., Eady, S., 2015. Rural Industry Futures: Megatrends Impacting Australian Agriculture over the Coming Twenty Years. Rural Industries Research and Development Corporation, ISBN 978-1-74254-811-1.
Hines, A., Zindato, D., 2016. Designing foresight and foresighting design: opportunities for learning and collaboration via scenarios. World Fut. Rev. 8 (4), 180–192.
Howells, J., 2006. Intermediation and the role of intermediaries in innovation. Res. Policy 35 (5), 715–728.
Huberty, M., 2015. Awaiting the second big data revolution: from digital noise to value creation. J. Ind. Compet. Trade 15. https://doi.org/10.1007/s10842-014-0190-4, 35–34.
IoF 2020, 2017. Internet of Food and Farm 2020. Retrieved from. https://iof2020.eu/.
Jakku, E., Taylor, B., Fleming, A., Mason, C., Fielke, S., Sounness, C., Thorburn, P., 2019. "If they don't tell us what they do with it, why would we trust them?" Trust, transparency and benefit-sharing in Smart Farming. NJAS - Wageningen J. Life Sci. https://doi.org/10.1016/j.njas.2018.11.002.
Kaplan, S., 2008. Framing contests: strategy making under uncertainty. Organ. Sci. 19 (5), 729–752.
Kernecker, M., Knierim, A., Wurbs, A., Kraus, T., Borges, F., 2019. Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe. Precis. Agric. https://doi.org/10.1007/s11119-019-09651-z.
Klerkx, L., Begemann, S., 2020. Supporting food systems transformation: the what, why, who, where and how of mission-oriented agricultural innovation systems. Agric. Syst. 184, 102901 https://doi.org/10.1016/j.agsy.2020.102901.
Klerkx, L., Leeuwis, C., 2009. Establishment and embedding of innovation brokers at different innovation system levels: insights from the Dutch agricultural sector. Technol. Forecast. Social Change 76 (6), 849–860.
Klerkx, L., Rose, D., 2020. Dealing with the game-changing technologies of agriculture 4.0: how do we manage diversity and responsibility in food system transition pathways? Glob. Food Security 24, 100347. https://doi.org/10.1016/j.gfs.2019.100347.
Klerkx, L., Jakku, E., Labarthe, P., 2019. A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. NJAS-Wageningen J. Life Sci. 90, 100315.
Knierim, A., Labarthe, P., Laurent, C., Prager, K., Kania, J., Madureira, L., Ndah, T.H., 2017. Pluralism of agricultural advisory service providers – facts and insights from Europe. J. Rural. Stud. 55, 45–58.
Lacey, J., Coates, R., Herrington, M., 2020. Open science for responsible innovation in Australia: understanding the expectations and priorities of scientists and researchers. J. Respons. Innov. https://doi.org/10.1080/23299460.2020.1800969.
Leonard, E., Rainbow, R., Trindall, J., Baker, I., Barry, S., Darragh, L., Darnell, R., George, A., Heath, R., Jakku, E., Laurie, A., Lamb, D., Llewellyn, R., Perrett, E., Sanderson, J., Skinner, A., Stollery, T., Wiseman, L., Wood, G., Zhang, A., 2017. Accelerating Precision Agriculture to Decision Agriculture: Enabling Digital Agriculture in Australia. Cotton Research and Development Corporation, Australia.
Lockie, S., Fairley-Grenot, K., Ankeny, R.A., Botterill, L.C., Howlett, B.J., McBratney, A. B., Probyn, E., Sorrell, T.C., Sukkarieh, S., Woodhead, I., 2020. The Future of Agricultural Technologies. Report for the Australian Council of Learned Academies. www.acola.org.
Merrie, A., Keys, P., Metian, M., Österblom, H., 2018. Radical ocean futures-scenario development using science fiction prototyping. Futures 95, 22–32.
Murphy, C., Nettle, R., Paine, M., 2013. The evolving extension environment: implications for dairy scientists. Anim. Prod. Sci. 53, 917–923.
Nettle, R., Crawford, A., Brightling, P., 2018. How private-sector farm advisors change their practices: an Australian case study. J. Rural. Stud. 58, 20–27.
Nordmann, A., 2014. Responsible innovation, the art and craft of anticipation. J. Respons. Innov. 1 (1) https://doi.org/10.1080/23299460.2014.882064.
OECD, 2019. Digital Opportunities for Better Agricultural Policies. OECD Publishing, Paris. https://doi.org/10.1787/571a0812-en.
O'Malley, A.L., Bronson, K., van der Burg, S., Klerkx, L., 2020. The future(s) of digital agriculture and sustainable food systems: an analysis of high-level policy documents. Ecosyst. Services. 45, 101183.
Oteros-Rozas, E., Martín-López, B., Daw, T., Bohensky, E.L., Butler, J., Hill, R., Martin-Ortega, J., Quinlan, A., Ravera, F., Ruiz-Mallén, I., Thyresson, M., Mistry, J., Palomo, I., Peterson, G.D., Plieninger, T., Waylen, K.A., Beach, D., Bohnet, I.C., Hamann, M., Hanspach, J., Hubacek, K., Lavorel, S., Vilardy, S., 2015. Participatory scenario planning in place-based social-ecological research: insights and experiences from 23 case studies. Ecol. Soc. 20 (4), 32.
Owen, R., Stilgoe, J., Macnaghten, P., Gorman, M., Fisher, E., Guston, D., 2013. A framework for responsible innovation. In: Owen, R., Bessant, J., Heintz, M. (Eds.), Responsible Innovation. Wiley, Chichester, UK, pp. 27–50.
Paschen, J.-A., Reichelt, N., King, B., Ayre, M., Nettle, R., 2017. Enrolling advisers in governing privatised agricultural extension in Australia: challenges and opportunities for the research, development and extension system. J. Agric. Educ. Ext. 23, 265–282.
Phillipson, J., Proctor, A., Emery, S.B., Lowe, P., 2016. Performing inter-professional expertise in rural advisory networks. Land Use Policy 54, 321–330.
Quigley, M.C., Bennetts, L.G., Durance, P., Kuhnert, P.M., Lindsay, M.D., Pembleton, K. G., Roberts, M.E., White, C.J., 2019. The provision and utility of science and uncertainty to decision-makers: earth science case studies. Environ. Syst. Decisions 39, 307–348.
Rijswijk, K., Klerkx, L., Turner, J.A., 2019. Digitalisation in the New Zealand agricultural knowledge and innovation system: initial understandings and emerging organisational responses to digital agriculture. NJAS - Wageningen J. Life Sci. 90–91, 100313 https://doi.org/10.1016/j.njas.2019.100313.
Robertson, M., Keating, B., Walker, D., Bonnett, G., Hall, A., 2016. Five ways to improve the agricultural innovation system in Australia. Farm Policy J. 15, 1–13.
Rose, D.C., Chilvers, J., 2018. Agriculture 4.0: broadening responsible innovation in an era of smart farming. Front. Sustain. Food Syst. https://doi.org/10.3389/fsufs.2018.00087.
Rutten, M., Achterbosch, T.J., de Boer, I.J.M., Crespo Cuaresma, J., Geleijnse, J.M., Havlik, P., Heckelei, T., Ingram, J., Leip, A., Marette, S., van Meijl, H., Soler, L.-G., Swinnen, J., van't Veer, P., Vervoort, J., Zimmerman, A., Zimmerman, K.L., Zurek, M., 2018. Metrics, models and foresight for European sustainable food and nutrition security: the vision of the SUSFANS project. Agric. Syst. 163, 45–57.
Scientific Foresight Unit, (STOA), 2016. Precision Agriculture and the Future of Farming in Europe, Annex 1: Technical Horizon Scan. https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016b)581892(ANN)_EN.pdf.
Stilgoe, J., Owen, R., Macnaghten, P., 2013. Developing a framework for responsible innovation. Res. Policy 42, 1568–1580.
van der Burg, S., 2014. On the hermeneutic need for future anticipation. J. Respons. Innov. 1 (1), 99–102. https://doi.org/10.1080/23299460.2014.882556.
van der Burg, S., Bogaardt, M.-J., Wolfert, S., 2019. Ethics of smart farming: Current questions and directions for responsible innovation towards the future. NJAS - Wageningen J. Life Sci. 90–91 https://doi.org/10.1016/j.njas.2019.01.001.
van der Duin, P., 2018. Toward "Responsible Foresight": developing futures that enable matching future technologies with societal demands. World Futures Rev. https://doi.org/10.1177/1946756718803721.
Voros, J., 2003. A generic foresight process framework. Foresight 5 (3), 10–21.
Wilsdon, J., 2014. From foresight to hindsight: the promise of history in responsible innovation. J. Respons. Innov. 1 (1), 109–112. https://doi.org/10.1080/23299460.2014.885176.
Wiseman, L., Sanderson, J., Zhang, A., Jakku, E., 2019. Farmers and their data: an examination of farmers' reluctance to share their data through the lens of the laws impacting smart farming. NJAS - Wageningen J. Life Sci. 90–91, 100301 https://doi.org/10.1016/j.njas.2019.04.007.
Wolfert, S., Lan, G., Verdouw, C., Bogaardt, M.J., 2017. Big data in smart farming—a review. Agric. Syst. 153, 69–80. https://doi.org/10.1016/j.agsy.2017.01.023.