Agriculture 4.0: making it work for people, production, and the planet

Abstract

Three tenets of sustainable intensification should guide the fourth agricultural revolution: people, production, and the planet. Thus far, narratives of agriculture 4.0 have been predominately framed in terms of benefits to productivity and the environment with little attention placed on social sustainability. This is despite the fact that agriculture 4.0 has significant social implications, both potentially positive and negative. Our viewpoint highlights the need to incorporate social sustainability (or simply 'people') into technological trajectories and we outline a framework of multi-actor co-innovation to guide responsible socio-technical transitions. Through the greater inclusion of people in agricultural innovation systems guided by responsible innovation principles, we can increase the likelihood of this technology revolution achieving social sustainability alongside benefiting production and the environment.

Keywords: agri-tech; co-innovation; multi-actor; social sustainability; sustainable intensification; technology

Introduction

Emergent technologies, such as Artificial Intelligence, robotics, big data, the Internet of Things, gene editing, and drones, are being presented as solutions to challenges associated with food production (Benke and Tomkins, 2017; de Clercq *et al.*, 2018; NFU, 2019; DW, 2019). The associated digitalisation of all farming systems is often presented as being 'inevitable' (The Telegraph, 2018) and is predominantly justified by the need to feed a growing human population (Hickey *et al.*, 2019). Smart technologies may increase yields and reduce inputs (*production*) (*ibid)*, whilst in many cases, reducing labour requirements. Furthermore, they may improve environmental health by enabling the production of more food on existing land, thus sparing further land conversion (Phalan *et al.*, 2011; Balmford *et al.*, 2018), also increasing eco-efficiency (*planet*) (Schieffer and Dillon, 2015).

A lack of attention has been given to the social impacts of new technologies in debates around the fourth agricultural revolution. Social aspects are notably absent from major reports (e.g. de Clercq *et al.*, 2018; NFU, 2019), something which has been acknowledged in a number of recent papers (e.g. Bronson, 2018; Eastwood *et al.* 2017). This is problematic since the benefits of a technology revolution will not be uniformly shared (Rose and Chilvers, 2018).

We argue here that the marginalisation of social sustainability (but see Wynne-Jones *et al.* (2019) on the importance of social sustainability in the context of collaboration) is a significant shortcoming and suggest that the fourth agricultural revolution (or 'agriculture 4.0') should be guided by the concept of sustainable intensification (SI), holistically defined, in order that benefits are provided to people, production, and the planet. Though the definition is contested (Garnett and Godfray, 2012), the concept of SI identifies three hallmarks of sustainable food production: people (social), production (of food), and the planet (environment) (Garnett *et al.*, 2013; Gunton *et al.*, 2016; Royal Society, 2009). SI and technology are closely linked, the latter being seen as a key way of achieving the former (Dicks *et al.*, 2019). Existing debates about agriculture 4.0 are rarely framed in the context of SI as many papers, policy documents, and speeches fail to address all three components. Indeed, work on SI itself has widely failed to give sufficient emphasis to social sustainability (Lobley *et al.*, 2018).

Of course, social sustainability includes people at all points in the food system, including consumers, but here our focus is more on those involved in agricultural production. If we neglect an investigation of the social context of agriculture, then three major challenges present themselves, which we outline in more detail below. After highlighting the value of social sustainability when considering the agri-tech revolution, we consider how new innovations could be subjected to a 'SI stress test' to ensure that all aspects of sustainability (people, production, and the planet) are considered during design and implementation.

Challenge 1 Dominant narratives of food insecurity

Justifications for agri-tech are predominantly built on the idea that we need to produce more food to feed a rapidly growing population (Hickey *et al.*, 2019). Furthermore, innovation pathways are increasingly being used by governments to address large-scale issues such as climate change and poverty (Schot and Steinmuller, 2018). Whether a lack of food production is the *main* problem can be questioned as food insecurity is caused by a lack of access to food for certain people (Sen, 1999; Nally, 2016). Unequal distribution of food caused by gender and economic inequality (amongst other forms) is the major cause of food insecurity in both developing countries and within unequal developed societies. Promoting technology as the solution can seem easier to powerful actors who wish to divert attention away from social inequality (Nally, 2016). Hence, we can easily be seduced by a techno-centric solution to a 'simple' problem. As a result, resources may be wasted if technologies are developed that do not provide positive social outcomes and thus fail to achieve SI which must provide benefits to all people.

Challenge 2 Losers of the fourth agricultural revolution

If the fourth agricultural revolution proceeds as predicted by some, then the nature of farming systems will inevitably change beyond recognition[1] (Fielke *et al.*, 2019). Several areas of potential controversy have been identified, including:

[1] Such changes are not necessarily negative (see Rose and Chilvers, 2018), but based on the relatively small amount of research addressing the social and ethical implications of the fourth agricultural revolution there are likely to be a significant number of losers who are receiving little to no consideration.

- *Changing nature of farm work* - the fourth agricultural revolution may improve some aspects of farming life, for example through reducing manual labour, but for some it will also change life on the farm in undesirable ways (Rose *et al.*, 2018). Research has demonstrated the importance of physical work, traditional farm practices and embodied experiences to farmers' engagement with, and understanding of, their land and environment (Carolan, 2008). Increased technology use could result in the marginalisation of experiential knowledge and a disconnect between the farmer and the landscape. This may lead to loss of enjoyment and work-satisfaction and exacerbate existing high levels of mental health problems prevalent in the sector (Lobley *et al.*, 2018). Changes to work practices may also challenge some of the core tenets of farming cultures and identities, which we know to be central to farmers' sense of self and wellbeing (Burton *et al.*, 2008). These consequences of changing farm workflows could lead to many farmers (particularly small farmers) leaving the industry. However, few decision-makers are envisioning what a world looks like with fewer farmers and bigger farms both from farmers' and rural communities' perspectives and the views of the general public surrounding aesthetics and cultural traditions.
- *Data ownership, lack of trust, and power imbalances* - A significant amount of data will be collected by new technologies, but ownership of this data and how it will be used and stored remains a concern (Regan, 2019; Wiseman *et al.*, 2019). Data produced by commercial machinery could be used to target farmers with products and to consolidate precious decision-making information in the hands of already powerful companies (Bronson, 2019; Lioutas *et al.*, 2019; Regan, 2019). A lack of trust may ensue (Jakku *et al.*, 2019). There is also the risk that developing countries involved in agriculture 4.0 may not receive the benefits experienced by the foreign investors who

run farming enterprises or by the wealthier countries which import the food (D'Odorico and Rulli, 2013).

- *Employment* - Nally (2016) questions the need for labour-saving technologies in parts of the world suffering from high unemployment. An agri-tech revolution will undoubtedly create jobs, but these will not suit many existing farm workers who are already marginalised and under-appreciated by society (Rotz *et al.*, 2019). It is not only workers such as seasonal pickers who might be fearful of their role in a digitalised work environment; Eastwood *et al.* (2019) consider how farm advisors might continue to provide value in an era of smart farming where machines increasingly make autonomous evidence-based decisions without human involvement.

The public may become dissatisfied with the way in which food is produced as other potential social implications, including concerns over perceived animal welfare impacts from the introduction of robotic milking techniques (Bear and Holloway, 2019), may result in public scrutiny. Both farmers and the public have also expressed scepticism towards UAVs due to concerns about drones capturing images of their work and private lives (DW, 2019), a process that Zuboff (2019) has termed 'surveillance capitalism' – the quest for powerful companies to monitor, predict, and control people. There may also be public concern surrounding the safety of autonomous farming vehicles.

Challenge 3 Resistance to new technologies

Cases of limited acceptance of agricultural technologies are not uncommon, resulting in a lack of decision support system uptake (Rose *et al.*, 2016), resistance to genetic modification technologies (Macnaghten, 2016), and societal resistance to insecticides (e.g. neonicotinoids) and other chemicals (e.g. glyphosate) (Dicks *et al.*, 2013). If there is a lack of trust in new technologies, widespread concern about private enterprises benefitting, worries about impacts on employment and the nature of farming and rural communities, and public suspicion of the way in which food is being produced, then resistance is more likely. It seems apparent that if the fourth agricultural revolution works for people, it becomes more feasible that the whole of society may embrace future agri-tech trajectories, which simultaneously allows us to maximise the promised production and environmental benefits (Jakku *et al.*, 2019).

Responsible sustainable intensification

Here, we propose a framework to govern agri-innovation which uses responsible innovation principles (Eastwood *et al.*, 2017; van der Burg *et al.*, 2019) and recognises that innovation occurs within systems comprised of multiple actors (Klerkx and Leeuwis, 2009; Klerkx *et al.*, 2010). Involving these multiple actors is not a pre-requisite to success; as well as being time consuming, this may create uncertainty if roles and objectives are not clear from the outset (Botha et al., 2017). If managed carefully, however, this can enhance the inclusiveness of the innovation process (see Fielke et al., 2018). Innovation is responsible if (1) diverse stakeholders, including consumers, are included in projects to *anticipate* possible impacts of new technology (both positive and negative), (2) the innovation system can *respond* to problems created by technology, (3) it manages to *include* all actors in order to achieve legitimacy, and (4) innovators listen to all stakeholders and respond by being *reflexive* and are willing to change technology trajectories (Stilgoe *et al.*, 2013). Our inclusive five-step framework of co-innovation (see Botha et al., 2014; Rijswijk *et al.*, 2018) can guide the fourth agricultural revolution so that it works for people, production, and the planet. It does so by placing people and social sustainability at the forefront of agri-tech futures.

1. Have open conversations about the future of agriculture (inclusion)

A range of techniques are required to reach out across agricultural innovation systems to collect the views of every stakeholder. We recognise the challenge of identifying the myriad of different stakeholders affected by agricultural technologies from primary producers, farm workers, and advisers through the supply chain to manufacturers, retailers, consumers, and rural communities. Yet, it should be possible to conduct stakeholder-mapping starting with the farmer's 'ring of confidence' (AIC, 2013) before expanding outwards to consider who will be affected by this innovation (see Reed *et al.*, 2009 for a stakeholder mapping method). Whilst it will rarely be possible to include everyone, a co-innovation process should always attempt to include stakeholders beyond the usual suspects that tend to drive innovation processes. Doing so will create a set of priorities which has not just been driven by policy-makers and the research/innovation community. Initial questions should be broad, asking participants to share their visions for the future and to identify challenges for food production. Typically, when governments or innovators have consulted publics, they have used closed questions through public forums, online consultations, or community meetings (Rose and Chilvers, 2018). For example, online consultations and public forum exercises on agriculture in the UK regularly engage the usual suspects – the same innovative farmers, middle-class members of the public, well-resourced trade unions and NGOs – on predetermined leading questions (e.g. what are the barriers to technology use?) rather than bigger questions about what the problem itself entails, which may not lead to a technology-based answer. These techniques therefore rarely include the crucial views of marginalised individuals, such as less technology-focused or geographically isolated farmers who might possess differing opinions.

Engagement of publics in agri-food issues can be much bolder. Much can be learned from scholarly attempts to 're-make' participation (Chilvers and Kearnes, 2016). Many of the more deliberative engagement techniques identified by Chilvers and Kearnes (2016) work on the premise that a range of stakeholders beyond the usual suspects need to be involved at an early stage, sharing decision-making power. Deliberative workshops might be one method to engage particular communities, for example through anonymous voting[2] to decide upon a mutually agreed future. Attention must be placed on ensuring that engagement methods occur at a time suited to the audience, which might be at a specific time in the farming calendar (or in the day) and there must be some incentive for attendance. More innovative engagement techniques include citizen juries (see e.g. Fish *et al.*, 2014), in which a representative range of individuals are brought together to achieve consensus. Interactions seen within the online farming press and social media can be extremely insightful as users often exhibit strong opinions when conversing online due to the online disinhibition effect (Suler, 2004). We should note, however, that many marginalised (older/rural) farmers may not have access to the internet or ICT skills and so will be unable to contribute to online debate (Farrington *et al.*, 2015).

2. Decide whether issues are techno-centric or not

If engagement exercises are carried out effectively, a list of key questions, challenges, and ideas for the future of agriculture will be gathered, though we note that these may be conflicting (Fielke et al., 2020; Klerkx and Rose, 2020; Klerkx et al., 2019). The first task is to decide which challenges demand a techno-centric solution (this could be scoped out in multi-disciplinary workshops involving the natural and social sciences, and the arts and humanities). Shortlisting of challenge types could be achieved relatively easily through collaborative workshops attended by trans-disciplinary groups of policymakers, academics, and innovators with expertise in food production, the environment, and society. For those challenges that need a technology-based solution, incentives are then required to stimulate innovation and a suite of key technologies could be developed.

[2] For example as used with farmers in: Fish *et al.* (2012) A license to produce? Farmer interpretations of the new food security agenda, *Journal of Rural Studies*, 29, 40-49.

3. Anticipate production, environmental, and social implications of new innovations (anticipation and inclusion)

At this stage, a list of key technologies for solving particular challenges should be in development. For example, if technology to further improve the precision application of chemicals was identified as a priority the first step would be to convene the same network of policy-makers, diverse academics, and innovators and ask those with technological expertise to explain how the underpinning technology works without using jargon. The claims of technologists can then be interrogated to assess how the product might contribute to all aspects of SI – people, production, and the planet. The research community is often able to anticipate environmental and production impacts as these can be tested rigorously and scientifically. However, social impacts, which are often complex and difficult to generalise, must also receive significant consideration. This will require the same participatory techniques as stage one: citizen juries, public forums, and other consultation methods in which the purpose of innovations are explained to diverse publics (including farmers, advisers, rural communities) before allowing participants to articulate their views on how these innovations might change the nature of farming, rural communities, and the nature of food production. These impacts may be positive or negative, and trade-offs are likely to be required in every case, but, crucially, technologies should only be prioritised if they are able to demonstrate probable benefits to the SI agenda. Step three might take time but may, in fact, reduce adoption time in the long run if more relevant technologies are developed.

4. Listen and change (reflexivity)

Stakeholder engagement exercises serve little purpose if policymakers and innovators fail to change course after hearing societal views. A period of reflection is vital in which the potential for technologies to achieve all aspects of SI are further interrogated (Fielke *et al.*, 2017;

Rijswijk *et al*., 2015). Those innovations which fail to satisfy the stress test, perhaps because they are likely to harm social sustainability, should receive less policy and private support (or may be regulated against). This may require legislative change for privately supported technology and/or alterations in guidelines for publicly funded innovation projects.

5. Maintain a responsive system (responsiveness, reflexivity)

Stages 1-4 have helped to identify a list of technologies which are relevant to real-world problems faced by farmers and wider society and which are most likely to achieve SI, including providing social benefits. The final stage is implementation to ensure benefits are realised. A supportive institutional framework, led by government[3], and ensuring that there are joined-up advisory stems for farmers to draw on is a prerequisite to hold the network together, preventing the fragmentation which currently plagues innovation approaches (Klerkx *et al.*, 2012). A long-term commitment is needed from policymakers and other senior actors in driving innovation systems. Ultimately, those who introduce innovations to (or ideally with) farmers need to ensure that responsive systems are implemented to correct errors and to prevent repetition of any potential controversies (e.g. safety issues/animal welfare). The government's role does not stop once innovations are adopted; a continued period of reflection is required, which will require updates to legislation, guidelines, and possible support for various technologies in the form of skills training, improved infrastructure, or perhaps funding (although we recognise the role of the market). Legislation and regulation can support or restrict the demand for certain technologies, but usually lags behind development. This process may be repeated at regular intervals as new food challenges and technologies appear.

Conclusion

[3] We acknowledge that this might be idealistic, particularly if government pursue short-term win-wins and attempt to win the race towards ever-more sophisticated technological innovation. If we are to ensure that stages 1-5 are undertaken, there must be clear leadership from government.

The potential benefits for productivity and the environment of the fourth agricultural revolution will be tempered if social benefits are not evenly shared. The concept of SI and its three components is vital; it is essential that decision-makers support people to thrive in a different agricultural system and that social issues relating to new technologies are resolved. Without attention to such issues, new technology may create more social problems than it solves (Schot and Steinmuller, 2018), raising the question of whether this transition to agriculture 4.0 is truly justified. We hope that this viewpoint fosters more interest in the social and ethical implications of the fourth agricultural revolution and consequently results in more research activity to understand how society can be better included in technology trajectories. The framework above, which encourages a multi-actor approach to agri-innovation, is one step towards determining a responsible course for the fourth agricultural revolution to ensure that benefits are provided for people, production, and the planet.

References

AIC. (2013) The Value of Advice Report. [Online]: http://www.agindustries.org.uk/latest-documents/value-of-advice-project-report [Accessed 10/05/2020].

Balmford, B., Green, R.E., Onial, M., Phalan, B., Balmford, A. (2018) How imperfect can land sparing be before land sharing is more favourable for wild species?. *Journal of Applied Ecology*, **56**, 73-84.

Bear, C., and Holloway, L. (2019) Beyond resistance: geographies of divergent more-than-human conduct in robotic milking. *Geoforum*, **104**, 212-221.

Benke, K., and Tomkins, B. (2017) Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy*, **13**, 13-26.

Botha, N., Klerkx, L., and Small, B. (2014) Lessons on transdisciplinary research in a co-innovation programme in the New Zealand agricultural sector. *Outlook on Agriculture,* **43**(3), 219-223.

Botha, N., Turner, J. A., Fielke, S. and Klerkx, L. (2017). Using a co-innovation approach to support innovation and learning: Cross-cutting observations from different settings and emergent issues. *Outlook on Agriculture*, **46**(2), 87-91.

Bronson, K. (2018) Smart farming: including rights holders for responsible agricultural innovation. *Technology Innovation Management Review* **8**, 7-14.

Bronson, K. (2019) Looking through a responsible innovation lens at uneven engagements with digital farming. *NJAS – Wageningen Journal of Life Sciences*, **90-91**, 100294.

Burton, R.J.F., Kuczera, C., and Schwarz, G. (2008). Exploring farmers' cultural resistance to voluntary agri-environmental schemes. *Sociologia Ruralis*, **48**, 16-37.

Carolan, M. S. (2008) 'More-than-representational knowledge/s of the countryside: How we think as bodies'. *Sociologia Ruralis*, **48** (4),408-422.

Chilvers, J., and Kearnes, M. (2016) *Remaking Participation: Science, Environment and Emergent Publics*. Abingdon: Routledge.

De Clercq, M., Vats, A., and Biel, A. (2018) Agriculture 4.0: The future of farming technology. *World Government Summit*. [Online]: *https://www.decipher.com.au/wpcontent/uploads/2019/02/Agriculture-4.0-The-Future-of-Farming-Technology.pdf* [Accessed 31/07/2019].

Dicks, L. (2013) Bees, lies and evidence-based policy. *Nature*, **494**, 283.

Dicks, L. V., Rose, D. C., Ang, F., Aston, S., Birch, N. E. *et al.* (2019). What agricultural practices are most likely to deliver "sustainable intensification" in the UK?. *Food and Energy Security*, **8**(1), e00148.

D'Odorico, P., and Rulli, M.C. (2013) The fourth food revolution. *Nature Geoscience*, **6**, 417-418.

DW. (2019) Next generation farming: How drones are changing the face of British agriculture. [Online]: https://www.dw.com/en/next-generation-farming-how-drones-arechanging-the-face-of-british-agriculture/a-49243454 [Accessed 01/08/2019].

Eastwood, C., Klerkx, L., Ayre, M., and Dela Rue, B. (2017) Managing socio-ethical challenges in the development of smart farming: from a fragmented to a comprehensive approach for responsible research and innovation. *Journal of Agricultural and Environmental Ethics*, **32**, 741-768.

Eastwood, C., Ayre, M., Nettle, R., and Dela Rue, B. (2019) Making sense in the cloud: Farm advisory services in a smart farming future. *NJAS – Wageningen Journal of Life Sciences*, **90-91**, 100298.

Farrington, J., Philip, L., Cottril, C., Abbott, P., Blank, G., and Dutton, W.H. (2015) Twospeed Britain: rural internet use. [Online]: https://ssrn.com/abstract=2645771 [Accessed 31/07/2019].

Fielke, S., Nelson, T., Blackett, P., Bewsell, D., Bayne, K., Park, N., *et al.* (2017) Hitting the bullseye: Learning to become a reflexive monitor in New Zealand. *Outlook on Agriculture*, **46**, 117-124.

Fielke, S. J., Botha, N., Reid, J., Gray, D., Blackett, P., Park, N., and Williams, T. (2018). Lessons for co-innovation in agricultural innovation systems: a multiple case study analysis and a conceptual model. *The Journal of Agricultural Education and Extension,* **24**(1), 9-27.

Fielke, S. J., Garrard, R., Jakku, E., Fleming, A., Wiseman, L., and Taylor, B. M. (2019) Conceptualising the DAIS: Implications of the 'Digitalisation of Agricultural Innovation Systems' on technology and policy at multiple levels. *NJAS – Wageningen Journal of Life Sciences,* **90-91**, 100296.

Fielke, S., Taylor, B., and Jakku, E. (2020). Digitalisation of agricultural knowledge and advice networks: A state-of-the-art review. *Agricultural Systems*, **180,** 102763.

Fish, R. Winter, M. Chadwick, D. Hodgson, CJ. Oliver, DM. and Heathwaite, L. (2014) Employing the Citizens' Jury technique to elicit reasoned public assessments of environmental risk: insights from a recent inquiry into microbial watercourse pollution, *Journal of Environmental Planning and Management*, **57**(2), 233-253.

Garnett, T., and Godfray, C. (2012) Sustainable intensification in agriculture: Navigating a course through competing food system priorities. *Food Climate Research Network and The Oxford Martin Programme on the Future of Food*, University of Oxford, UK.

Garnett, T., Appleby, M.C., Balmford, A., Benton, T.G., Bloomer, P., Burlingame, B., *et al.* (2013) Sustainable intensification in agriculture: premises and policies. *Science*, **341**, 33-34.

Gunton, R.M., Firbank, L.G., Inman, A., and Winter, D.M. (2016) How scalable is sustainable intensification? *Nature Plants*, **2**, 16065.

Hickey, L.T., Hafeez, A.N., Robinson, H., Jackson, S.A., Soraya, C.M. Leal-Bertioli, Tester, M., *et al.* (2019) Breeding crops to feed 10 billion. *Nature Biotechnology*, **37**, 744-754.

Jakku, E., Taylor, B. R., Fleming, A., Mason, C., Fielke, S., Sounness, C., Torburn, 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 Journal of Life Sciences*, **90-91**, 100285.

Klerkx, L. and Leeuwis, C. 2009. Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector, *Technological Forecasting and Social Change* **76**(6), 849-860.

Klerkx, L., Aarts, N., and Leeuwis, C. (2010) Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment, *Agricultural Systems* **103**(6), 390-400.

Klerkx, L. and 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?. *Global Food Security*, **24**, 100347 .

Klerkx, L., Jakku, E., and Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and T agriculture 4.0: New contributions and a future research agenda. *NJAS – Wageningen Journal of Life Sciences*, **90 – 91**, 100315.

Lioutas, E. D., Charatsari, C., La Rocca, G., and De Rosa, M. (2019). Key questions on the use of big data in farming: An activity theory approach. *NJAS – Wageningen Journal of Life Sciences*, **90-91**, 100297

Lobley, M., Winter, M., and Wheeler, R. (2018) *The changing world of farming in Brexit UK - perspectives on rural policy and planning*. CRC Press, Routledge, 1-246.

Macnaghten, P. (2016). Responsible innovation and the reshaping of existing technological trajectories: the hard case of genetically modified crops. *Journal of Responsible Innovation* **3**, 282–289.

Nally, D. (2016). Against food security: On forms of care and fields of violence. *Global Society* **30**, 558-582.

NFU (2019) The future of food 2040. [Online]: https://www.nfuonline.com/nfu-online/news/the-future-of-food-2040/ [Accessed 31/07/2019].

Phalan, B., Onial, M., Balmford, A., and Green, R.E. (2011) Reconciling food production and biodiversity conservation: land sharing and land sparing compared. *Science*, **333**, 1289-1291.

Reed, M., Graves, A., Dandy, N., Posthumus, H., Hubacek, K. *et al.* (2009) Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management*, **90**(5), 1933-1949.

Regan, Á. (2019(. 'Smart farming' in Ireland: A risk perception study with key governance actors, *NJAS – Wageningen Journal of Life Sciences*, **90-91**, 100292.

Rijswijk, K, Bewsell, D, and Small, B. (2015). Reflexive monitoring in New Zealand: evaluation lessons in supporting transformative change. *Evaluation Journal of Australasia,* **15**(4):38-43.

Rijswijk, J., Bewsell, D., O'Callaghan, M., and Turner, J.A. (2018) The next generation of biopesticides: institutional barriers and enablers to co-innovation in a science and commercialisation programme. *Rural Extension and Innovation Systems Journal*, **14**, 52-61.

Rose, D. C., Morris, C., Lobley, M., Winter, M., Sutherland, W. J., and Dicks, L. V. (2018) Exploring the spatialities of technological and user re-scripting: the case of decision support tools in UK agriculture. *Geoforum* **89**, 11-18.

Rose, D. C., Sutherland, W. J., Parker, C., Lobley, M., Winter, M., Morris, C., *et al.* (2016) Decision support tools for agriculture: towards effective design and delivery. *Agricultural Systems* **149**, 165-174.

Rose, D.C., and Chilvers, J. (2018) Agriculture 4.0: Broadening responsible innovation in an era of smart farming. *Frontiers in Sustainable Food Systems*, **2**, 87.

Rotz, S., Gravely, E., Mosby, I., Duncan, E., Finnis, E., Horgan, M. *et al.* (2019) Automated pastures and the digital divide: How agricultural technologies are shaping labour and rural communities, *Journal of Rural Studies*, **68**, 112-122.

Royal Society (2009) Reaping the benefits: Science and the sustainable intensification of global agriculture. The Royal Society. London, UK.

Schieffer, J., and Dillon, C. (2015) The economic and environmental impacts of precision agriculture and interactions with agro-environmental policy. *Precision Agriculture*, **16**, 46-61.

Schot, J., and Steinmueller, W. E., (2018). Three frames for innovation policy: R&D, systems of *innovation and transformative change*, *Research Policy*, **47**(9), 1554-1567.

Sen, A. (1999) *Development as Freedom*. Oxford; New York, NY: Oxford University Press.

Stilgoe, J., Owen, R., and Macnaghten, P. (2013) Developing a framework for responsible innovation. *Research Policy* **42**, 1568-1580.

Suler, J. (2004) The online disinhibition effect. *Cyberpsychology and Behaviour*, **7** (3), 321-326.

The Telegraph (2018) How Britain is using technology to lead a new farming revolution. [Online]:https://www.telegraph.co.uk/technology/2018/12/08/britain-using-technologylead-new-farming-revolution/ [Accessed 31/07/2019].

van der Burg, S., Bogaardt, M-J., and Wolfert, S. (2019) Ethics of smart farming: Current questions and directions for responsible innovation towards the future. *NJAS – Wageningen Journal of Life Sciences*, **90-91**, 100289

Wiseman, L., Sanderson, J., Zhang, A., and 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 Journal of Life Sciences*, **90-91**, 100301

Wynne-Jones, S., Hyland, J. Williams, P., and Chadwick, D. (2019) Collaboration for sustainable intensification: the underpinning role of social sustainability. *Sociologia Ruralis,* **60**(1), 58-82.

Zuboff, S. (2019) *The Age of Surveillance Capitalism: The Fight For A Human Future At The New Frontier Of Power*. Profile Books Ltd. London, UK.