Perceptions of the fourth agricultural revolution: what's in, what's out, and what consequences are anticipated?

Article

Published Version

Barrett, H. and Rose, D. C. (2022) Perceptions of the fourth agricultural revolution: what's in, what's out, and what consequences are anticipated? Sociologia Ruralis, 62 (2). pp. 162-189. ISSN 1467-9523 doi: https://doi.org/10.1111/soru.12324 Available at https://centaur.reading.ac.uk/92462/

To link to this article DOI: http://dx.doi.org/10.1111/soru.12324

Publisher: Wiley

Perceptions of the Fourth Agricultural Revolution: What's In, What's Out, and What Consequences are Anticipated?

Hannah Barrett and David Christian Rose*

Abstract

Technological advancement is seen as one way of sustainably intensifying agriculture. Scholars argue that innovation needs to be responsible, but it is difficult to anticipate the consequences of the 'fourth agricultural revolution' without a clear sense of which technologies are included and excluded. The major aims of this article were to investigate which technologies are being associated with the fourth agricultural revolution, as well as to understand how this revolution is being perceived, whether positive or negative consequences are given equal attention, and what type of impacts are anticipated. To this end, we undertook a content analysis of UK media and policy documents alongside interviews of farmers and advisers. We found that the fourth agricultural revolution is associated with emergent, game-changing technologies, at least in media and policy documents. In these sources, the benefits to productivity and the environment were prioritised with less attention to social consequences, but impacts were overwhelmingly presented positively. Farmers and advisers experienced many benefits of technologies and some predicted higher-tech futures. It was clear, however, that technologies create a number of negative consequences. We reflect on these findings and provide advice to policy-makers about how to interrogate the benefits, opportunities, and risks afforded by agricultural technologies.

Key words

adaptive capacity, agriculture 4.0, artificial intelligence, automation, data analytics, gene editing, fourth agricultural revolution, responsible innovation, robotics, technology

Introduction

Agriculture globally faces a 'perfect storm' (Thiault *et al*. 2019); a rapidly growing global population that is demanding more calories per day (Rockström *et al*. 2017; Hickey *et al*. 2019; Miranda *et al*. 2019) and environmental challenges such as climate change, soil degradation, water pollution, and biodiversity loss

 DOI: 10.1111/soru.12324

(Rial-Lovera *et al.* 2017), whilst needing to maintain the livelihoods of people working on the world's 570 million farms, the bulk of them family enterprises (Lowder *et al.* 2016). As a response, there are growing calls for the sustainable intensification of agriculture (Firbank *et al.* 2018) which attempts to increase productivity whilst minimising degradation to the environment, also providing social benefits (see also Rose *et al.* 2020).

Notwithstanding the obvious limitations of productivist lenses (see e.g., Nally 2016), technology has widely been promoted as a means of sustainably intensifying agriculture (Kamilaris *et al.* 2017; Dicks *et al.* 2019; Miranda *et al.* 2019). In recent years, frames such as 'precision agriculture', 'smart farming', and 'digital agriculture', have become commonplace in policy and popular discourse with public funds and media attention being devoted to driving forward the so-called 'fourth agricultural revolution'. This revolution is seen as distinct to previous revolutions[1] and is presented as offering the technological fix or silver bullet to current and future challenges (Shepherd *et al.* 2018; Van der Burg *et al.* 2019). For example, the UK government has committed £90 million 'for [a] new tech revolution in agriculture' (Department for Business, Energy and Industrial Strategy *et al.* 2018) and the EU through projects such as 'EIP-Agri' are investing millions of euros to facilitate digitalisation of farming, extending historical investment in innovation projects such as 'Smart-AKIS', 'EIT Food' and '4D4F'.

As we enter into a predicted fourth agricultural revolution, scholars have argued that we need to be clear about what future innovation trajectories look like, including which technologies are prioritised over others (Levidow *et al.* 2012; Schlaile *et al.* 2017; Klerkx and Begemann 2020; Klerkx and Rose 2020). As it is a relatively new term, the fourth agricultural revolution is, as yet, ambiguous and loosely defined, often used interchangeably with 'smart farming', 'precision agriculture', 'digital agriculture' and other similar terms (Regan 2019; Klerkx and Rose 2020). Academics using the phrase have struggled to define it and delineate exactly what type of innovation pathways are being articulated (Klerkx and Rose 2020). It may appear that the fourth agricultural revolution is associated with various emergent technologies, such as artificial intelligence, drones, robotics, and gene editing, but there is not currently a consensus. It is generally accepted too that the revolution will considerably alter current farming values and identities (Eastwood *et al.* 2019a; Fielke *et al.* 2020), but without a clear sense of which technologies are included in the revolution, it is difficult to understand how they are perceived by different stakeholders and the unequal impacts they may have across society.

Anticipating the impacts of the fourth agricultural revolution is a key component of responsible innovation, which scholars argue should underpin transitions towards different futures (Rose and Chilvers 2018: Bronson 2019; Eastwood *et al.* 2019a; Gremmen *et al.* 2019; Regan 2019; Klerkx and Rose 2020). Various positive impacts of new technologies are anticipated, including increased yields, greater eco-efficiency, and social benefits, such as reducing physical labour, filling gaps in migrant labour provision, and offering more time for farmers to spend with family as machines perform work (Rose and Chilvers 2018; Edwards *et al.* 2020). Yet, we know that the benefits of the technology revolution are likely to be unevenly spread across society and that its risks are similarly likely to be shared unevenly across farming communities. For example, several areas of risks have been identified including the changing nature of farm work (e.g., possible labour displacement, loss of connection with the land; Rose *et al.* 2018a; Rotz *et al.* 2019), issues of trust in the supply chain and lack of trust on data ownership, security, and privacy (Wiseman *et al.* 2019), potential impacts on animal welfare (Hansen 2015; Bear and Holloway 2019), public acceptance of technology (Macnaghten and Habets 2020), and many others (see special issue introduced by Klerkx *et al.* 2019).

The call for improved anticipation of the impacts of agricultural technologies has come from a number of different scholars, including Bronson (2019), Eastwood *et al.* (2019a), Regan (2019), Rose and Chilvers (2018), and Klerkx and Rose (2020). The roots of such concerns originate in Science and Technology Studies scholarship which is interested in the pace, direction, and uneven impacts of social and technical change, as well as who have the power to decide (Jasanoff 2005; Stilgoe *et al.* 2013). As Stilgoe *et al.* (2013, p. 1570) argue the 'detrimental impacts of … technologies are often unforeseen'. Anticipation, thus, requires us to ask 'what if' questions – exploring the potential impacts of technological change, both intended and unintended. Eastwood *et al.* (2019a) suggest engaging in foresight exercises and scenario building of possible agricultural futures through methods such as future-scanning. Ultimately, we need to be able to foresee whether specific technologies will contribute to sustainability (people, production and the planet [Rose *et al.* 2020]) or not, but there have been, as yet, relatively few empirical attempts to explore how impacts may be unevenly spread across society.

This article, therefore, undertakes such empirical work to understand how the fourth agricultural revolution is being perceived and talked about in policy and media sources and amongst practitioners. We investigate two aims relating to anticipating farming futures – (1) *which technologies are in and out of future visions,* exploring which technologies are being associated with the fourth agricultural revolution and which are being excluded, and (2) *how impacts of these technologies are perceived*, seeking to understand what the consequences of new technologies might be and whether these are presented in a positive or negative light. The latter aim will help us to understand more about the precise risks of the fourth agricultural revolution and for whom these risks are most prominent, shedding light on whether and how benefits will be spread (un)evenly across society.

Methods

We used a mixed-methods qualitative research design using a combination of media and policy document analysis and face-to-face interviews (interviews undertaken using the protocol of Young *et al.* [2019]). Prior to conducting data collection, this study was approved by the University of East Anglia's General Research Ethics Committee. All research participants prior to the interview were provided with an Information and Consent Form (Appendix 1).

Media content analysis

A content analysis of relevant media articles was used to understand how the media frames the fourth agricultural revolution. The analysis of media sources, including social media, is now being increasingly undertaken as part of the 'deliberative mapping' of policy issues, since their content can shed light onto the prominent conversations being held across society (Pallett *et al.* 2019). Media articles have also been considered important for constructing storylines that are discussed and taken on by society, such as in the case of carbon capture storage in Japan (Asayama and Ishii 2017). Although undertaken in a different context, the Japanese study used media articles in a similar way to our study, as they focused on how media portrayed stories of 'techno-optimism', which created storylines about the acceptability of a new technology. We do not claim here that media influences directly how innovation is funded and organised, but they are an interesting source in which storylines are created and presented to society, and in the case of emergent technology are one of the only ways in which people can make sense of what they might entail (Donk *et al.* 2011).

Our analysis focused on 28 UK media articles about the fourth agricultural revolution using LexisNexis® published between 2014 and 2019 (see Appendix 2). LexisNexis® allows UK national and regional newspapers to be searched as used by Morris (2018) in her assessment of the media debate surrounding 'Meat Free Mondays'. We chose UK media articles to reflect the fact that the interviews were conducted in the UK and because it has seen significant investment in agri-tech. We deliberately did not use terms such as 'digital', 'smart', or 'precision' when searching for articles relevant to the fourth agricultural revolution because they are associated with particular types of technology and were keen to ensure that we did not skew search results.[2] The criteria for excluding articles is presented in Appendix 2.

We undertook a form of content analysis inspired by Morris (2018), scoring articles based on how positively the scheme was talked about in each article. This was adapted and expanded upon in our work. We read each article and noted down every distinct piece of technology that was mentioned in relation to the fourth agricultural revolution and scored how positively the technologies were talked about. We also noted the sustainability challenge (productivity, environment, social) that each new technology was promoted as contributing to and listed the different types of positive and negative consequences of the technology that were listed (see Appendix 2 for more detail). We acknowledge that there may be several more articles published on this subject post-2019, as this is a fast-growing area of media interest, and thus further research would be useful. Some of the news articles reported the same political speech or scientific event, using standard press releases as their core and reporting on them in the same tone (e.g., on Michael Gove's [the then Secretary of State at the Department for Environment, Food and Rural Affairs] speech), but we included each one as they were separate articles reported in different newspapers (or other outlets).

Policy document analysis

An analysis of four relevant UK policy documents and speeches, a specific document on technology from the National Farmers' Union (as a powerful lobbying organisation on policy), plus a document detailing the successful projects funded by the first InnovateUK round of 'Transforming Food Production' (https://bit.ly/3cVmrAh – Government funding scheme to develop agricultural technologies) was conducted to understand how policy-makers frame the fourth agricultural revolution. To find the documents, the same search terms were used as for the media analysis (Appendix 2) on key UK policy websites (Department for Business, Energy and Industrial Strategy; Department of Environment, Food and Rural Affairs' websites). The list of policy documents are shown in Appendix 2 and they were analysed in the same way as the media articles (for a recently published assessment of how global policy documents frame new agricultural technologies, see Lajoie-O'Malley *et al.* 2020).

Interviews

Face-to-face semi-structured interviews were conducted between June and August 2019. Prior to conducting the interviews, a small pilot study was conducted with similar participants to ensure the clarity of wording and that interviews were an appropriate length. Respondents were predominantly recruited using snowball and purposive sampling from farming groups in the East of England. We were keen to speak to a range of different types of farmers and included five mixed farmers (arable and livestock, mainly dairy), four arable farmers, and one horticultural grower in the final sample. Farm advisers were also included in the study because they are a key influencer in the use of technology on-farm (Ingram 2008; AIC 2013; Rose *et al.* 2016; Ayre *et al.* 2019; Vrain and Lovett 2019). These were identified by speaking with the farmers and through university staff.

The sample size of ten farmers and five advisers was an achievable and pragmatic sample given the time frame. Interviewees varied in terms of farm type, farm location, farm size, technological usage, age and gender, providing a snapshot of perceptions of the fourth agricultural revolution amongst practitioners, which could be further explored in future larger studies. Advisers tended to be focused on arable production. We acknowledge that our sample is biased towards arable and dairy sectors of production in the East of England. Farmers in this sector and region tend to use technology more than others, for example in the upland or lowland livestock sector (excluding dairy) (Rose *et al.* 2016). We do not use this sample to be representative of farmers in the UK, and we note that different views on technology may have been shared if we had included, for example, upland livestock farmers who tend to be less technology-focused. Further research could be fruitful here. We also note, however, that few of our respondents were using emergent technologies such as artificial intelligence, drones, robotics (bar the dairy farmers), and the Internet of Things, thus the sample is not wholly atypical of arable and dairy farmers in the UK. All interviews were conducted in Norfolk (England), with the majority taking place in the respondents' home or workplace. This allowed respondents to physically show the researcher certain technologies around the farm/workplace aiding their explanations, which would not have been possible if using telephone interviews (Holton and Riley 2014).

As far as possible, we tried to gather information which was comparable to the analysis undertaken for the media and policy documents. We found unsurprisingly, however, that farmers' and advisers' grasp of terms like 'the fourth agricultural revolution' was limited. To overcome this challenge, we also asked them to predict what farming would look like in the year 2030 and also about the positive and negative impacts of the technology that they were using now (see Appendix 3). We also asked them to define the phrase 'agricultural technology' and list the types of technologies already being used on the farm (or on the farms they advised). We acknowledge that this is a slightly different approach to the media and policy analysis – yet comparisons are useful. It allows us to ascertain whether our sample of farmers and advisers talk about some of the same technologies in the context of future farming as media/policy sources did for the fourth agricultural revolution. It also allows us to compare the practice-based positive and negative impacts of technology being actively experienced by farmers and advisers now in order to see how far consequences predicted by the media and policy-makers match these themes.

All interviews took between twenty minutes to one hour to conduct. Interview schedules for farmers and advisers differed slightly, however, both interview schedules used a combination of open- and close-ended questions (Appendix 3). Open-ended introductory questions were used to explore farmers' background, perceptions of different agricultural technology types, and their future farming visions. Similarly, advisers were asked open-ended questions regarding their adviser background and current role, perceptions and experiences of agricultural technologies and future farming visions. Open-ended questions allow respondents to answer freely and shape the conversation. Close-ended questions were used to collect demographic information of respondents including age, gender, and education level, allowing the data to be contextualised. At the end of the interview, respondents were given the opportunity for further comments or questions. All interviews were audio-recorded. A notebook was also used to note down points of interest which the researcher could follow-up on during the interview. Once the interviews were conducted, respondents were contacted using email to thank them for their time and a summary of the research was provided to them afterwards where possible. All interviews were transcribed immediately post-interview allowing the researcher to explore the main emerging themes, commonalities, and differences in the data.

Interview transcripts were coded thematically. Initially, the researcher noted down and highlighted insightful themes in the data. Codes were focussed on the specific research objectives to avoid losing context of the data and were continuously revised and edited throughout the analysis process. This coding process was repeated by the co-author of this manuscript, which helped to check whether the other had identified the most prominent themes.

Which technologies are included in the farming revolution?

Media analysis

From the 28 media articles analysed, the top mentioned technologies were robotics (in 15 articles), artificial intelligence (13), gene editing (13), vertical farming (10), data analytics (9), drones (6), synthetic proteins (5), software/apps (5), sensors (4), GPS (4), blockchain (3) and autonomous vehicles (3). One article painted a particularly high-tech vision of the future, reporting a farmer as saying 'when my son is running the farm it will probably just be him and a couple of robots' (The Telegraph, 2018).

Policy analysis

An analysis of the successful technology projects funded in the first round of the UK Government's 'Transforming Food Production' illustrates the prominence of specific technologies. We include the vast majority of projects funded in this round, only excluding those that did not specify a specific technology in the publicly available document.

The list was as follows in alphabetical order – Autonomous farming (full system) – £1,577,964; Automated field analyser – £927, 394; Automated machine vision (fruit) – £716.905; Automatic health monitoring system (cattle) – £312,461; Artificial intelligence (2 projects) – £620,451 and £1,001,182; Big data (cattle) – £1,277,589; Data bank (beef) – £2,441,794; Decision support system (fertiliser) – £1,189,803; Disease forecasting system (livestock) – £398,845; Drone (crop disease) – £909,984; Electrical weeding – £690,380' GPS (track cows) – £233,286; Hardware and software (animal health) – £530,520; In-field cooling system (fruit) – £311,960; Robotics (five projects) – £507,309, £105,435, £507,309, £439,100, £697,058; Smart storage system (potatoes) – £520,046; Vertical farming (three projects) – £990,856, £447,425, £488,981.[3]

Artificial intelligence, autonomous farming systems, robotics (all related), and vertical farming projects all received significant investment, alongside others such as drones, big data analytics, and decision support systems.

Policy documents, and the NFU Future of Farming document, highlighted similar technologies as being associated with the fourth agricultural revolution. Technologies identified in more than one of the five documents were – robotics (in four documents); sensors (four); data analytics (four); gene editing (four); vertical farming (four); artificial intelligence (three); drones (three); GPS (three); software/apps (two); autonomous vehicles (two); precision fertiliser application (two).

Interestingly, the Health and Harmony public consultation document (Defra 2018) noted that some respondents felt that there was too much focus on high-tech farming, and not enough on 'lower-tech' technologies and non-technology based innovations that could already be implemented on-farm.

Farmer interviews

Defining agricultural technology. Farmers were asked how they would define 'agricultural technology'. This was interpreted in three ways:

1. *A modernising mindset* – one farmer said 'it's just forward-thinking isn't it, moving forwards all the time' (F1), whilst another was clear to point out that he thought it could 'be anything, not necessarily just computers, just progress' (F2).
2. *Specific technologies in use already* – several specific technologies were mentioned by respondents, including GPS, spray application, yield mapping, self-steering, computers, robotics, software, and data collection.
3. *New, emergent technologies* – as well as mentioning technologies that they were using at the moment, one farmer talked about the importance of emergent technologies

such as robotics, noting that agriculture has been really slow to adapt to technology (F3).

Technologies in use. Farmers were asked which technologies were currently being used on the farm. Arable farmers were routinely using GPS technology, variable rate application, remote sensing, yield mapping, self-steer, and software to collect, record, and analyse data. Some were using drones to take pictures of their crops with one farmer routinely using this to monitor crop health. The farmers with a livestock side to the business mentioned various technologies to assist with milking and animal health, including robotics and CCTV.

Adviser interviews

Defining agricultural technology. Advisers defined agricultural technology in a similar way to farmers. Some felt that it was a 'huge umbrella of various different things' (A1), which includes ideas and not just high-tech equipment. For example, better tyres were identified as an important new innovation (A1). Others mentioned precision technologies already in use such as remote sensing, sensors, yield mapping, genetic modification, and gene editing. One adviser defined the fourth agricultural revolution as 'the latest modern technology ... the next big thing that's going to take us to that next step' (A2), but others tended to be unsure how they would define it.

Technologies in use. Advisers predominantly gave guidance to arable farmers and thus technologies mentioned included a range of precision tools used in this sector, such as GPS, yield mapping, self-steer, and software as well as drones, and better tyre technology.

Anticipating the consequences of the fourth agricultural revolution

Media analysis

96 per cent of media articles spoke about the fourth agricultural revolution in respect of new technologies improving productivity (the only article that did not mention this talked instead about agricultural careers), largely using the lens of needing to feed a growing population. Just over half of the articles (57 per cent) substantively wrote about the role of new technologies in improving the environment, while just under half (43 per cent) talked about social impacts of new technologies. The social impacts, excluding economic improvement, were mainly discussed in the context of improving food traceability, diets, public acceptance, safety, food security, or employment opportunities in the farming sector. Most articles set out the potential productivity, profitability, and environmental benefits of new technologies, such as increased yields, improved crop quality, better animal health and welfare, improved eco-efficiency, reduced labour costs, lower carbon emissions, and reduced food waste and food miles.

Benefits for productivity, profitability, and the environment were much more prominent than social issues.

The articles were overwhelmingly positive in tone. On our scoring system (after Morris 2018, see Appendix 2), 71 per cent of articles were overtly positive about the role of technology, with the remainder mainly either developing a cautious tone because of the uncertain Brexit context, or highlighting the issue of public acceptance of technology (gene editing mainly) or how expensive it might be (mainly vertical farming, but also capacity of farmers to adopt new tech). The issue of lost jobs was raised as a potential issue. One article noted, for example, featured a farmer reflecting on past and current farming landscapes (The Telegraph, 2018):

> '[in the past] he could spot as many as three dozen labourers scattered amid the lush green landscape. Now those workers have been replaced by laptop-wielding technicians testing small, spidery orange robots that crawl over his patch of picturesque countryside'.

Policy documents

The treatment of the role of agricultural technologies was overwhelmingly positive in the policy (and National Farmers' Union) documents analysed. Emerging technologies, such as vertical farming were seen as 'part of the answer' to boost profits and the environment significantly (HM Government 2018, p. 36), and, in some cases, as having 'untapped potential' (NFU 2019). As written in the UK Strategy for Agricultural Technologies (HM Government 2013, p. 9), 'the potential rewards are increased productivity, reduced costs, growth, new investment and jobs and tackling the challenges of sustainable intensification and global food security'. Productivity, reduced labour demand, resource efficiency and reduced waste, improved animal welfare, achieving net zero carbon emissions, reducing soil compaction, were common themes and technology was seen as 'critical' (Gove 2019) or 'key' (NFU 2019) to solving these challenges. Indeed, the 25-year Environment Plan (HM Government 2018, p. 36) stated that:

> 'Properly implemented precision farming, resource efficiency, and better livestock and crop management can achieve more effective sustainable productivity growth'.

Social benefits were presented, including the ability to attract new entrants with technology skills into agriculture (Defra 2018) and helping us to address 'social issues like ending hunger and tackling health problems' (NFU 2019, p. 4), whilst improving food traceability and taste. The National Farmers' Union (2019, p. 19) also wrote about technology improving gender balance and safety in the farming sector:

> 'a positive by-product of labour-saving technologies is a safer and cleaner farming industry, which is more attractive to new entrants from more diverse backgrounds and opens up potential new supporting careers around professional advice and technical expertise. We may also see more women attracted to the industry as heavy manual jobs become less dominant'.

The positive tone is exemplified by the following extract from Michael Gove's (the then Secretary of State at Defra) major speech to the Oxford Farming Conference in 2019:

> 'Now, we are on the verge of another revolution in how we produce our food. That is why I particularly welcome the "brazenly positive" tone of this conference. Accelerating technological advances ... such as the drive towards artificial intelligence, the more sophisticated than ever analysis of big data, drone development, machine learning and robotics will together allow us to dramatically improve productivity on traditionally farmed land not least by reducing the need for labour, minimising the imprint of vehicles on the soil, applying inputs overall more precisely, adjusting cultivation techniques more sensitively and therefore using far fewer natural resources, whether carbon, nitrogen or water, in order to maximise growth. The potential for Britain to lead in this revolution is huge. Which is why [we are] right to look to the future with confidence'. (Gove 2019)

There was some discussion of the anticipated negative consequences of the fourth agricultural revolution beyond simply lack of adoption or poor knowledge exchange which were reasons given for a slow transition, rather than negative impacts. Related to this, though, the high degree of investment needed to purchase new technologies was consistently identified as a barrier to adoption (Defra 2018). The Health and Harmony consultation document on post-Brexit agricultural policy writes that 'most respondents mentioned finances as a barrier to adopting new technology' (Defra 2018, p. 36), whilst Gove (2019) noted that the 'level of capital investment ... is not available to all'. Expanding on this point, one can posit that some farm businesses (larger, higher cashflow) will have greater adaptive capacity to change than others, which could exacerbate inequality within the farming industry. High-tech solutions were not perceived by many as being able to help small-scale farmers (Defra 2018). This also relates to skills; some younger farmers may have the digital skills to thrive in a new farming world, others will not and this could drive inequality (Defra 2018). Other social issues, such as fears over data ownership and the power of technology companies over farmers and changing farm workflows potentially enhancing mental health issues in the sector, as well as leading to the loss of traditional farm knowledge were also raised, albeit in a less prominent way (NFU 2019). Consumer acceptance of new technologies, such as lab-grown proteins and gene editing, was also discussed in the documents (e.g., Gove 2019).

Also raised was the performance of the technology itself, which in many cases is still in its infancy (NFU 2019). Questions were raised about whether new technologies actually improved farm profitability and worked reliably (NFU 2019), particularly in isolated rural areas where broadband infrastructure is poor, and indeed whether they made problems they try to solve worse (e.g., vertical farming as sparing land, but potentially increasing energy use; Gove 2019).

Farmer interviews

Perceived benefits of technology use. Table 1 illustrates the range of benefits associated with the use of technology on-farm.

The most common benefits raised were reduced inputs and costs, improved productivity and profitability, increased eco-efficiency, better data analysis, and improved lifestyles. Improved animal welfare, reduced labour costs, and improved accuracy of farm work were mentioned by two farmers each.

Perceived negative impacts of technology use. Table 2 illustrates the negative impacts of using technology on-farm.

The most common negative consequences raised were lack of capacity to adopt or repair equipment, the technology not working as expected or not providing the expected level of benefit, and the potential impact on farm labour as a result of technology replacing workers or existing workers not having the skills to operate equipment. Two farmers talked about unequal power relations, whilst one each mentioned increased stress on farmers/workers, negative public perception, and loss of practical farming knowledge.

Future of farming. Farmers were asked what they thought farming would look like in the year 2030. The following themes were raised:

- *Increased use of technology* – three farmers predicted that farmers would be using more technology in 2030, probably 'more automation ... less people on farm and less involvement from humans' (F2). In the view of the same farmer, this would lead to 'healthier and happier animals, better for the environment, and more efficiency' (F2). Another felt that 'this is the most exciting period I have ever known in farming ... [and] would love to see a little robot going up and down my beet fields' (F4), a view shared by a further farmer who 'hoped' that the industry would have adopted new technology by 2030.
- *Little difference* – two farmers were more sceptical about whether some new technologies would be implemented on-farm by 2030. One farmer argued that 'ten years is not a big enough window to make changes in terms of robotics and machinery ... [he] would be very surprised if ten years is long enough to get that technology in place' (F3). Another stated that it would 'probably be quite similar really' (F6).
- *More focus on the environment* – three farmers felt that there would be less emphasis on increasing the land area for crops and more on setting aside land for the environment. One farmer said that 'there will be less areas for crops and more environmental measures definitely' (F5), whilst another noted that danger of the government getting it wrong and leaving 'an awful lot of land not being farmed' (F1). An additional farmer thought farming 'would be greener [with] less animals' (F6) and this may be enforced by 'restrictions on chemicals and red tape being brought in' (F6).
- *Brexit uncertainty* – understandably since the interviews were conducted in the Summer of 2019, envisioning the future of farming was difficult with an uncertain Brexit situation, and many farmers noted how 'difficult' it was to look ahead and make predictions in the current political climate.

Adviser interviews

Perceived benefits of technology use. Table 3 mentions the benefits of agricultural technology mentioned by arable farm advisers in interview.

Advisers spoke about improved data analysis, better productivity and efficiency most prominently, and improved eco-efficiency most prominently, also mentioning improved profitability, reduced labour costs, better working conditions, and improved public engagement.

Perceived negative impacts of technology use. Table 4 mentions the negative consequences of agricultural technology mentioned by farm advisers (one did not expand on this question).

Two advisers spoke about technology not working as expected, whilst one adviser each mentioned the lack of capacity for farmers to adopt and their lack of understanding of technology.

Future of farming. Advisers were asked what they thought farming would look like in the year 2030. The following themes were raised:

- *Increased use of technology* – two advisers predicted an increased use of technology. One adviser thought that farming would be 'completely different ... we are going to have to produce more food that's a given ... robotics [will] make it safer, probably in the big farming areas ... you don't need to have man and a machine, let the machine go and do the work' (A5). Another adviser hoped that some of the new technologies would be 'used more widely, smaller machines, precision equipment, everyone using guidance and everybody thinking about controlled traffic farming ... these things like robotics and artificial intelligence would potentially help all of those things'; however they thought 'it would be further away than 2030' (A4) (see below).
- *Little difference* – two advisers thought there would be little change. One adviser felt that farming would not look very different in 2030 because 'ten years really isn't that long'. This adviser thought that 'there will be more diversification but as for the actual adoption of technologies, I don't think it will be that different' (A1). Another said 'ten years away, it's not that long. I was hoping there would be a point where I won't buy another tractor with a cab on it, I will be having a cabless tractor and it will be autonomous, and I would almost like my guy on the farm to then be managing the machines, more of an office-based role, rather than out there doing it. But I don't know in ten years, I don't know if we are quite going to be there' (A3).
- *More diversification* – echoing the point made above, one adviser felt that farm enterprises would 'probably be more diverse' (A2).
- *More focus on the environment* – advisers generally felt that farming would be 'better for the environment' (A4), although one gave a note of caution saying that the right subsidy would have to be in place to stop farmers going back to 'produce, produce, produce'. A further adviser, however, strongly hoped that farming would be 'completely different, much more environmentally focused' (A5).

Table 1: *Positive consequences of technology use stated by farmers (n = 10)*

Benefit	Sample quotes
Reducing inputs and costs (Five farmers)	'you don't use half as much now with variable rate'. (F1) 'Save cost, inputs so you're not overlapping, save on operator tiredness you don't have to worry about steering and can concentrate on the operation rather than trying to keep in a straight line and accuracy which leads to cost savings in inputs'. (F5)
Improved productivity (Four)	'Better productivity, pure and simple'. (F4)
Improved eco-efficiency (Four)	'we get more with less inputs than that is really what we are trying to do but trying to look after the environment at the same time'. (F5)
Good data analysis (Three)	'robotics provide consistency so that's a huge advantage. they both provide that and provide feedback in real-time'. (F10)
Better lifestyle, better working conditions (Three)	'technology is so much easier, it makes farming so much easier'. (F1) [Using robotic milking]. 'Not being tied to milking twice a day [is a benefit]. X the main cowman has got arthritis so it's health reasons and he's got arthritis in his knuckles, so he physically can't milk his cows and it was either sell the cows or have a robot. Actually, having the robot has enabled him to manage a lot of other areas on the farm in a much better way. So, I think a big part of it is staff welfare, both for himself and for the rest of us. I think it creates a much better quality of life on the farm and not having to be tied to milking twice a day'. (F10) 'The job itself becomes a bit easier and more interesting, it is also easier to delegate a task because you have the information in front of you and you can set tasks and protocols according to data whereas before it would be more on gut feeling and experience of what you have seen before but now its numbers and graphs'. (F4)
Improved accuracy of farm work (Two)	'it's a huge amount more accurate'. (F1)
Reduced labour costs (Two)	'we have reduced labour costs'. (F2)

(Continues)

Table 1: *(Continued)*

Benefit	Sample quotes
Improved animal welfare (Two)	[using a herd management system] 'We used to be visited every week (by vet), but now every other month. Less traumatic now. Less intrusion on the cow now as the cow has to be milked, a milk sample is taken automatically, and we can observe the results on a computer whenever we like. It's much better for the cows and we get a lot more information and save money as well. Welfare and the health of the animals is better as we are seeing information and the data is shown to us, you can spot things sooner than you can spot a problem before it happens, so we've reduced our antibiotic use'. (F2)

Discussion

In terms of determining which technologies are seen as being part of the fourth agricultural revolution, media and policy sources placed a clear emphasis on emergent new technologies, such as robotics, artificial intelligence, gene editing, data analytics, and vertical farming. Although we did not use answers relating to a question to farmers and advisers on defining the fourth agricultural revolution (caused confusion), we did ask them to look ahead to the future of farming. Two farmers and two advisers mentioned similarly 'high-tech' technologies and expected them to be used more within the next ten years, with one saying that he would 'love' to see robots in his fields. Some were using precision technologies, including robotics, already. Yet, it was also clear that other farmers and advisers did not think that farming in 2030 would be utilising these emergent technologies, citing slow adoption rates, lack of skills, and limited tangible benefits of their implementation. Farmers and advisers also defined 'agricultural technology' broadly, sometimes referring to high-tech equipment, but also citing lower-tech equipment, ideas, or mindsets as 'technology'.

Looking ahead to the pace and scale of technological change in the fourth agricultural revolution, the mismatch between different stakeholders' opinions towards innovation could cause controversy. Historically, research has shown that agricultural changes are generally 'small and incremental rather than large and radical, and involve adaptations to fit with (new) local circumstances, rather than wholesale adoptions of technologies brought from outside' (van der Veer 2010, p. 10). Farm adoption of technology can be slow, perhaps taking several decades (Griffin *et al.* 2017; Barnes *et al.* 2019; Kernecker *et al.* 2020; Pannell and Claassen 2020), though not in all cases (Lowenberg-DeBoer and Erickson 2019). Mismatched priorities and values between technologists and scientists, policy-makers, and practitioners are nothing new in agriculture. In a chapter on co-innovation, Klerkx *et al.* (2012, p. 469) include a diagram of a chasm between different stakeholders (e.g., technologists and practitioners) because they 'belong to different worlds which have their own languages and cultures'.

Table 2: *Negative consequences of technology as stated by farmers (n = 10)*

Negatives	Sample quotes
Lack of capacity to adopt (or repair) (Six farmers)	'it's quite costly especially when you go over your data allowance, buying 1mb of data is about £10 so yeah that was a bit of a shock'. (F4)
Technology doesn't work as expected (Four)	'But with trees you lose satellite signal'. (F1)
	'We've had a couple of good examples of that where we've invested in something and it's easier to do it the old-fashioned way and quicker and probably more efficient. I think there needs to be more work on all of them, they need to be more user friendly and the costs need to come down and I need to see a real benefit from using them'. (F7)
Lack of understanding of technology (Two)	'I think the disadvantage is probably our lack of knowledge and understanding of these things. Yes the fact that we don't know the ins and outs ... so when it goes wrong the farmer can't ascertain what's wrong, you have to get someone else in to sort it out'. (F10)
Different worker skills, less workers (Two)	'it's understanding the technology as well, you have to have a sort of mind which can cope with the different skillset ... someone that can understand technology and is happy to not only work with livestock and do farming on a day-to-day basis but also understands how to run a computer and to solve a problem'. (F2)
	'Yeah, that is a big question because ... the farming revolution, when we got tractors and the horses and stuff went, you know the need for labour dropped'. (F6)
Power inequality – tech companies in charge, right to repair (Two)	'Probably the cost ... I think the companies that develop a lot of this stuff are quite clever about getting a buy in early doors and making it quite cheap to do so, and making you dependent on it and then gradually increasing costs and once you are locked in, it has certainly happened with GM crops in the US ... once everyone is dependent on it, you haven't got any choice but to use those companies'. (F3)
	'Disadvantage is when they go wrong because we are so reliant on them now and particularly the fertiliser, when the fertiliser thing goes wrong with our system we can't put fertiliser on, you just can't do it'. (F8)

(Continues)

Table 2: *(Continued)*

Negatives	Sample quotes
Increased stress on farmer/workers (One)	'Information overload, the robots have to work 24 hours a day, it is a different way of milking cows, you have to be on-call 24 hours and if there is a problem they will send an alert through and you have to be in a position where someone can respond ... they can cause different stress'. (F2)
Public perception (One)	'Well I suppose the real biggie is gene editing and that, you know, if you could edit it in ... but there are certain elements of society which doesn't want that kind of thing, they still think we should be wandering around with flints and in the Stone Age'. (F4)
Loss of practical knowledge (One)	'If it breaks there is a disadvantage that the operator has not been used to steering the machine in a straight line before, they can over rely on the technology and if it fails then other things fail as well'. (F5)

Table 3: *Positive consequences of technology use stated by advisers (n = 5)*

Benefit	Sample quotes
Good data analysis (four advisers)	'So I think providing information and data, and using data is always really positive as long as you can do something with it'. (A1)
Improved productivity (three)	'Key benefits that I see, we could produce something magical, have a better yield, better resistance to diseases'. (A1)
Improved eco-efficiency, reduced inputs, better environmental decision-making (three)	'in terms of the technology side of things, [they] do reduce chemical usage'. (A1)
	'cutting down chemical usage is one of the main things'. (A2)
	'but also ecologically if they're recording what they see [with software] then you know it's going to inform management choices on their environmental margins. So yeah, I think it can help push things along and if nothing else, help the general public know what farmers or some of farmers are doing'. (A4)
Improved profitability (one)	'we can get the biggest yield we can with the smallest possible area, we're going to utilise all the inputs we've put on that area, it must be the right thing for the farmer's bottom-line'. (A5)
Reduced labour costs (one)	'Robotics would be less labour, so lower your labour cost and also probably sometimes just be able to do the job a bit better than a human can'. (A2)
Better working conditions (one)	'the guidance we use on the tractors as well that's great for fatigue [reducing farmer fatigue]'. (A3)
Better public engagement (one)	[data can] 'help the general public know what farmers or some of farmers are doing'. (A4)

Rose *et al.* (2018b, p. 83) also present a series of quotations from farmers describing how decision support systems tend to be designed by 'clever people' (technologists/scientists) who want to tell practitioners 'what to do' despite having little idea about what will 'work on a farm'. Competing visions of farming futures can also occur at the policy level, as illustrated by Levidow *et al.* (2012), who explored the conflict between rival 'agroecological' and 'life sciences' approaches of EU agri-innovation policy.

In one sense, to create the step change needed to achieve sustainable intensification, meeting objectives such as net zero carbon by 2040 (UK target), radical new technologies may be required (De Clercq *et al.* 2018; NFU 2019). However, focusing policy attention on the development of products at lower technology readiness levels risks diverting resources away from the better implementation of 'lower-tech' technologies and other innovations that could lead to gains for people, production, and the planet now (Klerkx and Rose 2020). Scholars have argued that the prioritisation of hyped (see paragraph below on 'techno-optimism') 'big-tech' innovation pathways necessarily excludes other ideas from coming to the fore, including simpler measures such as improving advice provision to farmers, encouraging them to make better use

Table 4: *Negative consequences of agricultural technology stated by advisers (n = 4)*

Negatives	Sample quotes
Technology doesn't work as expected (Two advisers)	'Yeah sometimes they're just expensive, and they don't show any value and people get carried away with it like booking shiny machines sort of thing and actually they don't get that much money back as a result of spending money. I think drones is like that sometimes. There's quite a lot of interest in drones but it's difficult to see things actually really agriculturally where we see a lot of value from them'. (A2)
Lack of capacity to adopt (One)	'It concerns me a little bit ... it tends to be that my larger farmers, the ones who are quite clever, the ones that have got the big kit which they can spread it across the right hectarage, they are the ones that seem to be making the money, and my smaller farmers who haven't got the balance of machinery depreciation, haven't got the yield quite right, and are still doing cultivation that they were doing, that is the difficult balance. So I'm quite worried with this fourth revolution, that we are going to lose a lot of farmers that are doing a really good job, particularly for biodiversity'. (A1)
	'I think it mainly comes back to input costs, obviously these pieces of machinery/ technology are quite expensive to buy in the first place'. (A1)
Lack of understanding of technology (One)	'it kind of depends because there's a lot of farmers that are scared about technological advances because they might not be computer literate so obviously it's not for everyone is it'. (A4)

of technology that they already have on the farm (e.g., weighing cattle more regularly, Whatsapp communication), or scaling up farmer-led innovations, including retrofitting (Rose and Chilvers 2018; Klerkx *et al.* 2019; Klerkx and Rose 2020).

Turning to the second objective of this article, which was to explore how the fourth agricultural revolution or technology in general is being perceived, media and policy documents overwhelmingly presented high-tech innovations in a positive light. They mainly referred to the ability of new technologies to improve productivity and profitability and also environmental and social benefits, although less prominently. We asked farmers and advisers to talk about some of the positive and negative impacts of the technologies that they were using on-farm, including some newer products like robots. The positive benefits of agricultural technology were similar between media/ policy documents and farmers/advisers, including increased yields, improved animal welfare, reduced labour costs, attracting younger and female workers, better lifestyles, and reduced environmental degradation. Many of these perceived benefits are supported by evidence in the literature (e.g., Hansen 2015; Hickey *et al.* 2019; NFU 2019; Regan 2019; Vik *et al.* 2019), although other studies sometimes present evidence which challenges such claims (e.g., Hansen 2015 presents conflicting evidence on improved farmer lifestyles in automated milking; Werkheiser 2020 on animal welfare).

The hype around new technologies, referred to by phrases such as 'techno-utopianism' (Goldberg and Riemer 2006) and 'techno-optimism' (Dentzman *et al.* 2016), is nothing new. In a paper on herbicide resistance, Dentzman *et al.* (2016) present a three-pronged critique to such a notion, arguing that techno-optimism overlooks social factors, tries to solve social problems with technical fixes, and ignores the unintended negative consequences of new technologies. As such, it was interesting in our research that media/policy sources and practitioners talked slightly differently about the negative consequences of technology. Firstly, media and policy documents devoted substantially less time to negative consequences, although lack of adaptive capacity, poor rural infrastructure, consumer acceptance of gene editing, increased energy use of vertical farming, and the loss of rural jobs were mentioned. Farmers and advisers raised many of the same points, sometimes in the same breath as presenting potential benefits, and, thus, there is clearly need for further research and policy attention on mapping negative consequences of new technologies. Klerkx *et al.* (2019) introduced a special issue which explored many of these areas, such as rural employment and adaptive capacity (see also Rotz *et al.* 2019; Carolan 2020).

Lack of adaptive capacity for some farmers to adopt new technologies was most prominently raised by farmers and advisers, but also widely mentioned in the media and policy documents. Technological advancements may favour the already powerful, such as larger farm businesses over small family farms who have less capacity to invest in new technology (Rose *et al.* 2016; Sheng and Chancellor 2019; van der Burg *et al.* 2019; Stringer *et al.* 2020). This was mentioned by an adviser in our study who feared the loss of smaller farms because the larger farmers 'have got the big kit' and are 'making the money' (A1) to seize upon technological change. Bronson and Knezevic (2016) and Rotz *et al.* (2019, p. 112) speak of a rural 'digital divide', referring both to the potential loss of rural jobs with automation, but also to the differing capacities of farmers to adapt to a new world (see also Hennessy *et al.* 2016 on the digital divide in farming). Panganiban (2018, p. 52) supports this argument, stating that '[f] or those who have access or the information 'haves', technology offers opportunities, inclusion and wealth but for those who cannot or the information 'have-nots', it presents a risk of greater isolation and increased poverty'. In the UK, average Farm Business Income varies by sector – £106,400 for general cropping, down to £15,500 and £12,500 for Less Favoured Area grazing livestock and lowland grazing livestock respectively (National Statistics and Defra 2019). Geographically, there is also a divide in the quality of rural infrastructure with the North-East having the highest percentage of non-internet users and 4G 'not spots'. To expect the promised benefits of new agricultural technology to be spread evenly across the UK, and elsewhere, is optimistic without remedial policy action to boost adaptive capacity for some farm businesses.

In addition, some media articles did highlight the potential loss of jobs from farm automation, which was raised by two farmers who compared the upcoming revolution with past periods of technological change. This is a theme raised in a number of studies, including Rotz *et al.* (2019) and also Eastwood *et al.* (2019b), who explored the changing role of the farm adviser in an era of digitalisation, arguing that their role may have to change from information gatherer to data interpreter in order to remain relevant (see also Rose *et al.* 2018a). Consumer acceptance of new technologies was also mentioned as a barrier to the revolution in the media and policy documents, echoed by one farmer who wondered if the public wanted farmers to remain ‘in the Stone Age’ (F4) and not use some of the new technologies.

Power inequalities were briefly discussed in both the policy documents (issue of data ownership, NFU 2019) and interviews. Farmers discussed how technology companies could monopolise certain types of production systems, for example genetic modification in America, and concerns were raised about how reliant practitioners would be on companies to update and repair products, perhaps leaving them with little choice but to purchase their next or replacement product from the same company. The ‘right to repair’ movement is gathering pace across the world, including in agriculture in the USA (The Guardian 2017), and practitioners were clearly worried about who was driving the technology revolution in farming and who would benefit most (see adaptive capacity theme above). As one farmer argued ‘once everyone is dependent on it [piece of technology], you haven’t got any choice but to use those companies’ (F3) who make it. Though not specifically mentioned by our interviewees, other aspects of power inequalities have been raised by research into the social impacts of the fourth agricultural revolution, including an assessment of how the directionality of power can be used to create or resist change (Turner *et al.* 2020). The issue of data sharing and whether the vast amounts of information collected by sensors, robots, and drones would primarily benefit the farmer or the technology company through more targeted R + D and product placement has been raised in a number of studies, and was discussed in the NFU document (Wolfert *et al.* 2017; Fleming *et al.* 2018; Bronson and Knezevic 2019; Klerkx *et al.* 2019; Lioutas *et al.* 2019). In a survey of 1,000 Australian farmers, it was found that 74 per cent did not know much at all about the terms and conditions relating to data collection by service providers (e.g., from drones, sensors etc.), and only 24 per cent said they would be happy if companies had direct access to their farm data. Also, 67 per cent of farmers said they would not be happy if service providers used such data to make profits and 56 per cent said they did not trust them to keep their data safe (Wiseman *et al.* 2019; Jakku *et al.* 2019). A further study has argued that robots could place employees under greater surveillance (De Stefano 2018) and the use of drones could do likewise.

Interviewees spoke much more prominently about the performance shortcomings of precision technology than the media and policy documents. Interviewees spoke about how technology may not produce the promised benefits based on the existing precision equipment that was already being used on-farm. This was lacking somewhat from the media/documents, many of which outlined the promised claims of improved productivity, better lifestyles, and lower environmental footprint with little critical evaluation. Although precision technologies were found to be useful in many circumstances, some practitioners felt that their investment was not always cost-effective and that certain tasks could be done better without technology. One farmer said that some tasks could be better done ‘the old-fashioned way’ and needed to see ‘a real benefit’ (F7) from the technology coming on to the market before using it. Such a view raises the important question of how policy-makers, and indeed technology companies, are evaluating actual impacts on-farm, rather than predicting grand benefits from trial scenarios. It is worth interrogating the claims offered by proponents of technology, or as Kuch *et al.* (2020) write 'the promise of precision'; in a real-world scenario, to what extent do promised benefits actually become a reality?

The media and policy documents rarely discussed the potential mental health implications of new technology. In the interviews, though there was some discussion of how robotics was improving farmer lifestyles, by reducing the amount of physical work, freeing up time to do other things, and making dairy work accessible to a worker with arthritis (these benefits were also raised in a study on robotic milking in New Zealand (Edwards *et al.* 2020), the same respondents also argued that different forms of stress could be created. A dairy farmer spoke about information overload caused by robots constantly collecting data, potentially forcing workers to 'be on-call 24 hours a day' (F2). This illustrates the need for further research and policy attention to investigate how new technologies can act as a double-edged sword on farms, solving one problem, but potentially creating another, as has been highlighted in studies on precision dairy farming (Jago *et al.* 2013; Hansen 2015). A staff member of the NFU was quoted in one media source articulating such a view, saying 'it's exciting – as well as being a bit scary ... But then the two often go together' (The Telegraph, 2018). These trade-offs need to be understood so that they can be clearly articulated.

Lastly, farmers and advisers spoke about the loss of practical knowledge, which was not discussed widely in the media and policy documents, except as a note of caution in the NFU document. The tacit assumption in most of the media and policy documents was that increased use of emergent technologies would improve the evidence-base for decision-making, yet practitioners wondered whether an overreliance on machines would dilute vital experiential knowledge that farmers, advisers, and farm workers currently accrue (Rose *et al.* 2018b). One farmer, for example, spoke about workers becoming 'over-reliant' (F5) on technology. Policy-makers may find it useful to clarify the role of new technologies on-farm and consider how they can be deployed alongside experiential knowledge, rather than seeking to replace it.

Conclusion

To our knowledge this article represents the first empirical attempt to compare media, policy, and practitioner narratives about agricultural technology and the fourth agricultural revolution in particular. We found that the fourth agricultural revolution is generally associated with emergent, game-changing technologies such as artificial intelligence, gene editing, and robotics, at least in media and policy discourse, and the term itself does not seem to resonate with practitioners. In these sources, the benefits to productivity and the environment are prioritised with less attention to social impacts. Media articles and policy documents tend to 'hype' these individual technologies, portraying them in a positive light. It was clear that farmers and advisers too experienced many benefits of new or old technologies being used on the farm and some predicted higher-tech farming futures. It was much clearer from the interviews, however, that technologies do, and will, create a number of negative consequences on-farm, which was a perspective lacking attention in many of the media and policy sources. If we choose to pursue high-tech farming futures, then there will be a unique set of both positive and negative consequences, just as there would be if we chose alternative less 'high-tech' pathways, such as agroecology (Levidow *et al.* 2012; Klerkx and Begemann 2020; Klerkx and Rose 2020). These negative consequences may well be unevenly spread across society, particularly if some farmers are less able to adapt and benefit from new technologies.

In light of the growing number of studies showing how the benefits of the fourth agricultural revolution will be spread unevenly across rural communities, creating a set of winners and losers, anticipation exercises (e.g., horizon scanning) should be undertaken regularly by policy-makers and funders of technology development (Eastwood *et al.* 2019a). These exercises should start by clearly articulating visions of farming futures so that the consequences of individual technologies and ideas can be fully known (Rose and Chilvers 2018). When undertaking horizon scanning exercises, a wide range of farming stakeholders should be included and decision-makers should adopt a reflexive approach by being prepared to change technology trajectories if particular visions of the future are deemed unacceptable (Rose and Chilvers 2018).

Then, the claims of technologists should be interrogated, ideally in a participatory fashion including a range of different stakeholders (farmers, advisers, policy-makers, civil society), both in terms of questioning whether promised benefits to people, production, and the planet will occur in practice, and also those impacts that are not immediately foreseen, which may be good or bad for sustainability (Rose *et al.* 2020). Technology fixes may actually create more harm than good, solving one problem, but creating another, and thus trade-offs should be clearly articulated (Devkota *et al.* 2020). Policy-makers will also need to be aware of the differing levels of adaptive capacity across the farming community and be prepared to support those individual farm businesses that need greater support.

The findings from this research would be strengthened by including a greater range of farmers and advisers in the UK from different sectors and regions, analysis of media and policy documents from outside the UK (though see Lajoie-O'Malley *et al.* 2020 for one example of global analysis), and from further studies in different countries. It is necessary for scholarship to continue a focus on the benefits, opportunities, and risks presented by the fourth agricultural revolution; in essence, critically evaluating the 'promise of precision' which can be over-hyped amidst public and private spending sprees in the rush towards ever-more sophisticated technologies (Kuch *et al.* 2020). This will help to provide further empirical weight to encourage policy-makers and technologists to consider how farming futures can be made more responsible.

Data Availability Statement

Research data relating to the qualitative interviews are not shared because the ethics form stated that data would be destroyed at the end of the project. The media and policy documents analysed, plus search terms, are available in Appendix 2.

Notes

[1] *Corresponding author.

Previous agricultural revolutions all represented a paradigm shift with production systems dramatically changed, either through the adoption of new techniques or technologies. The first revolution saw hunter-gatherers move to settled agriculture, the second saw changing production systems in response to new technologies created, for example, in Britain in the eighteenth century, and the third saw technologies being exported to developing countries in pursuit of a 'Green Revolution' (Rose and Chilvers 2018).

[2] We acknowledge that the fourth agricultural revolution does not necessarily involve technology (Schlaile *et al.* 2017). Innovation or progress can be driven by new ideas or the introduction of new or old management practices. Here, however, since the fourth agricultural revolution is generally associated with technology, we felt it was important to consider which technologies were being included and excluded and to anticipate the consequences of particular technology trajectories. The articles we reviewed tended not to use terms about the fourth agricultural revolution interchangeably (though some did e.g., The Telegraph, 2018 and 2019).

[3] Just before the final revision of this manuscript was submitted, the UK government announced the second tranche of projects attracting investment in the Transforming Food Production scheme (https://bit.ly/30X1iTl). Technologies funded included automated robotics and growing systems, automated climate controlling tech, vertical farming (plus technologies to assist growth in vertical farming systems), precision livestock technology (e.g., wearable tech), technology to turn carbon dioxide into food for fish and poultry, and an innovation demonstrator system to measure average potato sizes and yield throughout fields.

Acknowledgements

HB acknowledges the support of the University of East Anglia in providing funds for the dissertation research that this article is taken from. Thanks to interview participants and A. Lovett, E. Vrain, and E. Emmett for help with the study. DCR is funded by the Elizabeth Creak Charitable Trust. We thank the two anonymous reviewers who improved the manuscript.

References

Agricultural Industries Confederation (2013) Value of advice project – report (Peterborough: Agricultural Industries Confederation Ltd). Available online at http://www.appg-agscience.org.uk/linkedfiles/AIC%20Value%20of%20Advice%20Report%202013%20pdf.pdf?LMCL=k_AF_j Accessed 5 February 2020

Asayama, S. and A. Ishii (2017) Selling stories of techno-optimism? The role of narratives on discursive construction of carbon capture and storage in the Japanese media. *Energy Research & Social Science* 31 pp. 50–59

Ayre, M., V. McCollum, W. Waters *et al.* (2019) Supporting and practising digital innovation with advisers in smart farming. *NJAS – Wageningen Journal of Life Sciences* pp. 90–91

Barnes, A., I. DeSoto, V. Eory *et al.* (2019) Influencing factors and incentives on the intention to adopt precision agricultural technologies within arable farming systems. *Environmental Science & Policy* 93 pp. 66–74

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

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

Bronson, K. and I. Knezevic (2016) Big Data in food and agriculture. *Big Data & Society* 3 (1) pp. 1–5

Bronson, K. and I. Knezevic (2019) The digital divide and how it matters for Canadian food system equity. *Canadian Journal of Communication* 44 pp. 63–68

Carolan, M. (2020) Automated agrifood futures: robotics, labor and the distributive politics of digital agriculture. *The Journal of Peasant Studies* 47 pp. 184–207

De Clercq, M., A. Vats and A. Biel (2018) Agriculture 4.0: the future of farming technology. *World Government Summit*. Available online at https://www.oliverwyman.com/our-expertise/insights/2018/feb/agriculture-4-0--the-future-of-farming-technology.html Accessed 9 October 2019

Defra (2018). Health and Harmony: the future for food, farming and the environment in a Green Brexit (London: UK Government). Available online at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741461/future-farming-consult-sum-resp.pdf Accessed 20 January 2020

Dentzman, K., R. Gunderson and R. Jussaume (2016) Techno-optimism as a barrier to overcoming herbicide resistance: comparing farmer perceptions of the future potential of herbicides. *Journal of Rural Studies* 48 pp. 22–32

Department for Business, Energy and Industrial Strategy, Department for Environment Food and Rural Affairs, and Rt Hon Greg Clark MP, Business Secretary (2018). Business secretary calls for new tech revolution in agriculture. Available online at https://www.gov.uk/government/news/business-secretary-calls-for-new-tech-revolution-in-agriculture Accessed 5 February 2020

De Stefano, V. (2018) "Negotiating the algorithm": automation, artificial intelligence and labour protection. Employment Working Paper No. 246 (Geneva: International Labour Office)

Devkota, R., L. Prasad Pant, H. Bath Gartaula *et al.* (2020) Responsible agricultural mechanization innovation for the sustainable development of Nepal's hillside farming system. *Sustainability* 12 (1) pp. 374

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

Donk, A., J. Metag, M. Kohring *et al.* (2011) Framing emerging technologies: risk perceptions of nanotechnology in the German Press. *Science Communication* 34 (1) pp. 5–29

Eastwood, C., L. Klerkx, M. Ayre *et al.* (2019a) 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 pp. 741–768

Eastwood, C., M. Ayre, R. Nettle *et al.* (2019b) Making sense in the cloud: farm advisory services in a smart farming future. *NJAS – Wageningen Journal of Life Sciences* pp. 90–91

Edwards, P., B. Kuhn-Sherlock, B. Dela Rue *et al.* (2020) *Short communication*: technologies and milking practices that reduce hours of work and increase flexibility through milking efficiency in pasture-based dairy farm systems. *Journal of Dairy Science* 103 (8) pp. 7172–7179

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

Firbank, L.G., S. Attwood, V. Eory *et al.* (2018) Grand challenges in sustainable intensification and ecosystem services. *Frontiers in Sustainable Food Systems* 2 pp. 7

Fleming, A., E. Jakku, L. Lim-Camacho *et al.* (2018) Is big data for big farming or for everyone? Perceptions in the Australian grains industry. *Agronomy for Sustainable Development* 38 pp. 24

Goldberg, A.K. and F.J. Riemer (2006) All aboard – destination unknown: a sociological discussion of online learning. *Educational Technology & Society* 9 (4) pp. 166–172

Gove, M. (2019) Oxford farming conference 2019 address by the environment secretary. Available online at: https://www.gov.uk/government/speeches/oxford-farming-conference-2019-address-by-the-environment-secretary Accessed 23 February 2020

Gremmen, B., V. Blok and B. Bovenkerk (2019) Responsible innovation for life: five challenges agriculture offers for responsible innovation in agriculture and food, and the necessity of an ethics of innovation. *Journal of Agricultural and Environmental Ethics* 32 pp. 673–679

Griffin, T.W., N. Miller, J.S. Bergtold *et al.* (2017) Farm's sequence of adoption of information-intensive precision agricultural technology. *Applied Engineering in Agriculture* 33 (4) pp. 521–527

The Guardian (2017) A right to repair: why Nebraska farmers are taking on John Deere and Apple. Available online at: https://www.theguardian.com/environment/2017/mar/06/nebraska-farmers-right-to-repair-john-deere-apple Accessed 23 February 2020

Hansen, B.G. (2015) Robotic milking-farmer experiences and adoption rate in Jæren, Norway. *Journal of Rural Studies* 41 pp. 109–117

Hennessy, T., D. Läpple and B. Moran (2016) The digital divide in farming: a problem for access of engagement? *Applied Economic Perspectives and Policy* 38 (3) pp. 474–491

Hickey, L.T., A.N. Hafeez, H. Robinson *et al*. (2019) Breeding crops to feed 10 billion. *Nature Biotechnology* 37 pp. 744–754

HM Government (2013) A UK strategy for agricultural technologies (London: UK Government). Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/227259/9643-BIS-UK_Agri_Tech_Strategy_Accessible.pdf Accessed 20 January 2020

HM Government (2018) A green future: our 25-year plan to improve the environment (London: UK Government). Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf Accessed 23 February 2020

Holton, M. and M. Riley (2014) Talking on the move: place-based interviewing with undergraduate students. *Area* 46 pp. 59–65

Ingram, J. (2008) Agronomist–farmer knowledge encounters: an analysis of knowledge exchange in the context of best management practices in England. *Agriculture and Human Values* 25 pp. 405–418

Jago, J., C.R. Eastwood, K. Kerrisk *et al*. (2013) Precision dairy farming in Australasia: adoption, risks and opportunities. *Animal Production Science* 53 (9) pp. 907–916

Jakku, E., B. Taylor, A. Fleming *et al*. (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* pp. 90–91

Jasanoff, S. (2005) Designs on nature: science and democracy in Europe and the United States (Princeton, NJ: Princeton University Press)

Kamilaris, A., A. Kartakoullis and F.X. Prenafeta Boldú (2017) A review on the practice of big data analysis in agriculture. *Computers and Electronics in Agriculture* 143 pp. 1–31

Kernecker, M., A. Knierim, A. Wurbs *et al*. (2020) Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe. *Precision Agriculture* 21 pp. 34–50

Klerkx, L. and S. Begemann (2020) Supporting food systems transformation: the what, why, who, where and how of mission-oriented agricultural innovation systems. *Agricultural Systems* 184 pp. 102901.

Klerkx, L., E. Jakku and P. Labarthe (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* pp. 90–91

Klerkx, L., B. van Mierlo and C. Leeuwis (2012) Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. In I. Darnhofer, D. Gibbon, B. Dedieu eds, Farming systems research into the 21st century: the new dynamic (DordrechtSpringer)

Klerkx, L. and D. Rose (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 pp. 100347.

Kuch, D., M. Kearnes and K. Gulson (2020) The promise of precision: datafication in medicine, agriculture and education. *Policy Studies* 41 (5) pp. 527–546. https://doi.org/10.1080/01442872.2020.1724384

Lajoie-O'Malley, A., K. Bronson, S.van der Burg *et al*. (2020) The future(s) of digital agriculture and sustainable food systems: an analysis of high-level policy documents. *Ecosystem Services* 45 pp. 101183.

Levidow, L., K. Birch and T. Papaioannou (2012) EU agri-innovation policy: two contending visions of the bio-economy. *Critical Policy Studies* 6 (1) pp. 40–65
Lioutas, E.D., C. Charatsari, G. La Rocca *et al*. (2019) Key questions on the use of big data in farming: an activity theory approach. *NJAS – Wageningen Journal of Life Sciences* pp. 90–91
Lowder, S.K., J. Skoet and T. Raney (2016) The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development* 87 pp. 16–29
Lowenberg-DeBoer, J. and B. Erickson (2019) Setting the record straight on precision agriculture adoption. *Agronomy Journal* 111 (4) pp. 1552–1569
Macnagthen, P. and M.G.J.L. Habets (2020) Breaking the impasse: towards a forward-looking governance framework for gene editing with plants. *Plants, People, Planet* 2 (4) pp. 353–365. https://doi.org/10.1002/ppp3.10107
Miranda, J., P. Ponce, A. Molina *et al*. (2019) Sensing, smart and sustainable technologies for agri-food 4.0. *Computers in Industry* 108 pp. 21–36
Morris, C. (2018) 'Taking the politics out of broccoli': debating (de)meatification in UK national and regional newspaper coverage of the meat free mondays campaign. *Sociologia Ruralis* 58 (2) pp. 433–452
Nally, D. (2016) Against food security: on forms of care and fields of violence. *Global Society* 30 pp. 558–582
National Farmers' Union (2019) The future of food 2040. Available online at: https://www.nfuonline.com/nfu-online/news/the-future-of-food-2040/ Accessed 20 January 2020
National Statistics and Defra (2019) Farm business income by type of farm in England, 2018/19 (London: Crown copyright). Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/847722/fbs-businessincome-statsnotice-21nov19.pdf Accessed 1 April 2020
Pallett, H., J. Chilvers and T. Hargreaves (2019) Mapping participation: a systematic analysis of diverse public participation in the UK energy system. *Environment and Planning E: Nature and Space* 2 (3) pp. 590–616
Panganiban, G.G.F. (2018) E-governance in agriculture: digital tools enabling Filipino farmers. *Journal of Asian Public Policy* 12 (1) pp. 51–70
Pannell, D.J. and R. Claassen (2020) The roles of adoption and behavior change in agricultural policy. *Applied Economic Perspectives and Policy* 42 (1) pp. 31–41
Regan, A. (2019) Smart farming' in Ireland: a risk perception study with key governance actors. *Wageningen Journal of Life Sciences* 90–91 pp. 1–10
Rial-Lovera, K., P. Davies and N.D. Cannon (2017) Implications of climate change predictions for UK cropping and prospects for possible mitigation: a review of challenges and potential responses. *Journal of the Science and Food of Agriculture* 97 pp. 17–32
Rockström, J., J. Williams, G. Daily *et al*. (2017) Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio* 46 pp. 4–17
Rose, D.C. and J. Chilvers (2018) Agriculture 4.0: broadening responsible innovation in an era of smart farming. *Frontiers in Sustainable Food Systems* 2 pp. 1–7
Rose, D.C., C. Morris, M. Lobley *et al*. (2018a) Exploring the spatialities of technological and user re-scripting: the case of decision support tools in UK agriculture. *Geoforum* 89 pp. 11–18
Rose, D.C., C. Parker, J. Fodey *et al*. (2018b) Involving stakeholders in agricultural decision support systems: improving user-centred design. *International Journal of Agricultural Management* 6 (3–4) pp. 80–89
Rose, D.C., W.J. Sutherland, C. Parker *et al*. (2016) Decision support tools for agriculture: towards effective design and delivery. *Agricultural Systems* 149 pp. 165–174
Rose, D.C., R. Wheeler, M. Winter *et al*. (2020) Agriculture 4.0: making it work for people, production, and the planet. *Land Use Policy* 100 pp. 104933. https://doi.org/10.1016/j.landusepol.2020.104933

Rotz, S., E. Gravely, I. Mosby *et al.* (2019) Automated pastures and the digital divide: how agricultural technologies are shaping labour and rural communities. *Journal of Rural Studies* 68 pp. 112–122

Schlaile, M.P., S. Urmetzer, V. Blok *et al.* (2017) Innovation systems for transformations towards sustainability? Taking the normative dimension seriously. *Sustainability* 9 pp. 2253

Sheng, Y. and W. Chancellor (2019) Exploring the relationship between farm size and productivity: evidence from the Australian grains industry. *Food Policy* 84 pp. 196–204

Shepherd, M., J.A. Turner, B. Small *et al.* (2018) Priorities for science to overcome hurdles thwarting the full promise of the 'digital agriculture' revolution. *Journal of the Science of Food and Agriculture*. https://doi.org/10.1002/jsfa.9346

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

Stringer, L.C., E.D.G. Fraser, C. Harris *et al.* (2020) Adaptation and development pathways for different types of farmers. *Environmental Science & Policy* 104 pp. 174–189

Thiault, L., C. Mora, J.E. Cinner *et al.* (2019) Escaping the perfect storm of simultaneous climate change impacts on agriculture and marine fisheries. *Science Advances* 5 (11) pp. eaaw9976

Turner, J.A., A. Horita, S. Fielke *et al.* (2020) Revealing power dynamics and staging conflicts in agricultural system transitions: case studies of innovation platforms in New Zealand. *Journal of Rural Studies* 76 pp. 152–162

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

Van der Veen, M. (2010) Agricultural innovation: invention and adoption or change and adaptation? *World Archaeology* 42 (1) pp. 1–12

Vik, J., E. Petter Stræte, B. Gunnar Hansen *et al.* (2019) The political robot – the structural consequences of automatic milking systems (AMS) in Norway. *NJAS – Wageningen Journal of Life Sciences* 90–91 pp. 1–9

Vrain, E. and A. Lovett (2019) Using word clouds to present farmers' perceptions of advisory services on pollution mitigation measures. *Journal of Environmental Planning and Management* 63 (6) pp. 1132–1149

Werkheiser, I. (2020) Technology and responsibility: a discussion of underexamined risks and concerns in precision livestock farming. *Animal Frontiers* 10 (1) pp. 51–57

Wiseman, L., J. Sanderson, A. Zhang *et al.* (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* pp. 90–91

Wolfert, S., L. Ge, C. Verdouw *et al.* (2017) Big data in smart farming – a review. *Agricultural Systems* 153 pp. 69–80

Young, J.C., D.C. Rose, H. Mumby *et al.* (2019) A methodological guide to using and reporting on interviews in conservation science research. *Methods in Ecology and Evolution* 9 (1) pp. 10–19

Hannah Barrett
School of Environmental Sciences
University of East Anglia
Norwich Research Park, Norwich
NR4 7TJ
UK

David Christian Rose*
School of Agriculture, Policy and Development
University of Reading

Earley, Reading
RG6 6AR
UK
d.c.rose@reading.ac.uk

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web site: