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Responsible development of digital livestock technologies for agricultural challenges: Purpose, practicality and effects are key considerations

Hugh F. Williamson PhD | **Sarah Hartley PhD**

Department of Management, Faculty of Environment, Science and Economics, University of Exeter, Exeter, UK

Correspondence
Hugh F. Williamson PhD, Department of Management, Faculty of Environment, Science and Economics, University of Exeter,UK.
Email: h.williamson@exeter.ac.uk

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Abstract

Digital livestock technologies (DLTs) are presented as solutions to grand challenges in post-Brexit British agricultural policy, such as climate change and food security. Evidence suggests technological solutions to agricultural challenges will be more effective with stakeholder and public engagement, yet there is little known about stakeholder views on these emerging technologies. We drew on responsible research and innovation, to analyse stakeholder perspectives on three case studies of DLT development through anticipatory focus groups with expert stakeholders in British animal agriculture. We found that stakeholders from broadly agroecological approaches to farming are at risk of exclusion from DLT development and policy, with negative implications for the ability of DLTs to resolve grand challenges in animal agriculture. We propose a heuristic framework of purpose, practicality and effects as key considerations for inclusive and responsible DLT development that contributes to ensuring effective solutions to grand challenges while avoiding wasted investments.

KEYWORDS
agri-tech, animal agriculture, data, digital technology, inclusion, responsible innovation

INTRODUCTION

Technologies are often accompanied by hopes that they will solve societal or 'grand' challenges through pathways of commercialisation that also contribute to economic development and productivity. These goals are frequently presented as the motivating purposes for the funding, development and use of digital technologies in agriculture, including the development of digital livestock technologies (DLTs) in animal farming. In February 2024, addressing the National Farmers' Union (NFU), the then-British Prime Minister Rishi Sunak announced a funding package worth £220 million for technological innovation on British farms (UK Government, 2024). Sunak framed this intervention as a response to a range of grand challenges currently facing farming, including climate change adaptation and food security in a rapidly changing geopolitical context, while surrounding press releases foregrounded the importance of increasing the productivity of the British farming sector and fostering economic growth. Sunak's speech builds on the continued growth of technology in this sector, visible in earlier policy reports (e.g., Pardoe & Bhattacharya, 2022) that garnered support from the NFU and UK parliamentary groups (National Farmers' Union, 2023).

Despite this political emphasis, the ability of DLTs to deliver solutions to grand challenges is not ensured. DLTs include a range of technologies, from automated infrastructures such as robotic milking systems (Schewe & Stuart, 2015) to a diversity of sensing and imaging technologies (Neethirajan, 2020; Neethirajan & Kemp, 2021). What characterises these technologies is the central role of data in their operation and use, whether to guide automated processes (as in robotic systems) or for use in decision-making, research and innovation. DLTs have a range of applications in regard to farm management and monitoring (Halachmi et al., 2019). They have been particularly valued in relation to grand challenges due to their ability to capture extensive data about complex phenomena, such as farm and animal performance under changing environmental conditions, that can be translated into adaptive management strategies or guide technological and biotechnological innovation, including animal breeding (Rosa, 2021). This value is often linked to discourses of precision (cf. Duncan et al., 2021). We follow Schillings et al. (2023, 2024) in referring to DLTs rather than the more commonly used term precision livestock farming. The latter phrase takes for granted the value of precision, when the value and relevance of this should be judged relative to specific goals and implementations of digital technology (Visser et al., 2021).

This research explores stakeholder perspectives on DLTs as solutions to grand challenges in agriculture through anticipatory focus groups where participants discussed three case studies of DLT development. Research in science and technology studies (STS) and responsible research and innovation (RRI) demonstrates that technological solutions to challenges in agriculture are limited in their effectiveness without engaging a broad range of expertise, diverse stakeholders and the public upstream in the decision-making that underpins technology development processes (Ludwig et al., 2022; Rose & Chilvers, 2018). In particular, RRI scholars draw attention to the need to address inclusion together with anticipation of the future impacts of technology development (Espig et al., 2022). Such anticipatory work is particularly important when technologies are framed as solutions to grand challenges, to anticipate whether and how they can in fact fulfil this function.

This article argues for the value of a heuristic framework of purpose, practicality and effects as key considerations for responsible development of DLTs and digital agricultural technologies more broadly, a framework derived from our empirical research and existing literature. In particular, our research indicates that failing to attend to purpose can lead to the exclusion of important stakeholders because the alignment of technological purpose with stakeholder goals and values is key to whether or not those stakeholders will engage with and adopt that technology. This in turn can jeopardise the chances of technologies contributing to the resolution of grand challenges in agriculture because such resolutions require the participation of diverse stakeholders engaged in multiple approaches to and areas of farming. We find that the current policy and development directions of DLTs do not engage sufficiently with the values and commitments of practitioners in alternative farming approaches such as organic and regenerative agriculture (sometimes captured under the umbrella term agroecology; Mason et al., 2024). We present a set of guiding questions that policymakers, technology developers and social scientists can use to reflect on their work and inform additional stakeholder engagement as part of co-productive digital technology development. Such co-production seeks to realise an inclusive and collaborative approach to science and technology development that is responsive to the needs, expertise and values of society more broadly (Chambers et al., 2021; Norström et al., 2020).

Responsible innovation in digital agriculture

In a recent editorial in this journal, Fielke et al. (2022) review the increasing role of RRI within the development of digital technologies in agriculture. RRI emphasises several key principles for technology governance and development, including anticipation of risks, inclusion of diverse perspectives, reflexivity about purposes and methods and responsiveness to stakeholders and changing circumstances (Rose & Chilvers, 2018; cf. Stilgoe et al., 2013). One theme that Fielke et al. (2022) draw out is the challenge of operationalising RRI within existing structures of agricultural research. This is analysed in more detail by Espig et al. (2022) in the same issue (cf. Jakku et al., 2022). Espig et al. (2022) note several broad challenges, including a lack of guidelines for translating RRI into practice and the fact that digitalisation is itself a transformative process, which makes establishing appropriate societal and institutional arrangements difficult (cf. Klerkx & Rose, 2020). They then address the specific challenges raised by implementing principles of anticipation, inclusion, reflexivity and responsiveness. Here, we focus on the areas of anticipation and inclusion, which (for reasons discussed below) Espig et al. (2022) note cannot be considered separately. Finding modes of research and engagement to facilitate anticipation in particular has presented a persistent challenge for RRI as highlighted by Guston (2013) a decade ago (cf. Muiderman et al., 2020, 2022). Espig et al. (2022) observe that anticipation in agricultural research is frequently practised at the funding proposal stage, where (in response to the pressures of funding evaluation) it is framed in terms of maximising beneficial impacts and minimising potential risks to delivery of the project itself. Conversely, anticipation of social and ethical impacts deriving from research and development outcomes is disincentivised within funding processes. The latter form of anticipation necessarily requires engagement with and inclusion of diverse stakeholders, yet this can prove challenging due to the differing interests of stakeholder groups: Commercial and industry stakeholders tend to prioritise ensuring successful innovation pathways, while public and government stakeholders tend to prioritise the public good and anticipation of transformational outcomes over the long run (Espig et al., 2022). Moreover, Fielke et al. (2022) argue that there remains a need for RRI practitioners in the agricultural domain to move beyond engaging the 'usual suspects', such as farmers and farm advisors, and towards more diverse stakeholders.

There is, therefore, a need for greater clarity and guidance around operationalising the inclusive and anticipatory dimensions of RRI in regard to digital agricultural technologies. One model for anticipatory engagement is Macnaghten's (2021) anticipatory public engagement methodology, which utilises focus groups with diverse stakeholders, organised around a particular set of design criteria. This methodology is targeted at collectively eliciting views on still-emerging science and technologies towards which people may not yet have fully formed views. The focus groups provide a deliberative space in which participants can form attitudes and standpoints collectively, during discussion (although it is not presumed that such deliberation requires or will produce consensus). This outcome is facilitated by several design features, including the *context* and *framing* of the focus groups. Establishing a context for discussion at the outset helps participants to situate their response to technological innovations that may be unfamiliar, while careful framing of the presentation of technologies to participants is necessary to avoid pre-emptively closing down or narrowing certain lines of discussion, understanding or evaluation (see Macnaghten, 2021). As such, this method provides one plausible solution for, on the one hand, engaging diverse stakeholders and publics (especially those outside the expert communities involved in scientific research or technology development) in anticipatory deliberation and, on the other hand, addressing the area of digitalisation in agriculture, which is still emerging and has not yet been subject to a great deal of political or public scrutiny.

Where anticipatory focus groups provide one appropriate methodology for inclusive anticipation in digital agriculture—although not necessarily the only one—there remains a gap in guidance for shaping such engagement (e.g., informing the context and framing of focus groups) that addresses the broader scope of social and ethical issues raised by digital agricultural technology development. This gap can be addressed, we argue, through applying a heuristic framework of purpose, practicality and effects as key considerations for responsible digital agricultural technology development. Work in RRI and related fields such as STS have identified what we systematise as three main areas of consideration when it comes to the social and ethical aspects of digital agricultural technologies:

- Considerations of *purpose* concern the motivating challenge behind a technology, and the relationship of the proposed technology to the challenge.
- Considerations of *practicality* concern the functionality of a technology, the conditions for effective development and the possibilities and challenges to adoption by farmers.
- Considerations of *effects* concern the potential effect of the technology on humans, animals and agricultural systems, as well as likely outcomes beyond the declared purpose.

These considerations were also evident in our empirical research and are analysed in more detail below. Nevertheless, the three considerations are not consistently given equal weighting in practice across the wider scope of RRI activity. This is significant because neglecting certain areas of consideration in the design of research (e.g., in the context and framing of focus groups) can lead to critical areas of concern for particular stakeholders being left out of the discussion, and stakeholders themselves being indirectly excluded.

We can illustrate this gap by surveying some of the existing literature on responsible innovation of DLTs in animal agriculture. There is a substantial body of work analysing the potential effects of DLTs, for example, on animals' welfare (e.g., Buller et al., 2020; Dawkins, 2021; Giersberg & Meijboom, 2021; Herlin et al., 2021; Schillings et al., 2021b, 2021a; Tuyttens et al., 2022). Other studies analysed the implications of introducing digital technologies into human–animal relationships, especially concerning the possibility that they may distance farmers from their animals (Bos et al., 2018; Cornou, 2009; Kling-Eveillard et al., 2020; Werkheiser, 2018). Researchers also note the potential for DLTs to affect human workers in agricultural settings, for example, through processes of deskilling (Bellet, 2022; Tuyttens et al., 2022), intrusions into privacy via audio–visual data collection (Giersberg & Meijboom, 2022) or increased monitoring of workers via DLTs (Ramirez et al., 2019). Others have raised questions about who is accountable and has a duty to act and how, if workers are recorded mistreating animals (Giersberg & Meijboom, 2022). Such considerations of potential effects may be formally introduced into the technology development process through methods such as early ethical assessment (Thompson et al., 2021).

In contrast to the above work, research on questions of practicality and purpose is more limited and has tended to take a narrower framing. The practicality of DLT development and adoption is widely recognised as a challenge and indeed is often framed as the major challenge in regard to DLTs and other forms of agri-tech by policymakers and technology developers. This perspective is evident in both policy-facing reports (Pardoe & Bhattacharya, 2022) and academic social scientific research (Drewry et al., 2019; Lima et al., 2018; Ramirez et al., 2019). Such work frequently takes the value of DLTs as self-evident and treats farmer attitudes as an obstacle to adoption rather than being closely tied to the purpose and design of the technologies themselves. Schillings et al. (2023) describe this dynamic as a case of 'technology push', where technical possibility leads the development process, resulting in DLTs that are not adequately adapted to farmers' needs and therefore not adopted.

The question of purpose and the motivations driving DLT development has received even less direct attention. There has been some exploration of the relationship between DLTs and stakeholders' perceptions of livestock farming systems (Giersberg & Meijboom, 2021). For example, Krampe et al. (2021) report that consumers in three European countries raised concerns about the extent to which digital technologies could lead to the increased industrialisation of livestock farming, through automation and digitalisation, but the authors ultimately see this view as an obstacle to technological acceptance that should be overcome rather than taking such concerns seriously. Looking beyond stakeholder attitudes towards how DLTs are presented in scientific literature and media—key sites for shaping attitudes—Bellet (2022) analyses how the value and use of sensors within dairy farming is predominantly framed within an industrial-focused vision of agriculture. Bellet argues that this industrial vision for DLTs serves to close down creative opportunities for improving human–animal interactions through digital technology, channelling their use into certain instrumental purposes, rather than facilitating novel applications. Most directly, Elliott and Werkheiser (2023) analyse the need for transparency in the development of DLTs. They observe that development can be motivated by a range of different goals and values, from animal welfare through profitability and sustainability, and that these may come into conflict with one another. For this reason, they argue that transparency about the aims and nature of DLTs is important to ensure that stakeholders can effectively judge which technologies respond to their goals and values.

The neglect of purpose is a serious concern because significant political investments are currently being made in agricultural technologies under the justification that they will contribute to resolving grand challenges in agriculture. As researchers in RRI and STS have observed (Ludwig et al., 2022; Rosemann & Molyneux-Hodgson, 2023), grand challenge approaches to innovation are often framed in ways that stress their urgency, take for granted the ability of innovation to provide an effective solution and downplay the anticipation of potential impacts, including whether or not innovations can successfully respond to challenges. Moreover, as our research demonstrates, failing to address purpose can lead to the indirect exclusion of certain stakeholders through a lack of recognition of what are to them fundamental commitments. Understanding and engaging diverse stakeholders' views on the overall purpose motivating technology development and what role a technology may actually play in relation to this is necessary if agricultural technology development (digital or otherwise) is to move forward responsibly, in line with recommendations by Fielke et al. (2022), Espig et al. (2022) and others (Ayris et al., 2024; Rose & Chilvers, 2018). In the remainder of the article, we present the results of anticipatory research on DLTs with expert stakeholders in British animal agriculture. This research highlights the importance of purpose, practicality and effects as guiding considerations for responsible digital agricultural technology development and policymaking. We reflect on this framework further in the discussion and conclusion.

Methodology

Research was undertaken using an adapted version of an anticipatory focus group methodology (Macnaghten, 2021). Five online focus groups were conducted, with each group comprising a different set of stakeholders in animal agriculture in the UK. The stakeholder groups were: Agricultural service providers ($n = 5$), including consultants and animal breeders; digital technology developers and providers ($n = 5$); mainstream animal farming ($n = 5$), reflecting intensive and productivity-focused approaches to farming and including veterinarians as well as farmers; organic and regenerative farming ($n = 7$), including researchers and advocates as well as farmers; and animal welfare experts ($n = 6$), including academic animal welfare scientists, critical animal studies researchers and Non-Governmental Organisation experts in farm animal welfare. Participants were primarily experienced in the sheep, beef cattle and dairy cattle sectors. One poultry farmer participated in the intensive farming group. Invitations were extended to representatives of three large pig breeding and rearing companies, but they declined to participate.

Participants were identified through the authors' own networks, recommendations from colleagues at the University of Exeter and partner institutions, Internet research and snowball sampling. Participants were approached via email and invited to participate. No financial or other recompense was offered for participation. Invitations were targeted to identify a balance of male-presenting and female-presenting participants, although the final distribution was weighted towards male-presenting (total M = 17, F = 11) and was uneven across the different groups, with female-presenting participants better represented in the two farming groups than the service provider and technology developer groups and forming a majority in the animal welfare group. Invitations were also targeted to include participants from Wales ($n = 2$), Scotland ($n = 3$) and Northern Ireland ($n = 1$), although the majority of participants were based in England ($n = 22$). Where the invitee was not already working in the area of digital technology, we attached a brief document on the topic of precision livestock farming and its potential positive and negative impacts, published by the Welsh Government (Hart, 2018), as additional background information.

The focus groups centred discussion on three case studies of DLT development at an early stage of development and are described in the next section. These cases focused on digital sensing and imaging technologies and associated forms of data analysis, reflecting the importance of data to DLTs' operation. The three selected DLTs were all developed with the participation of researchers at Scotland's Rural College (SRUC). This reflected the authors' interactions with SRUC during the research phase of the project and the prominent role of the institution in animal science and agricultural research in the UK. The aim of the case studies was not to comprehensively represent the existing range of DLTs but rather to stimulate discussion relative to a range of themes and possibilities within the constraints of the focus group format. Written descriptions of the case studies were provided to the participants in a three-page document in advance of the focus group and were introduced again by the moderator at the start of the focus group. The document provided an overview of the technology in the three cases, including the motivating challenge(s) and (where relevant) any risks identified by the researchers themselves. Case descriptions were developed based on interviews with academic researchers involved in the technology development and on relevant literature, where available. The researchers were asked to read and provide feedback on the descriptions to ensure scientific accuracy. They are nevertheless not responsible for any errors nor for decisions around content and framing.

Focus groups were conducted online via Zoom in July 2023, and moderation was led by Williamson. Focus groups each lasted 90 min. To establish context, participants were asked to reflect on what they saw as the major challenges currently facing animal agriculture. They were encouraged to approach this question broadly and not limit themselves to those that appeared most relevant to digital technologies or were referenced in the case studies. Following this, participants discussed in turn the three cases. The moderator probed participants' views on the potential benefits of the technology and any hopes they may have for it, who they thought might benefit from or be affected by it and any issues they thought might arise from it. Audio was recorded via Zoom and transcribed. Transcripts were then analysed by the authors using an iterative coding process to identify key discursive themes and frames across all five focus groups. Coded data were then disaggregated by group and by case study for further analysis. The framework of purpose, practicality and effects was derived from this coding process in combination with non-systematic review of the existing social science and ethics literature on DLTs.

Case studies

The three case studies of DLT development were selected to represent a range of different technology types, sectors of animal agriculture (including different species and both intensive and extensive systems) and motivating challenges (see Table 1 and Supporting Information).

- Case 1 comprised a proposal to use X-ray computed tomography (CT) scanning to estimate the volume of sheep rumen and reticulum stomach compartments as a predictor of individual animals' methane production and to use these measures to breed sheep with lower methane emissions. This case responded to challenges of Net Zero and the reduction of greenhouse gas emissions in animal agriculture.
- Case 2 involved the development of an automated early warning system for tail biting outbreaks among confined pigs in intensive farming systems, to mitigate the outbreaks and remove the need for tail docking. Outbreaks of tail biting are a major problem in intensive pig farming, leading to poor welfare of animals and economic losses for farmers and processors due to the need to discard meat infected from injury. The system uses 3D cameras and computer vision to analyse pig tail posture (tails held downwards) as an indicator of tail biting behaviour. This case responded to challenges of animal welfare and improvements in productivity and efficiency in animal agriculture.

TABLE 1 Summary of case studies used in focus groups, including challenge, digital technology type and animal rearing system.

Case	Challenge	Digital technology type	Animal rearing system
1. X-ray computed tomography (CT) scanning sheep to breed for smaller guts and lower methane emissions	Greenhouse gas emissions/Net Zero	Large imaging technology (X-ray CT scanner)	Extensive (sheep)
2. 3D camera early warning system for pig tail biting outbreaks	Animal welfare, productivity of meat sector	Small imaging technology (3D camera), machine learning	Intensive/confined (pigs)
3. Integration of production and supply-chain data for data-driven animal breeding	Efficiency and productivity of animal agriculture	Database and data analysis	Intensive and extensive (multiple species; primarily cattle and sheep)

- Case 3 concerned the development of a national, public database for animal breeding, integrating data from across the agricultural supply chain (such as milk recording services and abattoirs) with conventional sources of genetic and performance recording data about livestock. Contemporary scientific breeding is based on the calculation of estimated breeding values (EBVs), a statistical indicator of an animal's genetic merit for a particular trait. By integrating additional data, it can become possible to develop EBVs for new traits as well as for additional species or breeds of animals than were previously available. This case responded to the challenges of improving productivity and efficiency in animal agriculture.

RESULTS

In this section, we present the results from the focus groups organised in terms of the three considerations of purpose, practicality and effects. Discussion themes were not evenly distributed across the five focus groups, with differences not only in the particular questions raised by each group but also in the relative emphases put on the three areas of consideration (see summary in Table 2). Across the groups, there tended to be greater similarity in themes between the agricultural service providers, digital technology developers and mainstream farming groups on the one hand and the organic/regenerative farming and animal welfare groups on the other. Overall, while participants in the former three groups expressed interest in and support for digital technologies as solutions to ongoing challenges in animal agriculture (even if this varied across the case studies), participants in animal welfare expressed ambivalence or concern about the cases. Participants in organic and regenerative farming not only expressed little support for the cases but more broadly saw an absence of any digital technologies currently under development that supported their aims and farming methods, with the potential exception of virtual fences.[1] As the virtual fencing example indicates, this was not an outright rejection of the potential value of digital technologies but a sense that the majority of technology development was not addressing the needs and values underpinning their farming approaches. We discuss this further in the next section.

TABLE 2 Major discursive themes from focus groups, organised by case study and whether the theme relates to questions of the digital livestock technologies' (DLTs) purpose, practicality or effects, with illustrative quotes.

Case study	Purpose	Practicality	Effects
Case 1: X-ray CT scanning sheep to breed for smaller guts and lower methane emissions	The science behind the challenge is not settled **[MF, ORF]**. The target farming sector may not be a priority area for addressing the challenge **[DTP]**. Policymaking in regard to the challenge is politically motivated **[DTP]**. Alternative solutions could be more effective, such as increasing efficiency **[ASP, DTP, MF]**, management changes **[AW, ORF]** or reducing animal numbers **[ORF]**. *'Genetically engineering sheep to reduce their intestine size is not really going to tackle [the challenge], it's just going to cause more issues for the animal. And I think a better method of reducing the emissions from sheep production would be to just reduce the amount of sheep that we farm'*. (AW-P1)	The DLT is difficult to access, impractical to use at large scale, and unaffordable to farmers without subsidies **[ASP, DTP]**. Adoption of the DLT may be limited by poor engagement with technology in the sector currently **[ASP, MF]**. The value of DLTs to farmers is poorly articulated **[ASP, DTP]**. Data collected from the DLT may be too variable to be widely useful or an unreliable indicator of the target phenomenon **[ASP, DTP, MF]**. *'CT is a fantastic resource [but] as a producer, the only reason it's affordable is due to subsidies, because otherwise it just would not cost in and the benefits would be wiped out. So it is something that if it is going to be used will need support moving forwards because it's just too expensive to do it ordinarily any other way'*. (ASP-P5)	The DLT has environmental impacts **[AW, ORF]**. Using the DLT on animals negatively affects their welfare **[ASP]**. Lack of knowledge about the biological effects of the DLT is a concern given potential impacts on animals' health and welfare **[AW]** or adaptation to diverse environments **[ASP, AW, ORF]**. The DLT may produce animals that are only fit for intensive agricultural systems **[AW, ORF]**. The DLT may primarily benefit researchers and developers **[DTP, MF, ORF]** Data collected with the DLT may have as-yet unknown future value **[ASP]**. *'I really was not keen on this idea. I think there's big scope here for if you select on rumen size, or lack of, then there's a big risk of unintended consequences. And also, you're shifting away from a ruminant animal that has evolved those suite of characteristics for a reason… I think it would be a very crude measure that would have a lot of potential broader implications for the physiology and well-being of the animals'*. (AW-P3)

(Continues)

TABLE 2 (Continued)

Case study	Purpose	Practicality	Effects
Case 2: 3D camera early warning system for pig tail-biting outbreaks	The challenge is a function of intensive agricultural systems **[AW, DTP, MF, ORF]**. Alternative solutions that prevent the problem would be a better solution **[AW, MF, ORF]**. *'When I read the scenario, I probably wasn't as supportive, because I think I came from the view of, well, we create the problem by confining pigs or livestock in somewhere where there's no enrichment for them. So we create the problem, and then try and resolve the problem through technology'*. (DTP-P1)	The DLT can be easily installed, but is expensive to install at scale and will only work effectively in intensively managed farm spaces **[ASP, DTP, MF]**. The DLT would be most cost-effective if it can provide multiple functions **[ASP, DTP, MF]**. The DLT itself does not resolve the problem and still requires human verification and intervention **[ASP, DTP, MF]**. The DLT may fail to capture the complexity of animals' behaviour and its causes **[ASP, AW, MF, ORF]**. *'Surely with this, I mean, obviously welfare is number one, so anything that can improve a situation with tail biting has got to be good. But isn't it a bit like watching someone steal your car on TV? Or, sorry, CCTV? It doesn't actually stop it happening'*. (ASP-P5)	The DLT has environmental impacts **[AW, ORF]**. The DLT does minimal or no harm to the animals **[ASP, AW, DTP]** and any welfare benefits are also economic benefits to farmers **[ASP, DTP, MF]**. The DLT may legitimate intensive agricultural systems that are fundamentally problematic, but such systems are not going to disappear immediately and any improvements to animal welfare may be valuable **[AW, ORF]**. The DLT may reduce or otherwise affect human–animal relationships **[AW, MF]**. The DLT may primarily benefit retailers who want to demonstrate high concern with animal welfare **[DTP, MF]**. *'It's a bit of a halfway house, pragmatic, like if this allows us to detect before an outbreak happens and step in to do something, I think that's potentially a good thing. But equally… I'm aware that that it could be then used as a prop to not make further more systemic useful changes. So… this one is sort of a challenge and ethical dilemma, I think'*. (AW-P3)

(Continues)

TABLE 2 (Continued)

Case study	Purpose	Practicality	Effects
Case 3: Integration of production and supply chain data for data-driven animal breeding	The DLT is necessary for the effective development and use of other DLTs **[DTP, MF]** and for a range of livestock breeding and management activities **[ASP, MF, ORF]**. The challenge will become increasingly important as the political economy of British animal farming changes **[ASP, DTP, MF]**. The technology does not deliver sufficient or reliable benefits in certain sectors **[ASP, ORF]**. The technology may support solutions to alternative challenges, such as breaking monopolies over animal breeding **[MF, ASP]** or improving animal welfare, but the latter requires additional work and may not be possible through this technology or even make the problems worse **[AW]**. Data from the DLT may also be useful in debates about the impact and value of animal farming **[ASP]**. *'It's something that has to be done to improve the uptake of technology to make better decisions… if you don't have that in place, you're never going to use CT scanners or cameras for welfare issues, unless you have the uptake of data integration'*. (DTP-P2)	The DLT depends on collaboration between commercial actors, but incentives and terms are difficult to establish **[ASP, DTP, MF]**. Adoption of the DLT may be limited by poor engagement with technology in the sector currently **[ASP, MF]**. The DLT depends on high quality and quantity data collected on farms, which is not always reliable **[ASP, AW, DTP, MF]**. The success of the DLT will depend on trust between farm data providers and database owners **[ASP, DTP, MF, ORF]**. *'I'm slightly skeptical that it will actually deliver any more benefits than are being delivered at the moment. Because in the sheep industry, there's no point… giving people more data because they're not using what they've got. It's back to basics. They need to use what they've got and build on it, and then maybe revisit this in five years' time'*. (ASP-P5)	The DLT has environmental impacts **[AW, ORF]**. The DLT may primarily benefit researchers and developers **[ORF]**. The DLT primarily facilitates breeding animals for intensive farming systems **[ORF]**. *'Something that concerns me a lot is that whenever people discuss digital technologies… nobody ever presents the environmental damage of that digital system. There's an assumption that digital systems are somehow environmentally benign. And we've tended to forget that all of these digital approaches are reliant upon massive servers that use tremendous amount of energy, and are based on materials that need mining and that mining is highly controversial'*. (ORF-P5)

Note: Distribution of themes across stakeholder groups is indicated in square brackets, highlighted in bold: **ASP**, agricultural service providers; **AW**, animal welfare; **DTP**, digital technology providers; **MF**, mainstream farming; **ORF**, organic and regenerative farming.

Purpose

Questions about the purpose of DLT development and its relationship to motivating challenges were raised in relation to all three cases by participants in the organic/regenerative farming and animal welfare groups and to a lesser degree by participants in the agricultural service providers, digital technology developers and mainstream farming groups. The specific questions raised varied between the cases, reflecting the cases' different motivations and framing.

One line of questioning concerned the science and policy behind grand challenge narratives. This was clearest in relation to Net Zero goals and the reduction of methane emissions from livestock. Organic and regenerative farming participants actively questioned the significance of the contribution of livestock methane emissions to climate change relative to their status within biogenic carbon cycles. Methane emissions were recognised as a contributor to climate change, but participants questioned whether it was a priority issue. The status of methane emissions as part of a natural cycle was briefly referenced by a cattle farmer in the mainstream farming group, who simply noted that such cycles are already recognised within global warming potential metrics, effectively deferring questions of their importance to established scientific measures. Participants in the digital technology developers group, in contrast, questioned the politics of Net Zero discourses, asserting that farming was unfairly targeted for its contribution to climate change relative to other industries, by both policymakers and representatives of those industries looking to deflect responsibility. Concerns about politics were also raised in the agricultural service providers group, where participants argued that data integration had the potential to support arguments about the value of animal farming in public debate (although care needed to be taken about interpretation and the potential for manipulation). Participants from a mainstream farming background, however, sought to distance themselves from political decisions and debate, arguing that it was not their place to intervene in these discussions.

Another line of questioning concerned the appropriateness of DLTs as a solution to motivating challenges. In some cases, this was a matter of alternative options: In relation to Case 1, participants from mainstream farming and breeding backgrounds questioned whether breeding animals for reduced methane emissions was the most effective approach for reducing the climate footprint of livestock farming or whether improving the overall efficiency of the sheep industry would lead to equivalent reductions, either through management strategies or breeding for production and growth traits that reduced the number of days to slaughter. Similarly, some organic/regenerative farming and animal welfare participants noted that solutions such as feed selection and dietary supplements could be more effective at reducing methane emissions and more welfare-friendly than breeding. In other cases, participants scrutinised the solution relative to the cause. This was especially the case where the cause was seen to be systemic and resulting from human choices. In relation to Case 2, participants across multiple groups recognised that tail biting among pigs was a function of intensive agricultural systems that confined the animals in small spaces with little opportunity to engage in their natural behaviours. Several participants across mainstream farming, organic/regenerative farming and animal welfare questioned why, if giving pigs additional enrichment materials would resolve the problem of tail biting, these materials were not made available to the animals from the beginning.

Finally, in some cases, there was overt disagreement about the nature of the challenge that a DLT could respond to. This was clearest in relation to the scenario of livestock data integration in Case 3. For several participants in digital technology development and mainstream farming, the kind of data integration proposed in this scenario was a fundamental predicate for the effective development and use of other DLTs nationally. This reflected a wider sense, also held by an organic farmer, that the UK did not yet have reliable infrastructures for tracking animals and linking relevant data at a national level, with existing infrastructures such as those for recording animal movements being difficult to use and not well integrated with other services. Whether or not such data integration was valuable for breeding purposes, and why that was so, was contested across the groups, however.

Across the agricultural service providers, mainstream farming and digital technology development groups, participants situated the value of data integration for breeding in relation to the current political-economic context of British farming, specifically the ongoing changes to the agricultural subsidy system after Brexit. Several participants predicted a forthcoming situation where British farmers will be exposed to much greater competition and commercial pressures following the withdrawal of the current subsidies and that this would make it imperative on farmers to improve the productivity and efficiency of their farms if they wanted to survive, including through increasing their use of EBVs and data in breeding. In contrast, several organic and regenerative farmers expressed ambivalence towards using EBVs in breeding, and thus towards the value of an integrated database, stating that they did not see EBVs delivering promised improvements in animal performance in certain sectors, such as hill sheep farming. Where EBVs were recognised to lead to improvements in animal performance, such as in commercial dairy farming, the intensive nature of the sector was seen as undesirable. Similarly, animal welfare participants observed that while there had been progress in the incorporation of health and welfare measures among EBV criteria, such as lameness and fertility in cattle, significant work remained in this area, and it was unclear whether complex welfare considerations such as psychological wellbeing or affective states could be adequately captured through metrics that necessarily produce a degree of reduction. Reflecting the points raised above about the relationship between solutions and (systemic) causes, they observed that breeding itself was a major cause of poor welfare among farm animals through an emphasis on production traits and worried about whether extending the use of EBVs would increase welfare problems. An alternative value for breeding data was raised by participants in the mainstream farming group, who observed that, due to vertically integrated systems, breeding in the pig and poultry sectors was heavily controlled by key commercial operators, and farmers' choices were tightly constrained by their contracts. A poultry farmer noted that if breeding data could be opened up through public databases, this would be valuable in allowing farmers to have more autonomy and control over breeding their animals.

Practicality

Questions about the practicality of the technologies were not evenly distributed across the focus groups. Most discussions about the practicality of DLTs focused on the conditions for their effective development and adoption, but these discussions were limited to the agricultural service providers, digital technology developers and mainstream farming groups. Where organic/regenerative farming and animal welfare participants addressed questions of practicality, these were exclusively in relation to the functionality of the technology. For example, participants from all groups except the digital technology developers expressed concern that automated analytical systems may fail to capture the complexity of animals' behaviour, and its causes and are difficult to validate. Animal welfare experts were concerned that the camera systems' focus on tail posture in Case 2 could not capture the conditions leading up to changes in tail behaviour. For both animal welfare experts and organic/regenerative farmers, these issues reflected problems with the reductiveness of technological approaches to behaviour. For participants in other groups, concerns about functionality reflected more pragmatic considerations such as the potential for false positives in alerts, for example, or the lack of automated identification of individual pigs as tail biters that would allow rapid intervention, both of which potentially increased the labour costs of using the DLT.

A major practical challenge from the perspective of participants in the mainstream farming, digital technology development and agricultural service provider groups was how to negotiate collaboration and competition between commercial actors in digital technology development. This was particularly the case around data sharing, as in Case 3, which would require effective incentives and clear terms of use and protections regarding the data. Multiple participants across all focus groups except animal welfare also observed that farmers would need to have trust in database owners to be willing to submit data, which would depend on data governance strategies as well as the wider legitimacy of the institution (with public bodies concerned more trustworthy than commercial companies). Digital technology developer participants drew international comparisons to show that this was possible and had been demonstrated in other cases, for example, the Irish Cattle Breeding Federation's information systems.

A range of challenges to adoption by farmers were also raised by participants in mainstream farming, digital technology development and agricultural service provider groups. These included physical challenges of access and installation: For example, participants noted the physical inaccessibility of CT scanning to farmers due to the need to bring animals to a central location (even with a mobile scanning unit). Similarly, participants noted that 3D cameras were simple to install on farms but some digital technology developers and mainstream farmers observed that the system would only work effectively in particular kinds of sheds and pens reflecting intensive rearing conditions. Other challenges were related to the costs of adoption. Some participants saw 3D cameras as very expensive to install at the necessary scale, that is, in all pig pens, while others noted the high costs of CT scanning animals, which is currently subsidised by industry bodies. More broadly, participants observed that the value of digital technologies for farmers was often poorly articulated, making it difficult for farmers to make informed decisions, with some participants from the breeding sector raising scepticism about the accuracy of cost–benefit analyses produced by technology developers and academic researchers. Multiple participants across these groups also noted that DLTs such as 3D cameras would become much more cost-effective if they could be used for multiple purposes, for example, estimating pigs' weight or identifying disease alongside the early warning function.

A concern raised by participants in the same groups related to the existing landscape of technology and data in animal farming. In regard to Cases 1 and 3, participants debated whether breeding interventions were likely to be effective in achieving impact in the sheep industry given the limited uptake of even basic genetics-driven breeding techniques and the low level of data collection among farmers and other actors. More broadly, participants noted that DLTs were often dependent on the quality of data being inputted and observed that data recording on farms can be highly variable in quality, quantity and organisation. This variability was linked to the practical challenges of running a farm, where time and money for such recording were often lacking.

Finally, animal welfare and organic/regenerative farming participants did not address questions of development and adoption of DLTs because of wider concerns about the purpose and effects of the cases that they considered to be of greater priority, and which would need to be addressed before thinking about technology adoption.

Effects

Questions about the potential effects of DLTs on animals were a recurrent consideration for organic/regenerative farming and animal welfare participants, for example, regarding the need to use sedation while CT scanning (a concern also voiced by a consultant in the agricultural service providers group). In addition, participants from these two groups expressed concerns about the lack of established knowledge about the potential effects of interventions related to DLTs, for example, the relation between rumen size as measured by the CT scanner and complex biological functions such as the microbiome and animals' grazing ability, which might be negatively affected by reducing rumen size. Where DLTs did minimal or no direct harm to animals and were not invasive, like the 3D cameras in Case 2, participants across mainstream farming and animal welfare groups observed that the technologies were more acceptable to them, even if they had questions about the overall purpose.

Beyond specific effects on animals, animal welfare experts and organic/regenerative farmers voiced concerns about the potential instrumentalisation of animals and their absence as subjects with interests distinct from humans in cases where breeding was used to achieve external goals such as Net Zero and productivity improvements. Several animal welfare experts also pointed to the potential for DLTs such as cameras to affect human–animal relationships, potentially by reducing individual humans' understanding of animals through over-reliance on data, which cannot capture all the complexities of animal behaviour and wellbeing. As a counterpoint, a social scientist in the group observed that cameras can have benefits for both humans and animals through relieving humans' work burden and reducing disturbance of animals from workers entering barns in the night, for example.

Many participants raised questions about who the actual beneficiaries of digital technology were in practice, beyond the declared beneficiaries such as farmers and animals. Several participants across all groups except animal welfare questioned whether researchers and technology providers served to benefit the most from Cases 1 and 3, through expanding users of scanning and breeding services. Similarly, digital technology developers wondered whether retailers would be the primary beneficiary of the early warning system, given their investment in animal welfare as something valued by consumers and of reputational benefit to them. The latter was not just a question of hidden interests but was seen to have potential material implications, raising the possibility that installing such a system would end up serving as a formality, a tick box for farms in the context of welfare audit and certification schemes, rather than improving facilities or employing skilled workers, especially given the limited availability of skilled workers at present. A different kind of benefit, raised by participants in all groups except animal welfare and viewed positively, was the possibility for data collected by DLTs such as the CT scanner or 3D cameras to contribute to future research and understanding, alongside or alternative to their declared purpose.

Participants in the organic/regenerative farming and animal welfare groups additionally looked beyond the effects of DLTs on or for particular actors, whether human or non-human, to think about their effects on agricultural systems. These participants were especially concerned with whether and how DLTs might facilitate or legitimate the extension of intensive agricultural systems that they saw as fundamentally problematic and that probably should not exist: For example, whether breeding sheep for smaller rumens via CT scanning would create animals that required indoor rearing and feeding on monoculture-grown feeds such as soya or ryegrass, as opposed to extensive grazing, or whether introducing marginal improvements in pig welfare within intensive confined rearing systems would legitimise an industry that was fundamentally bad for welfare. These were not always clear conclusions, however. Some animal welfare experts felt that even though intensive systems were deeply problematic, they were not going to disappear overnight and that any potential improvements to the welfare of animals kept within them were important. This was nevertheless a troubling moral dilemma. The question of whether DLTs sustained existing agricultural systems was also connected to the challenges facing agriculture, given the possibility (raised by organic/regenerative farming participants) that some challenges might require system-level change, such as a reduction of overall livestock numbers to reduce methane emissions. Before discussion of the three cases began in the organic and regenerative farming group, one participant also intervened to assert that all digital technologies have environmental costs (of resource extraction, energy consumption and electronic waste) that often go unmentioned but should be part of any evaluation of the benefits and costs of DLTs. This point was echoed by participants in the animal welfare group.

DISCUSSION

The results of this research point to two conclusions: The value of purpose, practicality and effects as a heuristic framework for anticipatory and inclusive development of DLTs and of digital agricultural technologies more broadly and an ongoing exclusion of organic and regenerative farming stakeholders from the development and potential benefits of DLTs. The review of literature in the section Responsible innovation in digital agriculture, above, demonstrated the importance of considerations of purpose, practicality and effects within RRI and STS work on DLT development, yet these considerations are not uniformly acknowledged and there are currently no guidelines for addressing them in technology development processes. To rectify the latter situation, in Table 3, we present a set of questions that policymakers, technology developers and researchers could explore when deciding what kinds of technology to support, use or invest in and how to engage stakeholders. These questions are derived from the questions and themes raised by focus group participants and are intended to provide a heuristic framework for thinking about areas where additional work may be needed in terms of anticipation and inclusion.

The questions in Table 3 do not necessarily imply any single formal process for stakeholder engagement and can be used to guide reflection and generate discussion on who may need to be consulted as DLTs develop. Nevertheless, the methods we have presented here can be used to complement existing methods and tools in RRI. Addressing purpose, practicality and effects requires upstream engagement with stakeholders, at an early stage of policymaking and technology development. Examples of co-production methods that allow stakeholders to have an active role in shaping technology development are already available in relation to the potential effects of DLT, such as early ethical assessment frameworks (Thompson et al., 2021), while Schillings et al. (2023) have similarly argued for more and better processes of farmer participation in technology development to improve adoption, thereby addressing concerns about practicality. Combining these approaches with additional considerations of purpose will facilitate not only the development of technologies that work better for diverse stakeholders (including animals), objectives and farming systems but also highlight where the initial framing of technological aims may have excluded certain groups, demanding greater engagement with stakeholder groups beyond those immediately implicated in the proposed design of the technology. This can be operationalised through, for example, anticipatory focus groups that are carefully designed to elicit reflection on technological purpose as well as practicality and effects through the context and framing, as well as the moderation and sampling (Macnaghten, 2021).

TABLE 3 Guide questions for technology developers and policymakers to explore regarding the purpose, practicality and effects of DLTs. These questions can be used to identify areas where additional knowledge and stakeholder engagement might be necessary.

Purpose	Practicality	Effects
Why is the challenge important, and for whom?	Does the technology work effectively and efficiently?	Do we know enough about potential effects of the technology?
Do the goals accurately reflect current science and knowledge?	Can the technology adequately capture the complexity of the target phenomenon?	What are the effects on animals and their welfare?
Will the technology solve the challenge?	Is the technology accessible or easily installable on farm?	What are the effects on human–animal relationships?
Would alternative solutions to the challenge be better?	Is there sufficient engagement between technology developers and farmers?	What are the effects on the environment of using the technology?
Can the technology be repurposed?	Are there incentives for stakeholders to collaborate on technology development and/or data sharing?	How are the benefits of the technology distributed?
Do stakeholders agree on the best purpose for the technology?	Is the technology cost effective and the value clearly articulated?	Does the technology facilitate or legitimate problematic agricultural systems?
	Is the industry technologically ready to adopt the technology?	Could the technology contribute to future research and understanding?

The second conclusion of the research is that organic and regenerative farming research participants felt a clear sense of exclusion from DLT development due to the lack of technologies that served or supported their needs, practices and goals. This situation is not specific to the livestock sector but reflects the status of digital technologies in farming more broadly, where the majority of digital innovation has focused on providing tools for larger-scale, more intensive and more homogeneous farms, while innovations focused on small-scale or agroecological systems are few and far between (Bellon-Maurel et al., 2022; Ditzler & Driessen, 2022; cf. Vanloqueren & Baret, 2009). The development of 'agroecologically appropriate' digital technologies remains an underexplored area, with little clarity as yet on priorities and key technological criteria, as identified in a recent research project and report by Mason et al. (2024).

The absence of certain voices and visions in DLT development corresponds to the conclusions of Schillings et al. (2023) and Bellet (2022) and has direct consequences for the policy goals discussed in the introduction, namely, the application of technological innovation in agriculture to solve grand challenges such as climate change. As noted above, researchers in RRI have highlighted some of the pitfalls of grand challenge approaches to innovation policy (Brooks et al., 2009; Ludwig et al., 2022; Macnaghten et al., 2021; Rosemann & Molyneux-Hodgson, 2023). In particular, they have drawn attention to how the framing of grand challenges in terms of urgency and global importance can encourage policy approaches that are top-down and bypass public negotiations over the means and desired ends. This is not only a political point but has material implications for society's ability to respond to those challenges. Ludwig et al. (2022) observe that grand challenges may be presented as either 'tame' (simple) problems or as 'wicked' problems characterised by complexity and uncertainty, with implications for the kinds of solution strategy adopted: The presentation of problems as tame encourages strategies focused on technical solutions developed by expert actors that can work as 'silver bullets' to resolve the issue. In contrast, framing the problems as wicked, where the uncertainty stretches not only to solutions but to the definition and causes of the very problem itself, demands an approach to solutions that includes extensive participation of and negotiation between different actors, who may have very different views on the problem due to their position and expertise (cf. Conner, 2022). For Ludwig et al. (2022), the latter approach is not only desirable but also necessary because grand challenges are inherently wicked problems and cannot be resolved with silver bullets. Taking an example from our own research, in response to the challenge of reducing methane emissions from animal agriculture (Case 1), focus group participants highlighted a diversity of possible alternatives to solutions based on animal breeding, such as increasing efficiency of production, reducing overall numbers of animals or using dietary supplements. As was particularly clear from the differences between mainstream and organic/regenerative farmers, not all of these solutions fit within the same vision of agriculture, but they arguably all require consideration and negotiation when addressing such a complex problem as the contribution of animal agriculture to climate change in a broader context that also takes into account other considerations such as food production, work, land use and biodiversity. Whether and how digital technologies can contribute to these diverse potential solutions in a range of different farming systems are open questions of anticipation that require engaging diverse stakeholders.

Potential exclusionary dynamics were not limited to organic and regenerative farmers, however, and this further points to the stakes of addressing purpose alongside practicality and effects. Many farmers working in more intensive or productivity-focused approaches were unhappy with Net Zero policies and the politics surrounding these, which influenced their attitudes towards DLTs that served Net Zero goals such as the CT scanning in Case 1. On the other hand, Case 3, regarding data integration, remained at a much more open stage. Almost all participants agreed that there was potential value in collecting, sharing and using data, but there was little agreement on why or how. Data integration therefore reflected a site of possibility from which different participants did not (yet) feel directly excluded, but such exclusion remained possible depending on the future direction of development (e.g., in industry or national data infrastructures) and the values and interests that would shape this. A wide range of literature has identified how data protection and use and trust in data holders are critical to farmer attitudes and participation in data sharing initiatives (e.g., Jakku et al., 2019; Wiseman et al., 2019), while Eke et al. (2023) have highlighted the lack of attention to welfare concerns and regulations in animal data governance. Similarly, the focus group results demonstrate the different purposes of data integration that interested stakeholders, from improving post-Brexit farm competitiveness to opening up vertically integrated poultry and pig farming systems. Introducing open discussion about the purpose(s), practicality and effects of data integration, and the specific development opportunities that could result from this, will be necessary to ensure that digital technologies and data infrastructures do not exclude certain stakeholders, entrench particular approaches to agriculture or fail to address major challenges facing the sector.

CONCLUSION

Scholars in RRI, STS and agricultural ethics have formulated a range of tools to foster greater inclusion of stakeholders in the development of digital agricultural technologies and anticipate the potential impacts and risks of these technologies, at a moment in which digital technology is being positioned as a site of great promise, potential and peril for agriculture as well as the agent of major transformation (Ditzler & Driessen, 2022; Rose & Chilvers, 2018; Thompson et al., 2021). Bringing these methods together under the heuristic framework of purpose, practicality and effects serves not only to identify potential risks of and barriers to the adoption of new technologies but also addresses problems of exclusion of stakeholders that arise from the framing of technology development aims at the very earliest stage, including policymaking and funding. As Espig et al. (2022) and others indicate, operationalising anticipatory and inclusive principles in agricultural research settings can be difficult given incentive structures and funding systems. Nevertheless, additional frameworks and methods can make such operationalisation processes smoother.

Alongside research implementation, there is an urgent need to bring considerations of purpose, practicality and effects into political discussions concerning digital technology and innovation in agriculture more broadly. Our research indicates that digital technologies are only likely to be supported by a sufficient range of stakeholders to have meaningful impact if they can demonstrate that they have a clear and justifiable purpose, are practical to develop and adopt on farms and function effectively and have effects that are predictable and socially and ethically acceptable. Achieving all these goals is a challenge and requires support from multiple actors, including social scientists and experts in responsible innovation, research funders and policymakers themselves. Given the significant political and financial investments in digital technology and innovation and the new funds the UK Government has just committed to technology development in agriculture, there is a serious risk of wasted investment if technologies are ineffective and unsupportable, and an even greater risk that grand challenges will remain unsolved if top-down technological possibility is put ahead of stakeholders' knowledge of diverse farming systems and their own technological needs.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The author has provided the required Data Availability Statement, and if applicable, included functional and accurate links to said data therein.

ETHICS STATEMENT

Ethics approval was obtained prior to the start of this research from the University of Exeter Business School Research Ethics Committee (ID: 798590). Informed consent was provided by all research participants.

ORCID

Hugh F. Williamson PhD https://orcid.org/0000-0002-6381-7638
Sarah Hartley PhD https://orcid.org/0000-0002-4849-5685

ENDNOTE

[1]Virtual fences involve the use of Global Positioning System (GPS)-enabled collars that give animals a stimulus (e.g., an electric shock or sound) if they pass over a pre-programmed spatial boundary, to discourage them from crossing the boundary without the use of physical fencing.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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