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ARTICLES

Managing Socio-Ethical Challenges in the Development of Smart Farming: From a Fragmented to a Comprehensive Approach for Responsible Research and Innovation

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Abstract Smart farming (also referred to as digital farming, digital agriculture and precision agriculture) has largely been driven by productivity and efficiency aims, but there is an increasing awareness of potential socio-ethical challenges. The responsible research and innovation (RRI) approach aims to address such challenges but has had limited application in smart farming contexts. Using smart dairying research and development (R&D) in New Zealand (NZ) as a case study, we examine the extent to which principles of RRI have been applied in NZ smart dairying development and assess the broader lessons for RRI application in smart farming. We draw on insights from: a review of research on dairy technology use in NZ; interviews with smart dairying stakeholders; and the application of an analytical framework based on RRI dimensions. We conclude that smart dairying R&D and innovation activities have focused on technology development and on-farm use without considering socio-ethical implications and have excluded certain actors such as citizens and consumers. This indicates that readiness to enact RRI in this context is not yet optimal, and future RRI efforts require leadership by government or dairy sector organisations to fully embed RRI principles in the guidelines for large R&D project design (what has also been referred to as 'RRI maturity'). More broadly, enacting RRI in smart farming requires initial identification of RRI readiness in a given sector or country and devising a roadmap and coherent project portfolio to support capacity building for enacting RRI. Additionally, methods (such

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as RRI indicators) for operationalising RRI must be adapted to the context of the national or sectoral innovation system in which smart farming is being developed.

Keywords Smart farming · Digital farming · Ethics · RRI indicators · Big data · Internet of things · Pasture-based dairying · AKIS · Digital agriculture · Precision agriculture

Introduction

Smart farming (also referred to as digital farming, digital agriculture and precision agriculture) has been proposed to manage land, animals, and farm personnel more effectively (Tey and Brindal 2012; Wolfert et al. 2017). The smart farming approach implies that farm management tasks and upstream interactions in the supply chain are informed by collected data, enhanced by context and situation awareness, and triggered by real-time events (Wolfert et al. 2014; Wolfert et al. 2017). A range of sensors are used to collect these data to monitor animals, soil, water, and plants (Eastwood et al. 2012; Jago et al. 2013; Scholten et al. 2013). The data are used to interpret the past and predict the future to ensure more timely or accurate decision making both on-farm and in the supply chain (Carbonell 2016; Wolfert et al. 2017), where the accumulation of data from different farms also enables so-called Big Data analysis (Bronson and Knezevic 2016). Scientists and policymakers are increasingly looking to smart farming as a technological solution to address societal concerns around farming, including provenance and food traceability (Dawkins 2017), animal welfare in livestock industries (Yeates 2017), and the environmental impact of different farming practices (Busse et al. 2015; Wolfert et al. 2017; Carolan 2016).

Despite opportunities associated with smart farming in terms of improved productivity and positive environmental outcomes through more precise input use (Kaloxylos et al. 2012; Wolfert et al. 2017), smart farming potentially entails negative outcomes. Most smart farming literature focuses on the potential for improving agricultural practices and productivity (Wathes et al. 2008; Rutten et al. 2013), but some scholars have investigated the socio-ethical implications (Millar 2000; Wolf and Wood 1997; Carbonell 2016; Driessen and Heutinck 2015). These socio-ethical challenges in smart farming have been recognised at the level of the farm, the wider farming community, and society (Bos and Munnichs 2016). It has been argued that smart farming will reshape the practice of farming, with less 'hands-on' management and a more data-driven approach (Eastwood et al. 2012). Different skills will be required across the farming team to enact and adapt smart farming technologies (Eastwood et al. 2017b; Higgins et al. 2017), along with adapted advisory structures, potentially leading to displaced farm staff and service providers. Such changes could have a major impact on the cultural fabric of what it means to be a farmer (Burton et al. 2012; Carolan 2016), with the independence of managing 'your farm, your way' replaced with a far more structured and scrutinised approach, for example through detailed monitoring by agricultural equipment makers, input suppliers, processors and retailers (Bronson and Knezevic 2016).

The widespread use of *smart dairy farming* technologies (the empirical focus of this paper) presents both potential issues and opportunities, for example with robotic milking systems (Driessen and Heutinck 2015) and the use of technologies to replace animal husbandry tasks (Butler and Holloway 2016). Robotic milking adoption has been shown to involve varied outcomes for animals (e.g. levels of cow freedom), people (e.g. skills required of farm staff), and the environment (e.g. implications of intensification) (Schewe and Stuart 2014). Studies have also highlighted a technology-driven change in the relationship between cows and farmers (Driessen and Heutinck 2015; Holloway et al. 2014; Schewe and Stuart 2014). Driessen and Heutinck (2015) therefore identify a moral challenge in the ethics surrounding where technology ends and the animal begins in robotic milking; this may trigger debates in society around animal welfare.

These issues represent challenges for smart farming research and innovation and the further diffusion of smart farming technologies in terms of anticipating, and preventing, potential negative consequences (Wigboldus et al. 2016; Bronson and Knezevic 2016). These challenges are further complicated by the fast-moving and commercially driven nature of smart technology development (Eastwood et al. 2017b). It has been argued that research and innovation should incorporate societal values, needs, and expectations such as: privacy; use of information; sustainability; human reproduction; gender, minorities, and justice; power and control; impact on social contact patterns and human values; and international relations (Hellström 2003; Skorupinski 2002; Wigboldus et al. 2016; Palm and Hansson 2006; Bronson and Knezevic 2016). A desire to anticipate the implications of research and innovation better and to incorporate continuous responsiveness to societal concerns has led to the development of responsible research and innovation (RRI) (Stilgoe et al. 2013; von Schomberg 2011).

RRI has its roots in a European social and political setting, and, to date, most studies on the application of RRI have been undertaken within European or North American contexts (Stilgoe et al. 2013; von Schomberg 2011; Wiek et al. 2016; Guston 2014a, b), on topics such as nanotechnology and information and communication technology (ICT). However, similar concerns over the ethical implications of innovation are emerging globally, with questions raised on RRI application in different social, political, and cultural settings (Macnaghten et al. 2014), requiring exploration of RRI implementation in other settings. Studies on RRI enactment are still limited in agriculture and, although the number has grown in recent years (Asveld et al. 2015; Bruijnis et al. 2015; Bronson 2015; Macnaghten 2016; Macnaghten et al. 2014; Wigboldus et al. 2016), they do not focus specifically on smart farming. Furthermore, it has been argued that understanding issues around the practical implementation of RRI in commercially driven and corporate contexts such as smart farming requires more research attention (Blok and Long 2016; Stahl et al. 2017; Blok et al. 2015). Acquiring insights into RRI around smart farming is timely, for example to inform current European projects that include foresight exercises for precision agriculture (Schrijver et al. 2016), mapping and supporting the Agricultural Knowledge and Innovation System (AKIS) for smart farming (see https://www.smart-akis.com) and the application of the Internet of Things in farming (IoF2020 2017), or large efforts in this space in Australia (the Digiscape programme led by CSIRO) and France (the #DigitAg programme).

We aim to address these research gaps by assessing smart dairying development in New Zealand (NZ) from an RRI perspective, where there are emerging issues around the implications of innovation for personnel, animals, and the environment (Jay 2007; Saunders et al. 2016). Although these issues are already reflected in research and innovation projects in NZ smart dairying development, it is questionable how comprehensive these have been from an RRI perspective. Insights on the application of the RRI concept—or the lack of it—may thus be useful to aid in anticipating implications and responding to societal needs in respect of smart farming in NZ and to improve processes to enable the enactment of mutual responsiveness among stakeholders (Blok and Lemmens 2015). The insights gained may be helpful beyond the NZ dairy sector for the application of a comprehensive RRI approach in smart farming more broadly, and in different national contexts. The paper therefore focuses on two questions:

- To what extent, and why, have elements of RRI been considered to date to address socio-ethical challenges in NZ smart dairying development?
- What are the broader lessons for RRI application in smart farming?

We address these questions through a review of research projects focused on technology use in NZ dairy farming, in addition to interviews with stakeholders in smart dairying. We first review the literature on RRI dimensions and indicators to assess its application. From this review, we draw an analytical framework to assess smart dairying that will guide the interpretation of our findings.

Assessing Responsible Research and Innovation in Smart Farming

RRI Dimensions and Indicators

RRI, which is aimed at guiding socially and ethically acceptable innovation (Stilgoe et al. 2013), has links with concepts such as technology assessment (TA) and corporate social responsibility (CSR) (Iatridis and Schroeder 2016). RRI extends the TA concept to ethical issues of responsibility (Grunwald 2014) and broader processes for including public perspectives (Pellé and Reber 2013). CSR includes aspects such as identifying stakeholder concerns, understanding environmental and social impacts on a business, and the standards adopted to minimise impacts—also addressed in RRI (Hemphill 2016). However, RRI extends beyond approaches such as CSR and TA, particularly in terms of proactive anticipation of potential consequences of innovation and a greater responsiveness to changing societal norms (Wickson and Carew 2014).

There have been a range of conceptualisations of RRI, including the anticipation-inclusion-reflexivity-responsiveness (AIRR) framework (Owen et al. 2013; Stilgoe et al. 2013), to which a fifth element *transparency* is sometimes added (Ravn et al.

2015). The conceptualisation in the European Union RRI tools project describes the dimensions as diverse and inclusive, anticipative and reflective, open and transparent, and responsive and adaptive (Groves 2017). Another approach involves five RRI keys: engagement of all societal actors, gender equality, science literacy and education, open access, and ethics, with governance sometimes added as an additional key (Ravn et al. 2015). In this paper, we base our analysis on the AIRR framework as it provides a simple structural framework against which to assess whether smart dairying in NZ includes aspects of RRI.

The broad-ranging aims and undefined implementation methods of the proposed RRI approach have led scholars to question its practical applicability (Blok and Lemmens 2015). To enhance RRI application, indicators have been devised to monitor and assess RRI enactment. Wickson and Carew (2014), for example, developed seven quality criteria in an RRI performance rubric with examples of criteria from *exemplary* to *routine*. Also, Ravn et al. (2015) outlined the construction of 36 indicators guided by a set of criteria including: potential for sustained data collection, RRI conceptual coverage, representation of targeted actors and stakeholders (including all 28 EU member states), use of input-and output-based indicators, use of qualitative and quantitative data, with a range of quality criteria applied. In the development of the framework presented below, we describe each of the AIRR dimensions along with examples of indicators proposed in previous studies.

Framework for the Analysis of RRI in Smart Dairying

Drawing on discussions on RRI by authors such as Stilgoe et al. (2013), Blok and Lemmens (2015), Stahl et al. (2016), Asveld et al. (2015), and the indicators developed by Wickson and Carew (2014) and Ravn et al. (2015), we propose initial indicators for RRI in smart dairying (Table 1). We then use these indicators to guide our assessment of whether the AIRR dimensions have been addressed in NZ smart dairying research and development (R&D) activities.

Anticipation

To enhance anticipation in science and innovation governance, actors (e.g. researchers, professional practitioners, technology developers, and policymakers) should use processes to identify and minimise unintended consequences of future innovation. Potential indicators of anticipatory processes include the use of foresight exercises, horizon scanning, and scenario-building techniques (Stilgoe et al. 2013). Such future-casting processes should be applied at various times throughout the R&D project, with both positive and negative scenarios envisaged (Wickson and Carew 2014).

Inclusion

Inclusion, or participation, relates to broadening the debates around innovation from top-down governance mechanisms and the inclusion of stakeholders (Ravn et al. 2015) to a broader involvement of stakeholders (including the public) through

Table 1 Proposed indicators of responsible innovation activities in smart dairying, based on the RRI literature (Asveld et al. 2015; Blok and Lemmens 2015; Ravn et al. 2015; Stahl et al. 2016; Stilgoe et al. 2013; Wickson and Carew 2014)

	Indicator	Description	Potential activities
	Anticipation		
1	Foresight exercises	Future-scanning activities are undertaken to identify potential economic, social, and environmental implications associated with smart dairying	Technology-use surveys, assessing farmer perceptions of technology, public opinion surveys
2	Scenario building of smart dairy futures	Processes used to imagine potential positive and negative futures (e.g. changing role of farmers) where technology use is prevalent on NZ dairy farms	Visioning of smart dairy farms, assessing potential social, animal, and environmental outcomes
	Inclusion		
3	Involvement of relevant actors	A range of end-users and citizens are involved in socio-ethical discussions, for example relating to animal-technology interactions and farmer-technology interactions	Actively seeking critical feedback in workshops with stakeholders, use of citizen panels or online forums
4	Private sector engagement	Private companies are included as partners in publicly funded smart dairying R&D projects	Private companies co-fund projects, private sector represented in project governance
5	Encouraging transformative mutual learning	Processes exist for multiple stakeholders to engage in mutual learning within R&D projects	User-centred design, open innovation, and co-innovation
	Reflexivity		
6	Reflexive guidance	Processes to guide reflection within research teams on underlying assumptions and values around development and use of technology	Reflexive monitors used in project (i.e. persons dedicated to facilitating reflection)
7	Structures guide second-order reflexivity	Reflexivity is embedded in R&D projects using processes such as codes of conduct and standards	Creation of, and engagement with, codes of conduct, best practice guidelines
	Responsiveness		
8	Potential to adapt projects	Smart dairying R&D projects have the *ability* to change direction based on stakeholder feedback	Stage-gating, mid-project reviews, structures for adapting milestones and deliverables
9	Open research processes and access to research data	The design of smart dairy R&D is transparent, and the processes are accessible to private companies, farmers, and communities	Open data exchange, open access to research results, declaring conflicts of interest

small-group processes and other methods. The inclusion of stakeholder perspectives in technology development has been suggested as a method for improving stakeholders' trust in the innovation process (Asveld et al. 2015). Wickson and Carew (2014) identified the conscious use of transdisciplinary processes, openly and actively seeking critical input, and encouraging transformative mutual learning as exemplars of diverse processes. Techniques to facilitate inclusion include citizen panels, focus groups, lay representation on governance groups, and user-centred design (Stilgoe et al. 2013).

Reflexivity

Being more reflexive involves researchers assessing their own motivations and assumptions (e.g. social, ethical, and political norms and values) and acknowledging the perspectives of other actors (e.g. the public, companies) on particular issues (Pellé and Reber 2013). Certification and standardisation have been identified as ways for public and private institutions to communicate their norms (Asveld et al. 2015). Codes of conduct and standards can also facilitate second-order reflexivity, where the underlying values shaping research and innovation are scrutinised 'by drawing connections between external value systems and scientific practice' (Stilgoe et al. 2013, p. 1571); this also helps to build trust with the community and other organisations (Asveld et al. 2015). In RRI, reflexivity therefore becomes a public matter, and embedding social scientists in projects helps to facilitate the reflexive process (Stilgoe et al. 2013).

Responsiveness

Responding to societal needs requires the ability—applying a deliberative attitude (Asveld et al. 2015)—to change direction in the innovation process in light of emerging knowledge and perspectives. Stilgoe et al. (2013) saw the response to major societal challenges (e.g. climate change) as an indication of the responsiveness of innovation processes. Societal challenges, perspectives, and norms also change over time, so responsible innovation also needs to have the capacity to change direction or scope through techniques such as stage-gates (Stilgoe et al. 2013). Open access to research processes and results, along with declarations of conflicts of interest, are also potential responsive approaches, as they enable the public to respond to results and influence subsequent research directions (Stilgoe et al. 2013; Wickson and Carew 2014; Ravn et al. 2015).

Method

Timeline Analysis of Research and Development Activities in NZ Smart Dairying

In this paper, we used a timeline analysis methodology, as adopted by other studies (Hekkert and Negro 2009; Klerkx et al. 2012; Eastwood et al. 2017b), to analyse

Table 2 Dataset 1—published studies on smart dairying in NZ analysed

1—The Greenfield project, application of robotic milking in pasture-based dairy (Woolford et al. 2004)
2—Pastures from Space™ project developing satellite-based pasture measurement (Clark et al. 2006)
3—Overview of opportunities and risks associated with technology use in dairy farming. Two whole-day workshops held in 2011 between dairy sector representatives, researchers, and farmers from NZ and Australia (Jago et al. 2013)
4—Examining the use of pasture measurement technologies via interviews with 15 dairy farmers and service providers throughout NZ (Eastwood and Yule 2015)
5—Survey of 83 dairy farmers on factors including the reasons for investment in technology, initial expectations of benefits, and the impact/benefits of technology (Eastwood et al. 2016)
6—A survey in 2013 of 42 farmers, followed by interviews with 32 farmers and five farm consultants, regarding the use of individualised feeding technology on NZ dairy farms (Dela Rue and Eastwood 2017)
7—Two smart dairying technology-use surveys in 2008 and 2013 of 528 and 500 dairy farmers, respectively—see Edwards et al. (2015)
8—Interviews about the use of precision grazing technologies in 2015–16 with 12 dairy farmers and five farm consultants, and a workshop with technology developers (Eastwood et al. 2017a)

key research and development activities relating to smart dairying in NZ. Using a timeline method facilitates the identification of events associated with developing technologies and can aid the classification of trends. For this, we drew on two different data sources, as described in Tables 2 and 3. Dataset 1 involves published studies (termed Studies 1–8) on major smart dairying R&D projects in NZ that were reviewed to uncover activities and issues relating to responsible innovation. Dataset 2 consists of semi-structured interviews conducted with 10 key stakeholders acting as informants, giving their broad perspective regarding dairy technology use and research and innovation governance in the NZ dairy sector.

Semi-Structured Interview Approach

The semi-structured interview participants were selected through a purposive sampling strategy, with the aim of selecting highly knowledgeable and connected informants with broad experience in smart dairying issues. The interviews, conducted in January to March 2017, were approximately 60 min in duration and conducted by the same interviewer throughout (the first author of this paper). Verbatim notes were collected, supported by voice recordings, and were analysed for themes using NVIVO 10 software. The interviews were based on three themes: adoption of smart dairy technologies in research and development projects; current barriers and opportunities for the use of smart dairying; and foresight exercises on important considerations for future governance of smart dairying (including infrastructure, skills, ethical issues, social acceptability, regulation, and policy). These themes were chosen firstly to explore the current use of smart dairy technology and understand current socio-ethical issues, and then to triangulate knowledge on R&D activities from the review (Table 2), before focusing on issues relating to governance.

Table 3 Dataset 2—background on participants in semi-structured interviews investigating R&D projects based on smart dairying technologies, current issues, and considerations for the future governance of smart dairying

Role	Experience and responsibility
Smart farming researcher	Research leader in precision agriculture with over 25 years' international experience and a focus on technology applications for sustainable agriculture
Smart farming researcher	Farming systems researcher with over 20 years' experience at a major NZ agricultural research organisation. Research has included applying precision dairy technologies on a farm scale
Dairy animal welfare expert	Led the animal welfare programme for a dairy farmer-levy organisation in NZ. Worked closely with farmers and government in responding to community animal welfare concerns
Dairy environmental expert	Led the sustainability programme for a dairy farmer-levy organisation in NZ. Developed data capture processes for environmental, welfare, and social proof of practice on dairy farms
Agri-consumer researcher	Has over 30 years' research experience in agricultural trade in NZ and internationally, particularly the influence of consumers, policy, the environment, and new technologies
Technology developer	Responsibilities include installation and sales of smart dairy technology, and over 20 years' experience with technology in dairy
Technology developer	Responsibilities include strategic decision making for a livestock management and technology company servicing NZ and over 100 other countries
Milk processing company representative	An R&D manager for a small milk-processing company in NZ, with experience in data capture for quality assurance programmes
Milk processing company representative	An R&D manager for a major milk processing company in NZ, with a focus on technology use in dairying
Agri-business professional	The main rural economist for a major NZ bank, with over 10 years' experience in agri-economics. Special interest in the role of new technologies and data in agriculture

Findings and Discussion: Analysis of RRI Activities and RRI Gaps

In this section, we present and discuss the findings from the review of previous studies and the insights from informants. First, we describe the main issues facing the NZ dairy industry and relate these to smart dairying R&D activities. We then explore socio-ethical challenges associated with smart dairying uncovered in our analysis and informant interviews, and we identify examples of RRI activities, using the indicators in the analytical framework (Table 1). Finally, we identify gaps and lessons in respect to RRI application in this context, including why RRI dimensions have, or have not, been applied.

Issues Facing NZ Dairy Farming

Our case study is based on the NZ dairy industry, and therefore context relating to the issues facing dairy farming is presented here. New Zealand's economic prosperity in the last century was delivered by agriculture, and in the past 20 years

Table 4 Major social, ethical, environmental, and financial issues facing NZ dairy farming, the smart dairying R&D activities in relation to each issue (identified by the R&D project analysis, informants, and supported by literature)

Challenge	Description of issues	Smart dairying R&D and innovation activities relating to each issue
Economics and viability	The NZ dairy industry is dependent on exported commodity products (e.g. whole milk powder). The volatility in whole milk powder markets in the past decade has presented a major challenge to dairy farm viability and resilience (Wales and Kolver 2017). There has been a renewed focus on increasing farm productivity and providing tools to enhance profitability	In 2010, a 7-year precision dairy project was funded through farmer levies and the government as part of a Primary Growth Partnership (PGP) programme (P6, 8, 10, 11, 12 in Fig. 1) to assess use of smart dairy technologies for productivity improvements Pastures from Space project (P3), a project (with funding from the government, farmer levies, and a milk processing company) using satellite imagery to remotely measure pasture The Rapid Pasture Meter (P2) co-developed at Massey University in 2002, with a local commercial company.
Environment	Intensified dairying in NZ, growing from 3.5 million cows in 2000 to 5 million cows in 2015 (LIC & DairyNZ 2016), has been linked to concerns over water quality and quantity, greenhouse gas emissions, and soil conservation (Jay 2007; Chobtang et al. 2017; Doole and Romera 2015)	Massey University PhD study (P5) focused on sensors to measure nitrogen deposition from dairy cows (Draganova et al. 2016) A NZD $19.5 million, 7-year PGP programme funded by government and a fertiliser company started to develop technologies to manage nutrient inputs (P7) Optimum N (P9), a NZD $6.3 million project funded by the government in 2012 to develop N-sensing technologies
Attracting and retaining skilled people	Farmers have struggled to source skilled staff, with migrants with little prior experience of dairying often now employed (Tipples and Wilson 2005), leading to issues around farm management skills, animal husbandry, and staff retention	A 7-year Greenfield robotic milking project (P1) was driven by a desire to reduce hours spent milking and to make dairy more appealing as a career
Lifestyle and business	NZ farms were traditionally family owned and operated (Burton et al. 2012). Now with larger farms, more staff but less family labour, and increased regulations and compliance, farmers operate more as business managers of small to medium-sized enterprises and manage larger networks, in addition to technology providers. Changing roles for farmers and expanding information networks mean that farmers have to process much more information than in previous generations	The Greenfield project (P1) focused on adapting robotic milking to a pasture-based grazing system to improve lifestyle

Table 4 continued

Challenge	Description of issues	Smart dairying R&D and innovation activities relating to each issue
Community acceptance and connection	Non-farming public were historically connected to farmers, often through direct family links. A growing rural–urban divide has impacted this understanding, due to population growth and urbanisation, also a trend internationally (Boogaard et al. 2011; Grandin 2014). The broader public (and media) in NZ have expressed concerns about the impacts of intensification (Jay 2007; Burton et al. 2012)	The Greenfield project (P1) involved some minor activities aimed at linking the community with farming practice through automated milking open days
Animal welfare	National and international consumers, and consequently the NZ government, have also demanded greater scrutiny and proof of farm practice relating to animals and the environment (Jay 2007; Saunders et al. 2016)	As part of the Greenfield (P1) and the Precision Dairy PGP (P6) projects, there were activities to assess the use of technologies to monitor animal health and reproduction status
Technology performance and infrastructure	Adoption is limited by uncertain value, poor inter-technological integration, mismatch with farming systems, lack of national infrastructure or core enabling technologies, e.g. automated pasture measurement (Eastwood et al. 2017a)	The Precision Dairy PGP project (P6,8,10,11,12) also focused on dilemmas around technology meeting farmer needs, data privacy and sharing issues, and relationships between public and private R&D organisations
		Technology-use surveys (P4,10) were conducted to ascertain current and expected smart dairying uptake, along with issues that farmers were experiencing

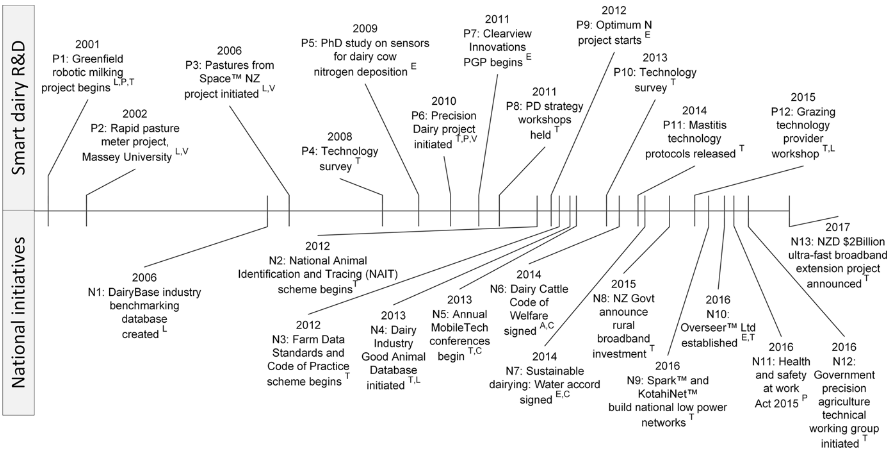

Fig. 1 Timeline diagram of major innovation events via R&D projects (labelled P1–P12) and related national initiatives (labelled N1–N13) in NZ smart dairying (2000–2017). Events are also linked to relevant issues from Table 4 by the following superscripts: [V] Economics and viability, [E] Environment, [P] Attracting and retaining people, [L] Lifestyle and business, [C] Community acceptance and connection, [A] Animal welfare, and [T] Technology performance and national infrastructure

dairy farming has been a significant export industry. Ambitious business growth targets, recently set by the NZ government, include doubling primary industry exports in real terms from 2012 to 2025 through value-added products and productivity improvements (Ballingall and Pambudi 2017). Innovation and technology-based solutions are seen as central to achieving these growth targets; however, the broader consequences of technology-driven farming have rarely been considered in the NZ context. Intensification in dairy farming is linked with a range of issues (Table 4), for example increased pressure on water quality (Jay 2007). There are also issues associated with attracting and retaining staff, health and safety on farms, maintaining a viable business while enjoying the farming lifestyle, meeting evolving animal welfare expectations, and meeting community and consumer expectations in general (Tipples and Wilson 2005; Jay 2007; Burton et al. 2012). To address these issues, R&D projects have been set up, as discussed in the next section.

Development of Smart Dairying R&D Projects in NZ

Informants noted that the commercial imperative of low-cost, grazed pasture systems has driven NZ farmers to remain relatively low-tech compared with their counterparts on European and North American dairy farms (Kamphuis et al. 2016). Labour-saving devices (e.g. automated cup removers, automated feeding) have proven most popular among dairy farmers internationally (Borchers and Bewley 2015; Eastwood et al. 2016), and this is mirrored in NZ (Edwards et al. 2015). In NZ, the uptake of the more complex (and expensive) technologies, such as robotic milking, has not proved popular because of lower costs of conventional milking and issues of scale, with only approximately 20 farms using milking robots by 2016. Informants noted that increased technology use will be required to enable dairy farmers to manage the issues listed in Table 4. They also noted that greater data collection will be required to provide proof of good management practice for environmental reporting. Technologies such as virtual fencing (Umstatter 2011), low power wireless networks, and robotic milking in rotary parlours (Kolbach et al. 2012) were identified as smart dairying innovations with an important role on future NZ dairy farms.

Increased interest in NZ regarding the potential use of smart dairying has led to the funding of several major R&D projects in the past 15 years. The projects included R&D focused on: adapting farming systems around robotic milking (P1 in Fig. 1); developing systems to use satellite imagery to measure pasture (P3); developing pasture measurement technology (P2); assessing technology efficacy and return on investment, and addressing issues around smart dairying (P4, 6, 8, 10, 11, 12); developing nutrient management technologies (P7); and developing nitrogen-sensing technologies (P5, 9). We have linked the R&D projects to the relevant issue (Table 4). However, although we have identified significant initiatives, there may also be some smaller projects not identified here. Additionally, community acceptance and connection and animal welfare have no dedicated smart dairying projects, but these issues may be addressed through other non-technology based projects.

Table 5 National initiatives with implications for smart dairy development in NZ

N1—DairyBase, a dairy industry financial and environmental benchmarking database, began in 2006
N2—The compulsory national identification and traceability (NAIT) scheme was introduced nationally in 2012, using electronic identification (EID) ear-tag technology to track farm-to-farm or farm-to-abattoir cattle movements. This technology acted as an enabler for other smart devices such as automated sorting, walk-over weighing, and milk meters, which rely on EID. It also enabled traceability for compliance and disease control
N3—Projects including Farm Data Standards (setting a common data vocabulary to allow easier data exchange) and a Farm Data Code of Practice and a Data Linker project were initiated in the primary industries. The code of practice requires organisations to outline how they safeguard farmer data. It was developed with farmer representative organisations, private companies, and milk processing companies
N4—The Dairy Industry Good Animal Database development began in 2013
N5—Researcher- and technology developer-focused forums for the discussion of smart technology development (including dairy) included the annual MobileTech conferences
N6—A Dairy Cattle Code of Welfare 2016 encourages all those responsible for dairy cattle to adopt the highest standards of husbandry, care, and handling
N7—The Sustainable Dairying: Water Accord is a set of national good management practice benchmarks aimed at lifting environmental performance on dairy farms
N8—An investment in rural broadband by the government began in 2015 to improve rural internet connectivity and mobile coverage.
N9—Around 2016, two initiatives sought to apply low power wide area networks across NZ and included a focus on agricultural use
N10—OVERSEER™ Limited was developed as a joint venture by the Ministry for Primary Industries, AgResearch Limited (a government-owned research organisation), and the Fertiliser Association of NZ. OVERSEER™ is a farm-scale nutrient model, adopted as a tool for achieving optimal nutrient use for increased profitability and managing within environmental limits. It is being used in some areas of NZ as a tool to determine whether farmers are operating within regulatory rules
N11—The Health and Safety at Work Act 2015 has also had immediate technological implications with the development of Apps and online systems to track health and safety compliance, incidents, and hazard identification
N12—In 2016, the NZ Government formed a smart agriculture technical advisory group potentially signifying greater government interaction with smart dairying issues and offering an opportunity to begin a broader national discussion about socio-ethical considerations associated with smart farming
N13—The rural broadband scheme (N8) was expanded in 2017

National Innovation Initiatives Beyond R&D Projects Relating to Smart Dairy Development

Our timeline analysis (Fig. 1) and overview in Table 4 highlight how the focus of NZ smart dairying R&D projects has been on technology development. However, innovation is also about simultaneous and interconnected changes in infrastructures and social and institutional structures (Kilelu et al. 2013; Geels 2004) in addition to R&D. Therefore, smart dairying development has been supported by several important national initiatives focusing on infrastructure and institutional structures. These initiatives include codes of practice, infrastructure investments, and 'industry good' databases as outlined in Table 5.

Assessing RRI in Relation to NZ Smart Dairying Development and Associated Socio-Ethical Challenges

In this section, we use the RRI framework (Table 1) to understand past RRI-related R&D activities and initiatives and how they connected to emerging socio-ethical concerns in smart dairy development. Also, we identify gaps in terms of RRI, and on the basis of these gaps we identify potential RRI issues and opportunities for researchers, policymakers, private companies, and society relating to smart farming in the context of NZ's dairy industry. There are limited explicit processes to identify and manage socio-ethical factors in the current NZ R&D structure, but these may be addressed at a research organisation level via human ethics approval processes. Also, stakeholder engagement has become a common early phase of large projects, and some funding application formats provide an opportunity for identification and management of socio-ethical factors. Furthermore, Maori (indigenous Polynesian people of New Zealand) input is included in all major government-funded research through the Vision Matauranga, a policy to include the innovation potential of Maori knowledge and people in R&D projects. Although RRI has not been specifically applied in NZ smart dairying R&D projects (many started before the RRI approach became well known), in this study we identified several aspects of RRI present in project activities but found that these were not conducted in an integrated and comprehensive manner. In Table 6, we summarise what has been done in terms of RRI to address socio-ethical challenges, and we consider how to incorporate missing aspects of RRI in future smart dairying in NZ.

Anticipation

The informants noted some socio-ethical dilemmas relating to potential future implications of smart dairying use. One related to farmers and their farm teams relying on technology, with the potential consequence of future deskilling of staff in animal handling and decision making. It was suggested that this could lead to some farmers resisting technology adoption. Building farmers' and service providers' capacity to use technology and data appropriately was also seen as a challenge, and one informant noted:

> *The market size (in NZ) limits investment in technical staff training.* [Smart farming researcher 2, 2017]

Another dilemma identified in relation to the need for foresight was the potential implications of reliance on technology for future farmers, particularly if there was technology failure, such as a power failure or internet disruption.

Our analysis identified limited activities relating to the anticipation indicators (Table 6). Surveys examining NZ dairy farmer use of smart technologies (P4, 10) provided a baseline of technology adoption, along with data collected about which technologies farmers thought were most useful and which were on their 'wish list'. The surveys provided some level of engagement in foresight exercises around on-farm adoption and potential barriers and enablers (*Indicator* 1); however, they did not explore socio-ethical aspects such as skill and labour changes. This study's

Table 6 Smart dairying R&D activities relating to indicators of responsible research and innovation (based on a review of previous studies and insights from informants)

Indicator (number in brackets)	Past and current RRI-related activities	RRI gaps: tensions and lessons related to these activities in light of RRI	Recommendations for future RRI activities
Anticipation			
(1) Foresight exercises	Precision dairy project discussed future needs with farmers and technology developers (P8)	The fast-moving smart farming domain requires regular foresight discussions	Include foresight exercises in scoping stages of project development and in the start-up phase of long-term projects
	Social scientist embedded in the precision dairy project (P6)	Precision dairy strategy (P8) is over 5 years old; the community's view of farmers has evolved in this time	Involve social scientists as participants (e.g. as reflexive monitors, see below)
	Limited foresight activities, e.g. the precision dairy strategy (P8)	Limited interaction with farm advisors and other networks to understand issues of changing advisory relationships	Use 5-yearly technology survey to assess farmer perceptions of smart dairying issues and implications—consider running survey biennially
(2) Scenario building of smart dairy futures	Limited evidence of scenario building (P8)	Scenario building may occur in areas not identified in our analysis (e.g. commercial R&D)	Involve technology developers and community/ consumers in scenario building
		Issues such as future use of data and implications of OVERSEER™ need to be explored via future-casting	Include processes to imagine future farming scenarios, e.g. (Shadbolt et al. 2017)
Inclusion			
(3) Involvement of relevant actors	Involvement of end-users (primarily farmers) in technology development discussions, e.g. including farmers and technology developers as stakeholders in R&D projects, through steering committees, workshops, and surveys (P4, 6, 7, 8, 10)	Minimal public debate or deeper consideration at national policy level on issues such as increased influence of technology companies on farmer access to data	Include community representatives or relevant CSOs on project steering committees
		The next 5 years are a pivotal time to include society in designing the future of smart dairying because of increased uptake	Use forums to include citizens, e.g. Weary and von Keyserlingk (2017)
		Including citizens effectively is difficult, therefore CSOs may need to be used as a proxy	Instigate open innovation protocols to enable the inclusion of smaller technology providers and other service providers

Table 6 continued

Indicator (number in brackets)	Past and current RRI-related activities	RRI gaps: tensions and lessons related to these activities in light of RRI	Recommendations for future RRI activities
(4) Private sector engagement	Some R&D projects (P1, 2, 7) were designed to include the private sector and therefore deal with issues such as intellectual property Some projects brought private company representatives together to discuss issues such as data exchange and acceptable technology performance	Balancing public and private interests highlighted tensions around intellectual property, trust, and open innovation New technology companies are rapidly emerging, need to include them in long-term projects	Smaller start-up companies should be represented, requiring flexibility on 5 + year projects, as the relevant start-ups may not be present at the project outset
(5) Encouraging transformative mutual learning	No evidence was seen of specific mutual learning processes within the R&D projects analysed	User-centred design methodologies used in the commercial sector have not included the wider community. Reflexive interactive design and participatory modelling have been used in non-technology dairy projects Potentially user-centred design has been viewed as too risky for R&D funding agencies	Apply participatory processes in future R&D projects Include community and socio-ethical perspectives Funding agencies need to understand the potential gains from mutual learning processes
Reflexivity			
(6) Reflexive guidance	Projects (P6, 7) included social scientists and farm systems experts Focused inward to understand the implications for farmers and networks	Social science in the R&D programmes has sought to address some of the tensions Wider interactions between technology and society have not been addressed	Focus reflexivity activities outward to examine the community and consumer implications, particularly at the start of R&D projects Greater researcher reflection required to incorporate perspectives of all actors Requires multidisciplinarity and co-development, commitment to reflexivity (Ayre and Nettle 2015)

Table 6 continued

Indicator (number in brackets)	Past and current RRI-related activities	RRI gaps: tensions and lessons related to these activities in light of RRI	Recommendations for future RRI activities
(7) Structures guide second-order reflexivity	Establishment of Farm Data Standards and a Farm Data Code of Practice (N3) Development of precision dairy strategy (P8) Standards were applied at the technology-specific level (P11, 12)	Power relationships between farmers and companies, and between companies, indicates a need for codes of conduct on transparent data use	Extend codes of conduct and standards beyond a technology focus to incorporate ethical codes of conduct, particularly for research and innovation practice
		Standards developed in NZ smart dairying are voluntary, with limited use potentially because of insufficient value proposition for technology companies	Potential role for government technical advisory group (N12) in identifying and championing open data processes and transparency
		Current codes of conduct and standards are designed for technology development, rather than for research practice	Standards around data ownership and transfer may need to be compulsory
Responsiveness			
(8) Potential to adapt projects	Several projects (P6, 7, 8) had the ability to change direction, based on stakeholder feedback (funders or farmers, not community actors), and had stage-gating provisions	Stage-gating decisions were based on technology feasibility rather than ethical considerations Recent investment in internet and low power network infrastructure suggests more rapid change, creating a greater imperative for responsiveness in R&D project design	Extend stage-gating to consider issues such as long-term impacts (positive and negative) and socio-ethical implications for dairy farming issues
(9) Open research processes and access to research data	Large smart dairy R&D projects publicly provided short annual updates (P6, 7) Release of research data occurred in some instances (P11, 12) but was not widespread	A major gap was the public release of research plans and progress (such as seen in the IoF2020 and GREAT EU projects) A socio-ethical tension involved the power of companies to control access to trial results, in the name of protecting intellectual property	Large PGP-style projects should adopt a research framework of public release of project designs and progress reports

analysis of R&D projects highlighted a need for greater embedding of anticipation methodologies within projects, such as scenario building (*Indicator* 2). One issue identified by informants was differences in worldviews and issues of power among actors (farmers, private companies, organisations, citizens, and consumers) involved in smart dairying in NZ. For example, the evolving power relationships between farmers and private companies in NZ, identified during interviews, centred on data collection and use, where data ownership was uncertain. This issue arose because some companies saw data as an asset to capture and control.

An issue not addressed in anticipation activities, but that would need attention according to informants, is contemplating the use of smart dairying data, for example in the nutrient accounting software OVERSEER™ (P9). Informants indicated that the end use of such data (e.g. for environmental regulation) should be made transparent when data are being collected. In NZ, we identified activities such as the creation of Farm Data Standards (N3), which aimed to clarify data ownership and transfer, and thereby address these issues (*Indicator* 7). The Government's technical advisory group could fill the identified gaps in anticipation and responsiveness activities by leading discussions on appropriate transparency of data use.

Inclusion

Some inclusion-related activities were identified, with the inclusion of farmers and technology developers in R&D projects (e.g. P1, 6, 7, 12) via workshops, both about general smart dairying issues and about specific topics such as use of individual feeding and walk-over weighing. Through these inclusion processes, the interaction and evolving power relationships between private companies and farmers were identified as significant tensions in smart dairying in NZ. Several of the R&D projects identified farmer frustration at poor access to their data and the lack of easily transferable data between the different software platforms of different companies (P4, 6, 8, 12). One informant noted that:

> *No one has cracked seamless integration of data.* [Milk processor representative 2, 2017]

Data integration was noted as an ongoing dilemma for more effective technology use. Several of the R&D projects (P6, 8, 11, 12) identified the tensions among private companies associated with smart dairying operating in NZ, as the companies compete to gain market share within a small dairy market. Informants noted that many of the large dairy processors and technology companies now have a digital strategy; this may exacerbate tensions as companies attempt to find their market niche. This highlights the need for greater private sector engagement in R&D projects (*Indicator* 4).

Some public inclusion activities were identified where smart dairying was used to engage the wider public with farming and technology through open days and media articles. However, despite these efforts, our analysis found limited inclusion of the wider community in the development of smart dairying (*Indicator* 3). Informants indicated that this resulted from a lack of perceived need, combined with the difficulty of engaging with community actors. One informant suggested that consumers had a limited understanding of what farmers do and that there was potential for smart technology to help farmers connect to consumers. Another informant commented:

> *In the past, farmers have said 'I'm a farmer, trust me', but now we need a new level of transparency.* [Smart farming researcher 1, 2017]

However, informants also suggested that consumer and community opinion of technology-assisted farming could '*go either way*' in the next decade, as technology could be seen as either facilitating more ethical treatment of animals or reinforcing negative perceptions of the industrialisation of agriculture. Although in NZ these socio-ethical tensions have received little research attention, informants indicated that negative perceptions of technology in the future could be especially pertinent around innovations such as virtual fencing and robotic milking within NZ's pasture-based grazing system. It may also exacerbate negative perceptions of modern farming, including the reduced naturalness of animals and reduced tradition in farming systems.

A recommendation for addressing this gap in comprehensive inclusion in smart dairying is for greater inclusion of citizens directly, or indirectly through organisations such as civil society organisations (CSO) (Table 6). Also, informants noted that smart dairying involves large incumbent companies (usually included in Primary Growth Partnership-style R&D because of their ability to access funding), but one recommendation emanating from our analysis was that smaller start-up companies, increasingly important in the smart dairy innovation system, should also be represented in R&D projects. Informants noted that user-centred design methodologies were most often used by private R&D but did include the community (*Indicator* 5). Increased use of such participatory processes in smart dairying R&D would help researchers and technology developers understand the wider implications of technology development and provide a platform for foresight exercises.

Reflexivity

Despite some examples, our analysis identified limited reflexivity practices. As regards *Indicator* 6, social science was included in some of the R&D projects; however, social scientists' roles mainly involved assessing farmer adoption factors, rather than roles such as reflexive monitoring (Mierlo et al. 2010) to guide reflection and learning within projects. One informant also noted that, although smart dairying could potentially provide proof of good animal welfare, increased social science was required to:

> *Understand expectations of consumers on wellbeing of animals [and] development of market expectations of sustainable development.* [Smart farming researcher 1, 2017]

We identified some informal standards and protocols developed for technology design criteria, such as mastitis detection (P11) and pasture measurement technologies (P12) (Kamphuis et al. 2016; Eastwood and Dela Rue 2017). Also, the Farm Data Standards and Code of Practice projects provided a baseline for reflexivity. A related dilemma identified both by informants and in the reviewed R&D projects was that, although data were useful for farm management and compliance activities, there were questions around data privacy and the eventual use of data. In the R&D projects (P6, 12), tensions were identified between farmers and smart dairying companies in terms of data ownership and use (as described earlier in relation to OVERSEER™). A gap identified was the development of methods to adjust R&D to address these tensions, an area where greater reflexive monitoring support would have been beneficial (*Indicator* 6).

Responsiveness

The potential for rapid technological change, through technologies such as the Internet of things, was identified by informants. This was noted as a tension in terms of responsiveness of R&D projects and highlights the importance of R&D projects having the ability to be agile and change direction (*Indicator* 8). The inclusion of stage-gating provisions, informed by ongoing socio-ethical reflexion and assessment, therefore becomes a vital mechanism for large smart dairy projects. Greater responsiveness was required for innovation actors to react to unintended consequences of innovation. For example, one informant identified OVERSEER™ as a very important factor in whether farmers would adopt potentially beneficial technologies for water and nutrient management. He noted that this software was not agile enough, because the failure to give the use of a smart technology relevant credit in the model output may be a disincentive for future use.

Some of the smart dairying R&D projects included *responsiveness* to changed circumstances, for example mid-project stage-gating, but the flexibility in R&D design concerned technological performance issues rather than social or ethical considerations. One example of mid-project review was the design of a strategy for precision dairy in NZ and Australia, co-developed with farmers and sector representatives (P8). This strategy was then used to guide R&D in the remainder of the project. However, lack of responsiveness to evolving socio-ethical issues can be noted as a gap here, which could lead to long-term R&D projects delivering technology solutions that society no longer wants. This could be improved by increased openness of project design and access to results, as suggested under *Indicator* 9 (Table 6).

Conclusion

Many of the smart dairying dilemmas identified in our study have also been noted in other studies internationally (Andrade and Anneberg 2014; Butler and Holloway 2016; Carolan 2016; Wolfert et al. 2017). These socio-ethical dilemmas included data privacy and power relations between farmers and companies relating to data acquisition and ownership. Changes to the nature of farming and human–animal relations were also identified as socio-ethical dilemmas, potentially leading to farmers and/or society rejecting smart farming technology-based approaches—as noted by Wathes et al. (2008). These insights indicate a need for RRI, and in our analysis we found that several socio-ethical challenges were addressed in smart dairying development (e.g. standard setting, infrastructure building), thus connecting with our proposed RRI indicators. However, our assessment of RRI in smart dairying (Table 6) also highlighted gaps relating to a lack of comprehensive and coordinated attention to the RRI dimensions. For example, the RRI indicators consisted mainly of imagining potential smart dairying futures through scenario building and transformative mutual learning through methodologies such as interactive and user-centred design.

Exploration of the causes for the lack of activity regarding RRI indicators is beyond the scope of this paper. However, some reasons could be rooted in the NZ agricultural innovation system setting. As Macnaghten et al. (2014) argue, interaction patterns and power structures in innovation systems influence how RRI can be enacted, and the NZ agricultural innovation system has been found to have a disconnect between different science projects, dividing science from broader innovation efforts, and also a laissez-faire attitude on the part of government towards innovation (Turner et al. 2016). These run counter to some of the principles of RRI. Furthermore, the strong presence of profit-driven private organisations (often multinational) in smart farming is highly influential in the innovation process—as also highlighted by Eastwood et al. (2017b), Blok et al. (2015), and Wolfert et al. (2017). Informants in our study noted the many companies in the innovation space compete for limited market share, thereby hindering their ability to work collectively as required in RRI. These companies may also seek to move faster than publicly funded R&D projects allow—an issue in the rapidly evolving information technology-dominated domain.

A lack of citizen inclusion in smart dairying R&D is notable in NZ smart dairying development, particularly in relation to Indicators 3 and 5. Reasons for this may include the techno-centric science focus of smart dairying development to date and the focus of the NZ public on broader debates around the challenges listed in Table 4, rather than specifically on technology. We identify an imperative for R&D funders and managers to use RRI as an inspiration to proactively involve citizens in ongoing conversations about smart dairying development. The potential interaction of a technology with society often becomes apparent only after the design phase (Buckley et al. 2017). Therefore, timing the ongoing involvement of citizens is important for constructive and meaningful anticipation (Stilgoe et al. 2013). Including community actors or CSOs in project teams would not provide sufficient legitimacy and engagement unless the project activities and agendas were *relevant* to the community actors, requiring a wider range of skills among project leaders to facilitate such engagement. Including the public in discussions on smart dairy issues, using tools such as internet forums (crowdsourcing), farm visits, and interactive design exercises explored by other studies (Weary and von Keyserlingk 2017; Ventura et al. 2016; Cardoso et al. 2016) could enable more ethical outcomes in the NZ dairy sector.

By applying the RRI lens to a case study of smart dairying in NZ, we can also identify lessons for the application of future RRI to smart farming more generally.

These lessons involve diagnosing existing RRI efforts to inform future RRI efforts and developing clarity about leadership and a roadmap to enact RRI. Our study confirms that enactment of RRI dimensions in R&D projects and other innovation activities requires a comprehensive, iterative, and reflexive process, as also noted by Stahl et al. (2016). Without this, a fragmented effort may emerge, potentially with elements of TA and CSR but not a proactive RRI approach. This may result in overlooking some RRI principles and having RRI as an add-on rather than a core feature of research and innovation, as Blok and Lemmens (2015) have noted. R&D and innovation projects in smart farming should explicitly design for RRI, and understanding the practical application of RRI indicators will provide insights for R&D funders and managers to assess RRI readiness and embed RRI principles up front in future projects. Our proposition of nine indicators of responsible smart dairying research and innovation represents a first step towards a translation of generic RRI principles into a functional framework in the smart farming space to assess RRI readiness.

The indicators helped guide our analysis of the R&D projects and other development activities, and aided the identification of areas where there was limited activity (i.e. RRI gaps), such as limited inclusion of citizen perspectives and limited reflexive practices. Our indicators were preliminary in nature, but they were designed to reflect specific attributes associated with smart dairying, such as the influence of private companies, changes to farmer practice, and community concerns over animal welfare and the environment. In contexts with fragmented application of RRI to smart farming, research providers, funders, and policymakers can use this framework for greater guidance of the comprehensive functional application of RRI. However, as exhibited by Wickson and Carew (2014), further effort is required to refine the indicators interactively and adapt them to specific contexts.

After diagnosing actual RRI efforts, innovation systems actors will require guidance regarding how and where they should embed RRI in R&D and innovation activities—particularly in contexts where the RRI process is acknowledged only to a limited extent and where innovation systems do not enable collective reflection processes. This will require leadership, for example by government, sector organisations, or funding bodies that have sufficient influence over R&D and innovation processes to enhance the engagement of a range of actors. Several of the large R&D projects analysed in this study applied transdisciplinary approaches to integrate private R&D, but, as highlighted by Blok and Lemmens (2015), a clear value proposition is required to engage these private players sustainably in more open interactive processes. In addition, such leadership should bring in civil society, which in our case study was almost fully neglected. Bringing diverse actors, such as private companies and citizens, together to consider future implications requires a high degree of trust (Asveld et al. 2015), but examples provided in this paper (e.g. P12—workshops with different technology developers) show that, in the right context, this can result in positive interactions. Greater use of existing peer communities (e.g. technology sector representative groups, environmental groups, animal ethics groups), as suggested by Hellström (2003), could help a wide range of actors to engage in RRI activities.

Where there has been a fragmented approach to RRI, actors will need a form of roadmap combined with coherent project portfolios to address issues relating to the four RRI dimensions to transition towards what Stahl et al. (2016) have referred to as maturity in implementing RRI. In smart farming, such a roadmap and associated project portfolios must link private and public interests in a collective approach. Additionally, following Wolfert et al. (2017) and Bronson and Knezevic (2016), it should promote attention on governance and socio-ethical aspects of issues such as open-source ICT development, data movement between platforms, and protection of farmer privacy. Defining and operationalising this roadmap could be supported by user-centric and design-oriented approaches, for example reflexive interactive design (Bos et al. 2009), design thinking (Pavie and Carthy 2015), and the use of open-source data and innovation (Blok and Lemmens 2015). However, following arguments by Macnaghten et al. (2014) and Klerkx et al. (2017), choosing the exact approach or methodology to enact RRI would also call for a deliberation on how to translate RRI to a specific country context or sector context, given the particularities of its innovation system.

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