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Social and ethical considerations for agricultural robotics

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Abstract

The scaling of agricultural robotics could help us to achieve sustainable agricultural transitions around the world, solving production, environmental, and socio-political challenges. Yet, for all the promises, there are social and ethical aspects to consider before pursuing pathways towards development and implementation. This chapter uses a responsible innovation framework to anticipate the possible challenges involved in the scaling of agricultural robotics, as well as how to include a wide range of stakeholder views. We discuss which stakeholders should be included in setting trajectories for agri-robotics, as well as how to engage harder to reach voices in a meaningful way. We then turn to how these stakeholder views can be reflexively incorporated into responsive practices, such as standards and codes of practice, to mitigate against some of the potential negative impacts of robotics.

Keywords: anticipation; ethics; inclusion; participation; reflexivity; responsible innovation; responsiveness.

1. Introduction

This chapter explores the social and ethical implications of scaling agricultural robotics. Despite the many promises offered by robots, a large number of social science studies have highlighted their potential to create winners and losers, which complicates the notion that their use will usher in a triumphant fourth agricultural revolution (see reviews by Klerkx *et al.*, 2019; Fielke *et al.*, 2020; also van der Burg *et al.*, 2019). Below, we use a responsible innovation framework to frame discussion of these debates (see e.g. Bronson, 2019; Eastwood *et al.*, 2019;

Rose and Chilvers, 2019; Regan, 2019). Responsible innovation contains four components (Stilgoe *et al.*, 2013) - *anticipation, inclusion, reflexivity, responsiveness* - and methods for agriculture specifically have been developed by Eastwood *et al.* (2019). We explore the social and ethical implications of agricultural robotics, and more importantly, what we can do to include and listen to a wide range of stakeholders when developing and scaling this technology. When listening to these stakeholders, we should be open to considering alternative visions for the future of agriculture. These could range from the dismissal of robotics as a solution all the way through to an uncritical scaling of existing robots, as well as other states in between, such as changing current approaches to the design and scaling of robotics.

2. Responsible robotics: anticipating impacts

In this section, we focus on anticipating or foresighting the effects of agricultural robotics on people, production and the planet; in other words, what impacts can we foresee, both positive and negative, from the scaling of robots. Foresighting exercises more generally have been conducted for digital agriculture (e.g. Ehlers *et al.*, 2022; Fleming *et al.*, 2021), but exercises for robotics have been limited to perspectives, rather than building on empirical data. For all their promises, agricultural robotics and their enabling technologies, such as Artificial Intelligence, may be a double-edged sword. Daum (2021), for example, argues that robots could lead us to ecological utopia or dystopia depending on how and why they are incorporated into agricultural production systems. Recent scholarship in this area from Sparrow and Howard (2021), Rose *et al.*, (2021), Daum (2021), Ryan *et al.* (2022), Ryan (2022), amongst other discussions of the ethics of robots and artificial intelligence (AI) in non-agricultural settings (e.g. Winfield, 2019), highlight the need for responsible development.

There are precedents in agriculture to learn from when it comes to the side-effects of innovation. At first, we celebrated the rise of modern machinery, such as tractors, as a progressive step away from horse-drawn or human-powered equipment. We praised the value of insecticides, fungicides, and fertilisers, as ways of increasing productivity. We promoted the use of genetic modification to boost yields and cut input costs. We glorified the so-called Green Revolution as bringing modern seed varieties and other technologies to boost yields in the developing world. Yet, despite their obvious benefits, all four examples have caused controversy. Modern large, fossil-fuel guzzling machinery has contributed to atmospheric pollution and soil compaction, chemicals from DDT and neonicotinoids have contributed to a so-called 'Silent Spring' (Carson, 1962) by killing pollinators and polluting rivers, and GM crops were banned in some parts of the world due to a public backlash. The Green Revolution has been criticised for its negative social impacts, as some people benefited more than others (Shiva, 2016; Kumar *et al.*, 2017). None of these precedents should stop us from making transitions in agriculture. Transitions are always normative and disruptive (de Boon *et al.*, 2022a, b), and there are winners and losers from the status quo. However, responsible innovation asks us to foresee potential negative consequences and take steps to minimise them.

The social science aspects of digital agricultural technologies has been growing in recent years (Klerkx *et al.,* 2019; Fielke *et al.,* 2020) illustrating their potential to create social and ethical problems. These include issues of power - for example, the inability of small-scale farmers to invest in new technologies and the fact that digitalisation tends to favour larger-scale farmers (Bronson and Sengers, 2022), the greater ability of existing powerful companies to set trajectories (Birner *et al.*, 2021; Duncan *et al.*, 2021), or the unequal ownership, use and privacy of data collected from a farm (Wiseman *et al.*, 2019). Concerns also include precision technologies causing further intensification of farming, including larger herds of animals made possible by individual monitoring which could create welfare issues associated with overcrowding (Schillings *et al.*, 2021); the capacity of the existing workforce to adapt to new conditions (Rotz *et al.*, 2019), including advisers (Charatsari *et al.*, 2021); a reduction in farmer autonomy (Brooks, 2021; Duncan *et al.*, 2021); and lack of trust in new technologies (Jakku *et al.*, 2019).

With the precedents in mind, as well as the wider critiques of digitalisation, a diagram by Rose *et al.*, (2021) summarised potential positive and negative impacts of autonomous robotics in agriculture, building on the work of Sparrow and Howard (2021). This is not replicated here, but Table 1 presents an overview of ten ethical concerns (see Ryan, 2022 for more), with additional insights from subsequent scholarship by Daum (2021), Streed *et al.* (2021), Tzachor *et al.* (2022), Ryan (2022), Rose and Bhattacharya (2023) and Tamirat *et al.* (2023). We also draw insights from a white paper led by the Agri-EPI Centre and "Hands Free Farm" (2022), which covered issues of health and safety, cybersecurity, connectivity, data ownership and trust. The risks associated with AI in agriculture are considered important by policy-makers, including in a European Union Joint Research Centre document, which discussed its advantages and disadvantages (Loudjani *et al.*, 2020). The benefits and risks of agricultural automation was also the subject of the FAO's State of Food and Agriculture report in 2022

(FAO, 2022). By mapping the AI in agriculture literature, Ryan (2022) was able to show how 11 overarching ethical principles were discussed, finding that least mentioned areas were transparency, dignity and solidarity.

Table one: Ten prominent ethical concerns for agricultural robotics

Theme	**Positive impacts**	**Negative impacts**	**Further information**
Trust and data	Robotics could allow more data to be collected to improve trust in the supply chain	AI lacks emotive state to be trusted and farmers may not understand how it works or how data is used	Rose and Bhattacharya (2023) Ryan (2022) Tzachor *et al.* (2022)
Health and safety	Robots could replace dull, dirty, dangerous jobs and reduce already high levels of farm injury	Robots could injure workers or the public accessing farmland (or near farmland)	Agri-EPI Centre/Hands Free Farm (2022) Rose and Bhattacharya (2023) Tamirat *et al.* (2023)

Cybersecurity	Provides skilled jobs for cybersecurity experts	Robots could be hackable and present a security risk	NCC Group (2019) Sparrow and Howard (2021) Agri-EPI Centre/Hands Free Farm (2022)
Employment	Robots can fill labour shortages and attract skilled workers	Robots could displace labour and the workforce might not be able to retrain	Rotz *et al.* (2019)
Energy Use	Robots could run on renewable energy	Material required to build robots could be unsustainable	Streed *et al.* (2021) Pearson *et al.* (2022)
Economics and performance	Robots could reduce input costs	Robots may only be investable for richer farmers They may lack reliability	Rose *et al.* (2021) Rose and Bhattacharya (2023) Tamirat *et al.* (2023)

			Sparrow and Howard (2021)
Loss of farmer control	Robots can assist farmers in doing manual tasks	Robots could reduce the autonomy of a farmer	Rose *et al.* (2021) Ryan (2022)
Connectivity	N/A	Robots may not work in areas of poor connectivity widening the digital divide	Agri-EPI Centre/Hands Free Farm (2022) Rose and Bhattacharya (2023)
Animal welfare	Robotic milking collects data to allow monitoring of individual animals for health and welfare	Robots could lead to larger herd sizes or the further objectification of animals	Schillings *et al.* (2021)
Ecological utopia or dystopia?	Robots could allow more targeted and precise use of chemicals (reduced inputs)	Robots could further intensify production systems and facilitate existing models of damaging large-scale agriculture	Daum (2021) Sparrow and Howard (2021)

	Robotic UVC disease treatment could reduce chemical usage Small robots could facilitate agroecological systems		

There will be spatial differences across the world for these social and ethical challenges. For example, we know that many parts of the developing world suffer from an intense digital divide (also present in many developed nations to a lesser extent); whereby rural farmers do not enjoy 3G, 4G or 5G coverage, or if they do, data is unaffordable (Mehrabi *et al.*, 2021). Poorer regions of the world, as well as those places lacking digital skills (including in cybersecurity), will be less able to take advantage of some robotic solutions. Furthermore, many parts of the developing world in particular do not suffer from a rural labour shortage, and so the rise of robotics could be a greater threat to livelihoods here. These ethical challenges are thus place dependent and there are no one-size-fits-all solutions.

We have little empirical data of farmers encountering these challenges in practice since many autonomous robotic technologies are not implemented at scale. One useful proxy where autonomous robotics, albeit in a fixed form, has been rolled out at scale is robotic milking machines. Research on the impacts of these machines can help us to understand the potential social and ethical challenges that will be encountered in the further scaling of autonomous milking, as well as field robotics. Evidence of outcomes reinforces the concept of robotic technology as a double-edged sword. Whilst farmers have reported improved job satisfaction and more flexible lifestyles, improved animal welfare and profitability (Hansen *et al.*, 2020), and better working conditions including for workers with disabilities (Barrett and Rose, 2020), there have also been changes to the farm industry. In places where there has been widespread scaling, smaller farms have closed and the structure of the industry has moved towards a model of fewer, larger farms (Vik *et al.*, 2019). Concerns have been raised about effects on the human-animal relationship as farmers spend less time with their stock, potentially raising welfare issues and reducing enjoyment of the job (Bear and Holloway, 2019). Farmers report being more stressed due to being overwhelmed with the amount of data that the robots are collecting

(Barrett and Rose, 2020). With the potential side-effects of agricultural robotics in mind, it is important to take steps to include stakeholders in development and implementation, as well as to translate their views into responsive practices.

3. Inclusion for responsible agricultural robotics

Here, we discuss the inclusion strand of a responsible innovation framework. The white paper by the Agri-EPI Centre and "Hands Free Farm" (2022) on the future of agricultural robotics called for greater inclusion of stakeholders. Several participatory methods are highlighted by Eastwood *et al.* (2019) in their framework of responsible innovation in agriculture, whilst Rose and Chilvers (2018) urge us to open-up conversations to question underlying assumptions, rather than simply being guided by a user acceptance lens. Activities such as public dialogues and deliberative exercises can open-up avenues for greater engagement (Stilgoe et al, 2013; Rose and Chilvers, 2018).

3.1 How do we achieve inclusion with participatory methods?

Inclusion has been identified as a clear point of emphasis for many of the most well-known frameworks for participation (Bell and Reed, 2021). However, definitions of inclusion across frameworks can differ greatly. Arnstein's classic typology (1969) is a seminal work in participation, characterising levels of participation as rungs of a ladder. In this work, success is measured by the empowerment of citizens to be involved in decision-making, with their role ranging from full power to drive decision-making and trajectories (citizen control) through to having no power at all and being 'manipulated' in a tokenistic participation exercises. The idea of a spectrum of participation has been adapted by the 'Think Local Act Personal Partnership'[1] (Figure 1). Here, stakeholders can play a leading role in setting research questions, methodologies, and directions (co-production, co-design) or be tokenistically included in a sham consultation process in which key decisions have already been made (coercion). In order for innovation to be responsible, inclusion must be substantive (Bronson, 2019).

[1] https://www.thinklocalactpersonal.org.uk/_assets/Resources/Coproduction/LadderOfParticipation.pdf

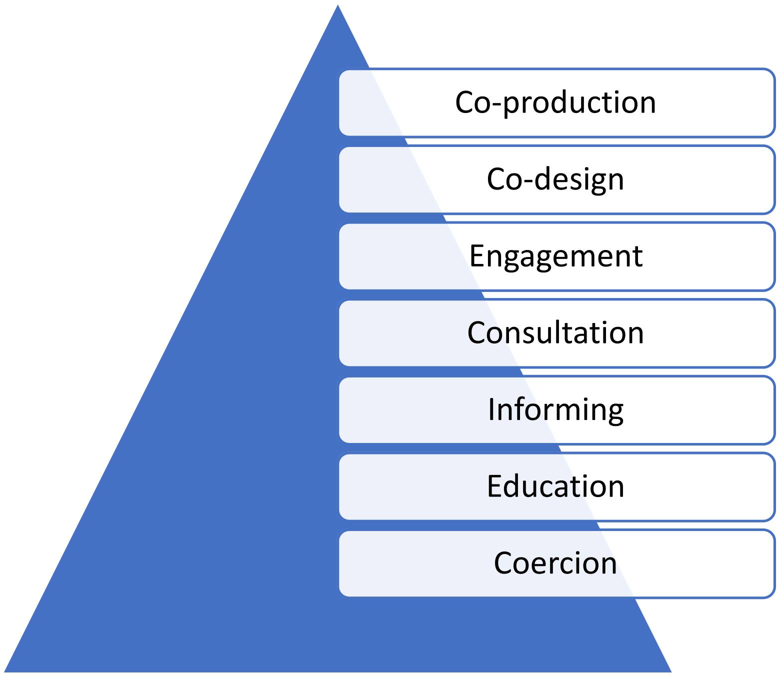

Figure 1: Ladder of participation adapted by the 'Think Local Act Personal Partnership'. Inclusion is more substantive the further up the pyramid.

Other models of participation, such as the *Split Ladder* (Hurlbert and Gupta, 2015) and the *Tree of Participation* (Bell and Reed, 2021), can also guide efforts to make inclusion more substantive. Key principles for co-production or other forms of substantive inclusion are: early and continued engagement of stakeholders; all affected stakeholders are engaged with, stakeholders have decision-making power; conflicts between stakeholders are well managed; trajectories are open to change; and two-way dialogue is established throughout.

More recently, Chilvers and Kearnes (2015) identify inclusion as an aspect of a residual realist approach, and advocate for more reflexivity, diversity, and responsibility as a move beyond participatory approaches which may have previously closed down forms of inclusion. But, there are challenges in doing participation. The first such challenge is how to ensure that 'inclusion' within a participatory exercise is truly inclusive. In examples such as the study of Bavarian farmers in section 3.2 (Spykman *et al.*, 2021), the authors identified a barrier to inclusivity via the self-selecting nature of participants. This highlights a challenge that is particularly prominent for agriculture – how can innovators and developers ensure that inclusion is truly inclusive in a system with so many diverse stakeholders? In agriculture, there are a vast number of possible stakeholders - farmers, farm workers, industry members, governments, rural communities, consumers. There is heterogeneity within these broad groups;

e.g. large/small farmers, rich/poor, digitally skilled/unskilled, varying within regions and across countries. The agricultural sector is one in which everybody has a stake – we all need to eat. Based on this, there will always be fierce debate and discussion over who should be included in any participatory exercise. Answering this question is one of the key problems to be solved in making inclusion truly inclusive.

Participatory approaches have been criticised for failing to engage with wider groups of stakeholders (Cleaver, 1999; Chilvers and Kearnes, 2015), and this issue is particularly striking in the agricultural sector. Approaches must start with a stakeholder mapping exercise (Figure 2) to determine who is affected by the issue and who has the most influence to effect change, although the latter should not restrict the involvement of less powerful stakeholders who may be more likely to lose from disruption. Before starting stakeholder engagement, stakeholder groups and individuals should be laid out on the matrix. The most important axis relates to how far stakeholders are affected by the decision (interest) – in farming, this will certainly be farmers, farm advisers, and others in the farming community, but also likely consumers and others in the supply chain. None of these stakeholders should be excluded, but we know that some often are, for example farm workers (Burch and Legun, 2021). Also, there is a need to be wary of including too many high influence, high interest stakeholders (top right) as compared to the high interest, low influence group (bottom right) as this could reinforce power inequalities and make participation less inclusive. Only the bottom left segment could be excluded, although decisions on the level of participation may be determined by the level of time and resources.

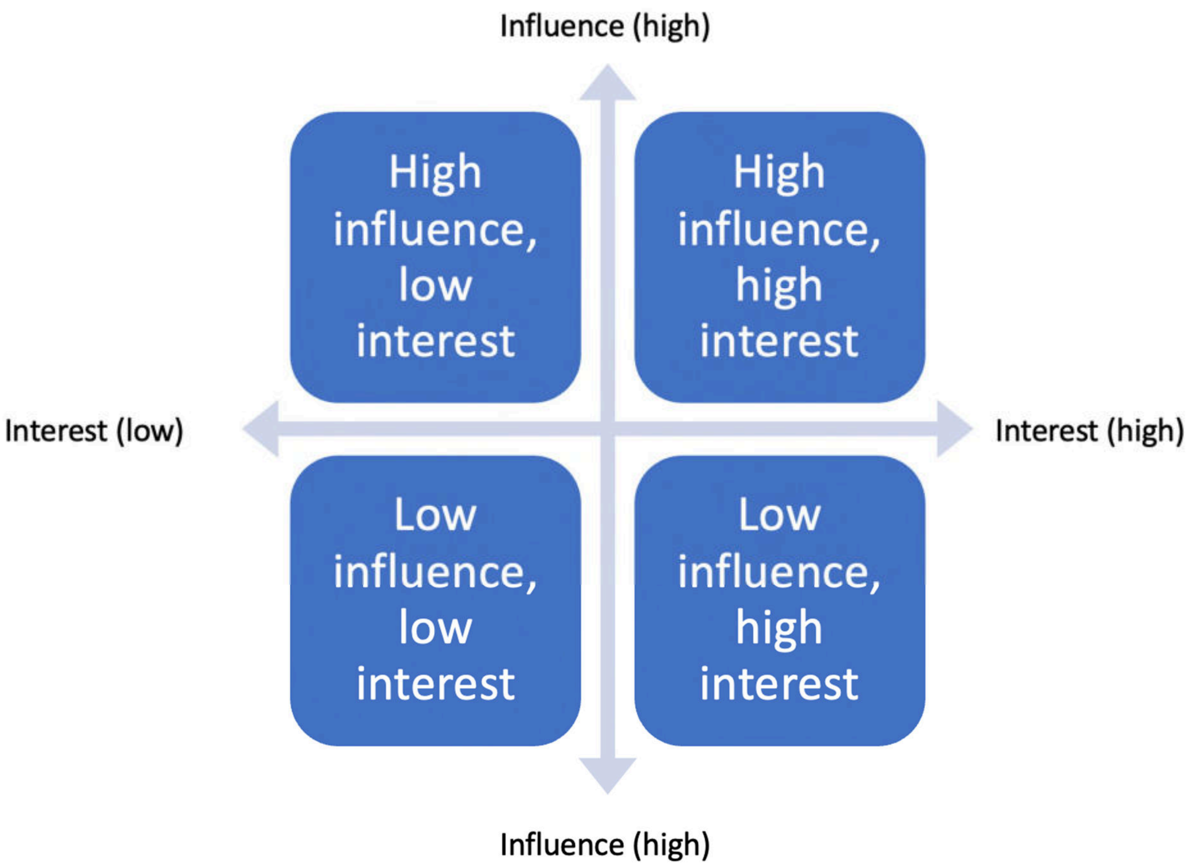

Figure 2: Matrix to guide stakeholder mapping

Engaging hard to reach stakeholders is a challenge (e.g. bottom right), but these people must be included in order for innovation to be inclusive. In agriculture, Hurley *et al.* (2022) identified why some farmers can be harder to reach, as a result of a digital divide, lack of time, lack of trust in government, and other business factors. They suggested a number of methods for how policy-makers and industry groups could engage these harder to reach groups; from working through skilled intermediaries who have developed trust with farmers, to increasing rural connectivity and digital skills, and the establishment of two-way communication so that those who have engaged know how their views were incorporated into policy design.

As many scholars have highlighted, power and its distribution is a key aspect of participation. Where power dynamics are not addressed within a participatory process, that process does not represent typologies of participation as portrayed within many frameworks (Arnstein, 1969; Reed *et al*., 2018; Bell & Reed, 2021). With the hourglass shape of the food industry, in which there is a small number of multinationals in the middle of the chain and large numbers of producers and consumers at either end, addressing power imbalances is crucial to substantive inclusion and participation for the agricultural sector (Patel, 2007, p13; Thompson *et al.,* 2007). However, it is not enough to be aware of power dynamics for the sake of inclusion of stakeholders. It is also crucial to continuously address and manage the issue of power throughout any participatory activity (Reed *et al.,* 2018). For example, it is not enough to include farm workers in a participatory activity without acknowledging the power imbalances that may influence their input or their willingness to take part. Many workers may be on precarious contracts, face language barriers, or feel otherwise unable to express their honest thoughts on a given subject for fear of losing their livelihood (Rye and Scott, 2018; Fiałkowska and Matuszczyk, 2021). Substantive inclusion does not just look like inviting these stakeholders to the table – it also requires protecting their capacity to take part and contribute in an open and robust manner.

A further challenge highlighted by participatory exercises which have thus far taken place for the development of agricultural robotics is one of framing – in particular, the framing of the "publics" participating in exercises. The outcomes and perceived success of a participatory exercise are highly interpretable (Lezaun and Soneyrd, 2007) and may depend on the ways in which participant groups have been defined by the goals of the exercise. One pitfall of a framing of participation as an exercise in engaging a "general public" is the trap of believing that members of such a public should have no preconceived notion of the issue they are to discuss: the search for what has been termed both an "innocent citizen" (Irwin, 2006) and as the classical notion of the privately and internally focussed "idiot" (Lezaun and Soneyrd, 2007, p280). This framing may be intended to avoid perceptions of bias, but excludes those deemed to be high interest "activists" with strong opinions formed outside the boundaries of the participatory exercise.

3.2 Inclusion for agricultural robotics to date

To date, participatory approaches used in the development of agricultural robotics have predominantly involved consultation on technical challenges in the field and technical problems in agriculture that require solutions (Rose *et al.*, 2021). These approaches lack the principles of substantive inclusion identified above (Rose and Bhattacharya, 2023). Examples of participation and inclusion in the technical dimensions of agricultural robotic development have thus far employed a range of tools, including the use of augmented reality (Huuskonen & Oksanen, 2019), on-farm trials (Adamides *et al.*, 2017) and simulation events (see Riek, 2012 for methods), farmer surveys (Rose and Bhattacharya, 2023; Spykman *et al.*; 2021; Tamirat *et al.*, 2023; von Veltheim and Heise, 2021; von Veltheim et al., 2022), public surveys (Pfeiffer *et al.,* 2021*;* Spykman *et al*., 2022) and farmer interviews (Redhead *et al.*, 2015). A recent study in four European countries by Tamirat *et al.* (2023) went further than including only farmers, and instead interviewed robotic companies, academics, project managers, public authorities, and environmental conservation societies. Other studies with a focus on technical issues have also integrated some social dimensions into investigations for technical robotic development, for example by gathering data on farm worker attitudes to robotic futures (Baxter *et al.*, 2018).

As robotic technologies for agriculture have shifted closer to being ready for real-world application, some participatory exercises have begun to consider these technologies within the context of wider societal questions and challenges. Ditzler and Driessen (2022) marry the design of agricultural robotics with wider questions around the sustainable future of the agricultural sector. Their approach integrated a series of creative methods to develop robotics as a tool for agroecology, including group discussion, a World Café workshop, a design challenge with undergraduate design students, and on-farm trials. Each of these elements reflexively influenced the next in terms of design and focus, and this reflexivity is highlighted by the authors as one of the key strengths of their study. Other more inclusive deliberation exercises included the process for the Australian code of practice for field robotics (see section 4) and the Agri-EPI Centre/Hands Free Farm white paper. In addition, lessons will be learned from a robotic co-design project in New Zealand in which multiple academic disciplines are collaborating with stakeholders to develop farm robots (Legun and Burch, 2021). These approaches start to move in the direction of more substantive inclusion needed for responsible innovation. As the development of these robotic technologies progresses, further investigation into the wider implications of their use will be necessary. From the examples above, it is possible to identify some of the key challenges inherent in designing and applying such approaches for agricultural robotics, particularly in the context of achieving substantive inclusion.

3.3 Participation in robotic futures

While the vision of the role of participatory approaches can be debated and disputed, there is clear potential for their use to enhance responsible development and innovation of agricultural robotics. The application of participatory approaches has continued to evolve from the original ladder of participation (Arnstein, 1969), experiencing growing popularity as a replacement for the deficit model during the 1990s following a series of scandals which impacted public trust in science (Gibbons, 1999; Irwin, 2001; Bensaude Vincent, 2014), to the 21st century, in which several scholars have proposed revisions to the original frameworks of both practice and evaluation of participation (Rowe & Frewer, 2000; Hurlbert and Gupta, 2015; Chilvers and Kearnes, 2015). With this continued refinement and evolution of participatory processes, there is a need to ensure that 'perfect' is not the enemy of 'good' when it comes to creating more inclusive visions for the development of agricultural robotics. However, it should be noted that participation done badly can actually make approaches less inclusive by reinforcing existing power inequalities.

This section has discussed the inherent challenges in creating substantive inclusion, and it is clear that there is great complexity in achieving "perfect" inclusion in a system in which the potential pool of stakeholders is so wide. Furthermore, several scholars have highlighted that participation is not always the solution, and while it can be a useful approach for some problems, for others it can make little to no progress (Neef and Neubert, 2010; Hurlbert and Gupta, 2015). Reed *et al.* (2018) highlight that the normative idea of participation as following a ladder from low to high fails to account for variations in efficacy of different approaches to participation. A more reflexive approach is here called for in order to achieve better outcomes for decision-making processes (Reed *et al.*, 2018).

A framework for participation in the development of agricultural robotics would benefit from reflecting upon the tensions of attempting participation within a pre-defined goal framework, rather than allowing participants to define their own goals (Bruges and Smith, 2008). Avoiding a predetermined goal allows for the development of a coupled innovation approach (Meynard *et al.*, 2017), which has been shown as a benefit within the development of agroecological tools for sustainability transitions (Salembier *et al.*, 2020; Dietzler and Driessen, 2022). It is important for the ethical development of agricultural robotics that participation is not undertaken for participation's sake. To avoid tokenistic participation, reflecting upon the purpose of the exercise is crucial – facilitators may find that some areas require goals to be defined externally, and in such cases participatory approaches may not be effective.

4. Responsible robotics: reflexivity and responsiveness

We now turn to reflexivity and responsiveness in a shorter section, as research and action in this area is relatively under-developed given that many robots are only now being scaled on the ground. Reflexivity means listening to the views of stakeholders and acting on them through the development of responsive mechanisms for innovation. Including stakeholders is insufficient if robotic development trajectories are impervious to challenge and change. Here, we report on two initiatives from Australia and the UK to develop codes of practice and standards for agricultural robotics as a means of inspiring further work elsewhere. These are crucial in setting supportive regulations to allow agricultural robotics to be used safely and sustainably, and we encourage them to be developed across the world, targeted at national and regional regulatory environments.

The forebearer of current attempts to develop a code of practice for agricultural robotics comes from Australia. Here the code of practice 'Agricultural Mobile Field Machinery with Autonomous Functions in Australia'[2] was developed through a consultation between Grain Producers Australia and the Tractor and Machinery Association – with engagement from machinery manufacturers, the agricultural industry, and in consultation with the Department of Mines, Industry Regulation and Safety, an industry which has utilised autonomous vehicles for some time. It actually goes further than a voluntary code of practice, and instead has legal bearing. It is designed to *'operate under the Safe Work Australia Model Work Health and Safety (WHS) law and regulation, Australian and State government agricultural environment legislation and regulations and the Agricultural and Veterinary Chemicals Code Act 1994 and supporting state government legislation and regulations.'* It presents the roles and responsibilities for manufacturers, importers, distributors, owners and operators.

The code of practice covers several areas, including:

1. Safety and risk management
2. Information needs, training and supervision
3. Hazard controls, emergency preparedness and farm planning
4. Operational management
5. Vehicle transport between fields
6. Maintenance and repair requirements

[2] https://www.graincentral.com/wp-content/uploads/2021/08/Code-of-Practice.pdf

7. Emergency management

In covering these areas, the code of practice sets out expectations on who is responsible for various aspects of health and safety, data privacy, and maintenance, amongst other issues. This gives users confidence to use the autonomous vehicles and sets a clear, enabling regulatory environment. In many places in the world, regulations still restrict the optimal use of agricultural robotics (Lowenberg-deBoer *et al.*, 2022).

A similar process is now underway in the UK, led by the Agri-EPI Centre and Hands Free Farm team in consultation with industry groups (see Agri-EPI Centre/Hands Free Farm, 2022 white paper). They highlighted key issues such as cybersecurity, health and safety, and data ownership and are taking steps to develop standards and a code of practice to deal with them. This is being done through stakeholder inclusion with groups such as the National Ramblers Association (walkers who use farmland), the Institute of Agriculture Engineers (manufacturers), farming industry groups, the Health and Safety Executive, and policy-makers. A special working group on smart farming at the ISO is also considering standards for the use of agricultural robotics.

5. Conclusion

Agricultural robotics, like all disruptive technologies, is a double-edged sword. For all the benefits promised to people, production, and the planet, there are potential side-effects. To adapt a quote from Daum (2021), robots may offer us agricultural 'utopias' or 'dystopias', depending on how they are used. If robots are used to maintain current unsustainable models of production, or further intensify them, there are great risks. However, if they are used to create a step change in how we do agriculture, including embracing more regenerative or agroecological processes, challenging models of large, fossil-fuel based machinery, and eliminating imprecise use of inputs, they could revolutionise farming for the better. A farming future that achieves more output, with less and more targeted use of inputs, could be facilitated by the use of robotics.

Though the scaling of robots will be disruptive, it does not mean that we should shy away from embracing robots in agriculture; innovation is an inherently normative and disruptive process and sticking with the status quo also presents a set of winners and losers (de Boon *et al.*, 2022a, b). We have shown how a process of responsible innovation could be undertaken to allow stakeholders to co-develop agricultural transition pathways, including interrogating the role of robots within them. This starts with a process of stakeholder mapping to guide substantive inclusion. These stakeholders need to be listened to in a reflexive process and their views taken into account in order to guide development and implementation, using standards, codes of practice, regulation, and other policy instruments to ensure desirable outcomes. We recommend that proponents of agricultural robotics follow such a process from the very start of development and carry it on through and beyond implementation.

Data availability statement

Not applicable, no primary data collected as part of this chapter.

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