# *Agriculture 4.0: broadening responsible innovation in an era of smart farming*

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# Agriculture 4.0: Broadening Responsible Innovation in an Era of Smart Farming

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Agriculture is undergoing a new technology revolution supported by policy-makers around the world. While smart technologies, such as Artificial Intelligence, robotics, and the Internet of Things, could play an important role in achieving enhanced productivity and greater eco-efficiency, critics have suggested that the consideration of social implications is being side-lined. Research illustrates that some agricultural practitioners are concerned about using certain smart technologies. Indeed, some studies argue that agricultural societies may be changed, or "re-scripted," in undesirable ways, and there is precedent to suggest that wider society may be concerned about radical new agricultural technologies. We therefore encourage policy-makers, funders, technology companies, and researchers to consider the views of both farming communities and wider society. In agriculture, the concept of responsible innovation has not been widely considered, although two recent papers have made useful suggestions. We build on these interventions by arguing that key dimensions of responsible innovation—anticipation, inclusion, reflexivity, and responsiveness—should be applied to this fourth agricultural revolution. We argue, however, that ideas of responsible innovation should be further developed in order to make them relevant and robust for emergent agri-tech, and that frameworks should be tested in practice to see if they can actively shape innovation trajectories. In making suggestions on how to construct a more comprehensive framework for responsible innovation in sustainable agriculture, we call for: (i) a more systemic approach that maps and attends to the wider ecology of innovations associated with this fourth agricultural revolution; (ii) a broadening of notions of "inclusion" in responsible innovation to account better for diverse and already existing spaces of participation in agri-tech, and (iii) greater testing of frameworks in practice to see if they are capable of making innovation processes more socially responsible.

**Keywords: agri-tech, artificial intelligence, responsible innovation, inclusion, publics, smart farming, sustainable intensification, technology**



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## THE FOURTH AGRICULTURAL REVOLUTION

Some would argue that the "fourth agricultural revolution" (Lejon and Frankelius, 2015) or "agriculture 4.0" (Bartmer in Frankelius et al., 2017) has already begun. Each previous agricultural revolution was radical at the time—the first representing a transition from hunting and gathering to settled agriculture, the second relating to the British agricultural revolution in the 18th century, and the third relating to post-war productivity increases associated with mechanization and the Green Revolution in the developing world. While technological innovation is thus not new to agriculture, emergent technologies, such as the Internet of Things, Cloud Computing, robotics, and Artificial Intelligence (AI), have the potential to change farming beyond recognition (Wolfert et al., 2017), hence the shift toward agriculture 4.0 (see section Technological Re-scripting of Society).

There is certainly not a shortage of uses for these technologies; smart farming approaches are being used to increase the precision of fertilizer, pesticide, and herbicide application (Carolan, 2016). Smart farming approaches, including the use of Microsoft's Cortana Intelligence Suite, are currently being used to determine optimal planting dates for crops around the world, such as in India and Colombia (López and Corrales, 2018). Unmanned aerial vehicles, or drones, are being used to aid weed identification (Lottes et al., 2017), and robots are helping farmers to milk their cattle (Driessen and Heutinck, 2015) and remove weeds (Fennimore, 2017).

Signals from policy and the private sector suggest that there will be growing momentum behind agriculture 4.0. The UK Secretary of State for Business has recently announced a £90 million investment to generate a "technical revolution" to transform food production, which would put the UK at the "forefront" of forward-thinking sustainable agriculture (Department for Business Energy Industrial Strategy et al., 2018). Greece has announced the digitisation of agriculture, with big data and the internet of things, placed at the forefront of farming (Euractiv.com, 2018). Much of this investment would be made in developing smart technologies, the use of which has been projected to grow exponentially in the next 10 years.[1] Similar agri-tech revolutions have been predicted globally, such as in Japan (Japan Times., 2017), other parts of Asia ("Second Green Revolution," The Economist, 2014), Ireland (Irish News, 2017), and Australia (Financial Review, 2016).

Prominent concepts within sustainable agriculture, particularly "sustainable intensification" (SI), are also embracing emergent smart technologies. Since appearing as a concept in the 1990s, SI has been defined in various ways (Gunton et al., 2016), and it remains contested. Smith et al. (2017) trace the origins of SI to the work of Pretty (1997) whose work sought to establish collaborative projects between researchers and farmers for the benefit of productivity, profitability, the environment, and society. These pillars of sustainability are still commonly included in definitions of SI; for example, Gunton et al. (2016) consider it to be a process by which productivity is increased without damaging the environment, and where possible, also generating social, and environment benefits. It is also associated with eco-efficiency (Gadanakis et al., 2015), as a trade-off between economic and ecological performance, and may be considered as a goal, a process, or a set of principles (see Firbank et al., 2018). Regardless of its definition, the idea of sustainable intensification is becoming ever more popular in research and policy. Reviews of how the idea is evolving are finding that it is embracing technological approaches to achieving its goals (Mahon et al., 2017; Smith et al., 2017), while attempts to define a series of standard SI practices also favor high-tech, smart approaches (Dicks et al., 2018).

In light of increased policy attention on funding smart agri-tech, and prominent research and policy concepts such as sustainable intensification which embrace smart approaches, we consider how the fourth agricultural revolution can be socially responsible. This is an especially pertinent question given that new innovations have the potential to change the nature of farming in a radical way relative to past technology revolutions (Nordmann, 2014). As outlined in the following section, some of the smart technologies may have undesirable impacts on-farm, as well as to wider society. They are thus likely to be resisted in a similar way as technologies like genetic modification have been (Macnaghten, 2015). In this perspective, we encourage policy-makers, technology companies, funders, and researchers to develop, test, and refine, responsible innovation frameworks to guide the development of smart farming technologies.

The work of Eastwood et al. (2017) on responsible innovation in smart dairying, and associated suggestions by Bronson (2018), provide a useful starting point for us to think about how to develop a plan. Yet, both of these contributions focus on translating existing concepts into an agricultural context without seeking to develop them further. In addition, there is little evidence that responsible innovation frameworks make a difference in practice. Here, we discuss how we can build a more comprehensive framework for responsible innovation, which is appropriate to the wider contexts of sustainable agriculture and learns from its application in practice.

## TECHNOLOGICAL RE-SCRIPTING OF SOCIETY

We do not dispute that smart farming technologies can play an important role in sustainable agricultural production, although the need for a technical revolution would be reduced if there were societal changes elsewhere.[2] The potential for improved productivity is likely to provide social benefits (e.g., greater food/income security), and environmental benefits, as less land is put into production. Precision agriculture, in combination with more productive crop varieties/livestock and the use of decision support systems to foster evidence-based decision-making (see Rose et al., 2016; Rose and Bruce, 2017), can lead to the smarter use of inputs with greater rewards. Furthermore, robotic technology could provide benefits to farming communities in compensation for lost labor, which is becoming a serious problem in the developing world[3] as the population migrates to urban centers (Struik and Kuyper, 2017). Technology-based SI could enhance social sustainability by supporting the profitability of farming businesses, and by providing different high-tech jobs.

Despite the potential benefits of a new technology revolution, the dominant techno-centric narratives associated with smart

[1] AI is projected to be globally worth $2.6bn in 2025 up from $518.7 million in 2017 (Farminguk, 2017).

[2] E.g. reducing over-consumption, Satterthwaite (2009); especially of environmental damaging foods, Woolston (2014); less food waste; equitable food distribution in the developing world, Sen (1999).

[3] And in the developed world too e.g., the potential loss of migrant agricultural labor in the UK after Brexit.

farming should be treated with caution (Whitfield et al., 2018). Technology is a double-edged sword because it has the potential to cause harm, as well as provide benefit (Stilgoe et al., 2013). In agriculture, we have witnessed several controversies over the use of chemicals, including DDT (Carson, 1962) and the ongoing issue of neonicotinoids (Dicks, 2013), as well as intense debates over genetic modification (Macnaghten, 2015). We have seen, for example, how previous technology revolutions have caused mass rural unemployment (Goodman et al., 1987). The potential side-effects of smart technology like AI are being seriously considered now in policy (e.g., House of Lords., 2018).

Studies have shown that technology shapes agricultural society at several scales; on-farm, and across farming and non-farming communities (Eastwood et al., 2017). Rose et al. (2018a) argued that the requirement to use decision support tools would change, or "re-script," the ways in which farmers interacted with their land (see also Higgins et al., 2017 on how technology "orders" agricultural society). Other studies have looked at the impacts of robotic milking technologies on-farm (Holloway et al., 2014; Bear and Holloway, 2015; Driessen and Heutinck, 2015; Holloway and Bear, 2017). Driessen and Heutinck (2015) argued that robotic technologies could change what it is to be a "good" farmer. The introduction of technologies to aid livestock management will mean that farming becomes less "hands-on" and this may change the nature of stockmanship and the relationship between animals and farmers (Driessen and Heutinck, 2015; Holloway and Bear, 2017). Bear and Holloway (2015) argue that such technologies could create new rural subjectivities, in other words what it is to be a farmer or advisor.

Negative impacts on-farm also influence imaginaries at wider scales. Rose et al. (2018a) found evidence that the requirement to use emergent technologies are mismatched with the expectations of farmers about what farming is. Wolf and Wood (1997) argued that a focus on precision farming legitimates a narrative of chemical-based agriculture, and Wolfert et al. (2017) suggested that the emphasis on big data could further move decision-making power from the farmers into the hands of private companies who have control over such data (see also Carbonell, 2016). In terms of wider impacts on society, the use of emergent technologies may not chime with societal expectations of sustainable food production. Using GM and other emerging technologies as analogs, it is likely that similar controversies will occur during this technology revolution if the views of publics are not adequately addressed (Macnaghten and Chilvers, 2014). It is true that some smart technologies, such as precision agriculture, have so far been embraced with little societal "backlash," yet it is argued that large-scale use of AI, robotics, and other emergent innovations have the clear potential to cause unintended, unforeseen, and unwanted societal consequences. Indeed, Hartley et al. (2016) use the same precedent of the GM controversy to argue for the responsible governance of agricultural biotechnology.

We have been here before. Past controversies have reinforced the notion that science and technology are socially and politically constituted, and that emergent technologies can be met with societal resistance (Stilgoe et al., 2013; Asveld et al., 2015). Since there is often an institutional void for new technologies (Hajer, 2003), it can be difficult to know how to govern implementation. Yet, past experiences highlight the peril of ignoring risks, the danger of becoming "seduced" by innovation (Nordmann, 2014), and the fallacy of not seeking the views of publics in an effort to construct a shared vision of the future.

## BROADENING RESPONSIBLE INNOVATION FOR THE FOURTH AGRICULTURAL REVOLUTION

The concept of responsible innovation should underpin the fourth agricultural revolution; simply, ensuring that innovations designed to improve productivity and/or eco-efficiency also provide social benefits, meet human needs and are socially responsible. Noting that the concept is not well-developed in agriculture, Eastwood et al. (2017) sought to develop a framework for responsible innovation in the context of smart dairy farming, while suggesting its possible applicability to other agricultural contexts (also see Bronson, 2018 who interprets the framework of Eastwood et al. in a Canadian context). Eastwood et al. (2017) build on the framework by Stilgoe et al. (2013) by suggesting mechanisms to guide technology development organized around four dimensions—anticipation, inclusion, reflexivity, and responsiveness.

To summarize the useful suggestions by Eastwood et al. (2017), it is argued that the impacts of technological innovation need to be anticipated through various techniques, such as foresight exercises and scenario building. In the context of the fourth agri-tech revolution, responsible innovation would mean anticipating impacts at all scales: on-farm, across farming landscapes, throughout the food chain, as well as considering effects on rural communities and publics as a whole. Sometimes these impacts may be difficult to anticipate, but Nordmann (2014) argues that the precautionary principle should guide actions. Eastwood et al. (2017) also argue that the responsible innovation process should seek to include all affected actors, such as technology companies, farmers, and local communities. Since sustainable food production has impacts across society, inclusion should be considered holistically. Indeed, we argue that inclusion should underpin all aspects of responsible innovation frameworks since anticipation, reflexivity, and responsiveness, cannot be undertaken without the inclusion of diverse voices.

In addition, Eastwood et al. (2017) also suggested that agri-tech innovation projects should adopt structures to guide reflexivity, in other words there should be many opportunities to assess whether mutually beneficial trajectories are being followed. If not, then it is argued that innovation projects should be able to respond to challenges and be adaptable. Agri-tech innovators should also be able to respond quickly to problems caused by a new technology.

While these signs of progress are to be encouraged, and the recent interventions of Eastwood et al. (2017) and Bronson (2018) have made good progress in directly translating principles from the existing responsible innovation literature to smart farming, we argue that this agenda needs to go further. There are signs that responsible innovation is being taken more seriously in policy and funding circles.[4] But, the specificities of the smart farming revolution create challenges for responsible innovation frameworks that have largely been developed in other fields, and have not been tested in practice in an agricultural context. For the purposes of the current discussion we highlight three main areas where we feel further work is needed.

## Responsible Innovation Systems

First, is the need to develop a more comprehensive and systemic approach to responsible innovation for the fourth agricultural revolution. The proposals by Eastwood et al. (2017) and Bronson (2018) mainly focus on possible tools and actions to enhance responsible innovation at the level of "R&D projects" and discrete technological innovations in the areas of smart dairying and smart agriculture. This partly reflects the frame of established responsible innovation frameworks which have been, for good reason, drawn to focus attention on controversial emerging technologies where one might expect to see significant negative consequences and questions of responsibility. We suggest, however, that in addition the frame of responsible innovation needs to be broadened. The fourth agricultural revolution is associated with many innovations in sustainable agriculture, some emerging and some more established, which are interacting and co-evolving in a wider *"ecology of innovation"*; or, as Klerkx et al. (2012) argue, throughout "agricultural innovation systems" in which many different actors (e.g., farmers, advisors) are influential. Such an *ecology of innovation* includes "big" emerging smart technologies (e.g., AI, Internet of Things, Cloud Computing, robotics), as well as "smaller" farmer and/or community-led innovations (Waters-Bayer et al., 2015; e.g., Tambo and Wünscher, 2017) through to more mundane or low-tech sustainable agriculture solutions (e.g., Kerr, 2015). In the rush to embrace smart agri-tech, we are in danger of forgetting the wider network of other innovations that play an important role, but may also affect societies in different ways.

We should ensure that the concept of responsible innovation is not attached solely to "big" emergent smart technologies. This would help to deliberately foreground questions over possible *alternatives* and the *directionality* of innovation pathways (Leach et al., 2010) in addressing problems of sustainable agriculture, which have been shown time and time again to be associated with deeply held public concerns about emerging science and technology (Macnaghten and Chilvers, 2014). In addition, a more systemic perspective would enable responsible innovators to consider interrelations between multiple co-existing innovations in sustainable agriculture. This could promote the cultivation of distributed responsibilities across wider innovation ecologies, as opposed to thinking about particular smart technologies in isolation. The more systemic thinking we advocate here demands methods capable of mapping multiple innovations—and tracking their emergence and interactions—across fields of innovation in sustainable agriculture. It also facilitates (and in turn demands) more strategic levels of governance and coordination between public, private, and civil society actors involved in steering innovations in the agri-tech revolution toward more socially responsible and humane ends.

## Broadening Notions of 'Inclusion'

Second, there is a need to broaden notions of "inclusion" in responsible innovation to attend to the diverse ways that societal actors are already engaging with smart farming innovations on their own terms. This is a particular blind spot in frameworks for responsible innovation and an important omission in the proposals for "inclusion" put forward so far in relation to smart farming. Agricultural research is still dominated by top-down, non-inclusive approaches, and rarely includes relevant stakeholders, such as farmers, at an early stage (Macmillian, 2018). The power to shape research trajectories, including innovation design, rests with research institutions, and project narratives are rarely opened up in consultation with stakeholders (Paul, 2018; Pimbert, 2018; Rose et al., 2018b). Responsible innovation encourages us to think of what technologies are for, who they are serving, and who is driving the process (Crossley, 2018). Inclusion has sometimes been regarded as problematic by innovators, who see public involvement as potentially increasing time to market and releasing sensitive information publicly (Blok et al., 2018; Purwins and Schulze-Ehlers, 2018). But, research has also shown that open innovation and responsible innovation can be complementary (Long and Blok, 2018).

In order to include all relevant actors and address the "gap in comprehensive inclusion" in smart dairy farming, Eastwood et al. (2017) propose a range of tools and procedures including citizen forums, "workshops," "surveys," internet forums, interest group representation on steering committees and "user-centered design." Bronson (2018) echoes these procedures for including "rights holders" and advocates deliberative processes to open up democratic debate over the social and ethical implications of smart agriculture technologies. Such moves are important and necessary to open up inclusive debate and that might socially shape these emerging technologies. However, as Chilvers and Kearnes (2016) have argued, notions of participation and inclusion in responsible innovation need to go further. These existing proposals for smart agriculture fit in with what they identify as a dominant imagination of inclusion in science and innovation—i.e., a drive to invite all relevant actors into inclusive fora and collectives to socially shape specific projects or innovations that are the target for responsible innovation. Chilvers and Kearnes (2016) suggest that while this is important, there is a need to also open up to wider "ecologies of participation" and already existing forms of societal engagement around these very same projects and innovations, which are legitimate sources of public concern, values, and actions that would otherwise be excluded from processes of responsible innovation. Such moves resist new forms of inclusion in responsible innovation succumbing to an "public acceptance" model of innovation, where the onus is on innovators to change public opinion to accept technologies, rather than making technological trajectories more responsive to the needs of society (see Gupta et al., 2012).

This calls for a new range of tools and methods in responsible innovation of smart farming and beyond, which are

[4](E.g., underpinning research in Horizon 2020 projects https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation and decision-making within the Engineering and Physical Sciences Research Council in the UK https://epsrc.ukri.org/index.cfm/research/framework/).

capable of mapping across diverse forms of societal engagement with emerging technologies and across innovation systems. This can draw on a number of promising mapping methods that are emerging in the social sciences and humanities, including digital methods (Rogers, 2013), issue mapping (Marres, 2015), systematic mapping (Chilvers et al., 2018) and forms of comparative case study and meta-analyses (Macnaghten and Chilvers, 2014). Such methods can produce new forms of social intelligence about diverse forms of societal and farmer engagement with smart farming, for example: more formal spaces like farmer networking events, farmer clusters, demonstration farms, demonstration test catchments, and consultations, through to a multitude of informal spaces where farmers and publics are interacting with sustainable agriculture including interactions with vets, advisors, seed merchants, and livestock markets, discussions on social media, more low-tech forms of agricultural practice, community-based agri-environment solutions, and so on. This forms a key part of a more comprehensive responsible innovation framework for the fourth agricultural revolution capable of mapping existing spaces of participation, finding out what innovations and ideas are being considered there, what alternative public concerns are being mobilized, and so on. This is not only a question of inclusion, but can also enhance reflexivity, anticipation, and responsiveness in responsible innovation frameworks. The field of sustainable agriculture can learn from other domains where such mapping approaches have been developed, and new institutional architectures of observatories have recently been proposed, for the responsible development of low carbon energy transitions (Chilvers et al., 2017) and gene editing (Burall, 2018; Jasanoff and Hurlbut, 2018).

### Responsible Innovation in Practice

Third, research needs to assess whether responsible innovation frameworks make a difference in practice. This is a point that Macnaghten (2016, 282) makes in the context of genetic modification. He argues that responsible innovation frameworks must "demonstrate their capacities to shape existing technological trajectories." We find little, if any, evidence that responsible innovation frameworks have been tested in practice in the context of smart farming, before then being refined on the basis of feedback. If we do not know whether and how they affect the innovation process—in other words forcing innovators to *anticipate* problems caused by their product, to *respond* to emergent problems, to *include* diverse publics in an attempt to accommodate concerns, and lastly to adopt a *reflexive* and flexible approach to development—then they serve little practical purpose. We argue, therefore, that the development of a refined responsible innovation framework for smart farming in the context of sustainable agriculture could be undertaken concurrently with practical trials. For example, prototypes of the framework could be introduced into innovation teams to see whether and how design practices are influenced, before then being refined based on observation and feedback from the innovators themselves. This iterative approach, which could also involve an assessment of how innovators themselves come to "know" diverse publics, would make a valuable contribution both to the broad field of responsible innovation as well as to the application of its principles to the fourth agricultural revolution.

## CONCLUDING REMARKS

In the context of the fourth global agri-tech revolution, we should ask what the direction of travel is, and whether we want to go there as a society. This question is topical in the UK with current large investments in smart agri-tech, but also in many other countries across the world where smart agri-tech is also being prioritized. In light of controversial agri-tech precedents, it is beyond doubt that smart farming is going to cause similar controversy. Smart farming can of course provide enormous benefits to sustainable agriculture, increasing the efficiency and productivity of food creation, as well as potentially providing environmental and social benefits. This fourth agri-tech revolution also, however, brings potential environmental, ethical, and social costs. While the frameworks of responsible innovation proposed by Eastwood et al. (2017) and Bronson (2018) certainly need to be applied to the agri-tech revolution, we argue that they do not go far enough. Rather, further work is needed to map the wider ecology of innovations associated with the agri-tech revolution, including within ideas such as sustainable intensification, as well as the formal and informal spaces of participation where farmers, advisors, publics, and other key practitioners are sharing their views, hopes and concerns. Ultimately, a framework for the responsible innovation of smart technologies needs to prove capable of socially shaping innovation trajectories. This requires us to test responsible innovation frameworks in practice to determine whether they are capable of changing the trajectories of innovation design. Responsible innovation frameworks should allow questions to be led, and opened out, by those people who are (likely to be) affected by the use of new technologies; including farmers, advisors, vulnerable communities and wider publics. They should be able to question and contest whether benefits to productivity should supersede social, ethical, or environmental concerns, and be able to convince innovators and policy-makers to change the directions of innovations for sustainable agriculture.

## AUTHOR CONTRIBUTIONS

DR led the writing of this manuscript and JC contributed several sections of the final text.

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The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.