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Critical support for different stages of innovation in agriculture: What, when, how?

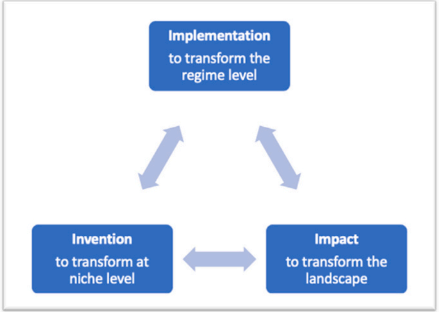
Egil Petter Stræte [a,*], Jostein Vik [a,b], Eirik Magnus Fuglestad [a], Mads Dahl Gjefsen [a], Anders M. Melås [a], Roger A. Søraa [a,c]

[a] Ruralis – Institute for Rural and Regional Research, 7491 Trondheim, Norway
[b] NTNU, Department of Sociology and Political Science, 7491 Trondheim, Norway
[c] NTNU, Department of Interdisciplinary Studies of Culture, Dragvoll, 7491 Trondheim, Norway

HIGHLIGHTS

- Exploring critical support functions at different stages of technological innovation in agriculture
- Balanced Readiness Level assessment (BRLa) highlight technology, market, regulation, social acceptance, and organization
- Technology is socio-technically constructed by multiple stakeholders negotiating technological innovation
- Crucial to identify the supporting functions that have an impact to stimulate the system's transition at the macro-level

GRAPHICAL ABSTRACT



- The agriculture sector is transforming through innovation
- Critical support functions at different stages of technological innovation
- A multi-level and a long-term perspective on innovations is needed to study transformations
- Multilevel: From micro to meso to macro
- Each stage of the innovation process will most likely benefit from specifically targeted support

Innovation and process oftransition (inspired by Geels et al. 2016)

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ABSTRACT

CONTEXT: The agricultural sector is undergoing several transitions through "smart-farming" technologies. To make this innovation responsible, it is critical to support technological innovation at different stages of innovation with customized strategies for the individual technology.
OBJECTIVE: What are the critical support functions at different stages of technological innovation in agriculture?
METHODS: Four technologies are analysed: Automated Milking Systems (AMS), a digital fencing system for the virtual herding of goats, a technology for drone-based observation and management in agriculture and forestry, and round baler silage systems. These are analysed as sociotechnical constructions of multiple stakeholders, with heterogeneous pathways to societal acceptance and practical usage on the farm.
RESULTS AND CONCLUSIONS: To provide information about how such technology can be created in a responsible manner, the paper suggests a Balanced Readiness Level assessment (BRLa) to highlight five dimensions for technological maturity: technological, market, regulatory, social acceptance, and organizational maturity. Through this approach, the findings show that each phase of the technological development benefits from specifically targeted support and that support functions should not be underestimated in order to get technology to a higher level of acceptance.

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* Corresponding author.
E-mail addresses: egil.petter.strate@ruralis.no (E.P. Stræte), jostein.vik@ntnu.no (J. Vik), eirik.m.fuglestad@ruralis.no (E.M. Fuglestad), mads.d.gjefsen@ruralis.no (M.D. Gjefsen), anders.m.melas@ruralis.no (A.M. Melås), roger.soraa@ntnu.no (R.A. Søraa).

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SIGNIFICANCE: Agriculture is facing challenges that demand transition of the sector. Supporting invention to stimulate innovation is important; supporting implementation is also important, but identifying the supporting functions that can have an impact at the societal level is crucial to stimulating transition of the system. This paper clarifies the variations of the supporting functions.

1. Introduction

Agricultural innovation is accelerated by *smart farming* technologies that transform the sector (Wolfert et al., 2017; Klerkx et al., 2019; Estrada Bonell and Vaccaro, 2022; Klingenberg, 2022; Maffezzoli et al., 2022). Previous efficiency procedures used in agricultural technologies and practices now face new challenges like climate change, demands for reduced greenhouse gas emissions, a more circular economy, safety regulations, and accountability and countability regarding where and how food is produced. Although the agriculture sector is transforming through innovation, "innovation" is a complex and multi-faceted term, with many actors involved along the value chain, which both influence and promote innovation. There is also a great will and ambition, both in industry and politically, for innovation in agriculture to increase in scope, and importance is assigned to meeting the aforementioned societal challenges. An important question is how this can be done efficiently and responsibly. Outcomes for success and failure are many. In this article, we look at how, and at which stages, potential bundles of support work towards innovation and what can be learned from these complex modes of support.

Innovation processes can be complex and vary widely, which makes them unpredictable. A need to know more about involvement in processes becomes particularly clear in light of the normative ambitions increasingly being built into research and innovation activities via mechanisms for Responsible Research and Innovation (RRI) (Owen et al., 2012). RRI seeks to mitigate unintended negative effects and maximise the benefits of innovation by incorporating a multitude of voices and perspectives early in – and throughout – research and innovation processes, including agenda-setting and need-mapping stages that precede technical development; moreover, and critically, RRI demands that deliberative and participatory activities have a meaningful influence on the directions of technical trajectories (Gjefsen and Vie, 2021). However, while RRI has increasingly been incorporated into funding and support mechanisms on the EU level and within national funding regimes (Shelley-Egan et al., 2020), it has been more challenging to operationalize RRI in innovation contexts characterized by geographically and organizationally distributed activities and where different actors, interests, and support mechanisms are at play at different stages of the innovation process (Stahl et al., 2021), such as in Norway's fragmented agricultural sector.

Many innovation studies provide interesting insights into how business organizations work with innovation and what indicators one can look for, for example, to evaluate the company's innovation capacity and company-related factors that are important for innovation (Boly et al., 2014; Läpple et al., 2015). However, such studies say little about how support functions for companies work in practise to stimulate innovation (Läpple et al., 2015).

The Technological Innovation Systems (TIS) framework is one of the key approaches in sustainability transition studies. However, so far, scholars have focused mostly on the early stages of technology development; thus, we know relatively little about mature TIS (Markard, 2020), including the last steps in technologies that are becoming mature and achieving a broad diffusion. Rakas and Hain (2019) point to "the crucial role of institutions and academic entrepreneurs in shaping these developments in interdisciplinary and diverse fields, in processes of increasing diversity" in the knowledge bases from which the field draws, accompanied by a decreasing coherence of collective research efforts.

It is important to know more about how individuals and actors at a micro-level can act through the networks to "configure capabilities and resources across multiple levels in agricultural innovation systems (AIS), from the individual to the network, to mobilise and build systemic innovation capacity" (Turner et al., 2017). In other words, many actors and factors (tangible and intangible) are important for innovations and technological development, and there is limited insight from the long-term perspective, i.e., from the very beginning of an innovation until mature diffusion at the aggregated level.

The main research questions we discuss in this paper are: What are the critical support functions at different stages, or phases, of technological innovation in agriculture? What and how do they support, and who assists with which step in the innovation process?

The critical support functions help an innovation get past bottlenecks and advance the innovation process. Thus, in this paper, we will take a closer look at the success factors with regard to the innovation or technology reaching a higher degree of maturity and thereby increasing the chance of its use in agriculture. To illustrate our inquiry, we have used case studies from technological innovations in various stages of agriculture. We describe the methodological approach and theoretical framework before presenting our empirical findings, which we then discuss.

2. Methods and data

The empirical basis of our investigation is a mixed-method study of four farming technologies selected through careful mapping of automation in agriculture, which we further analyse to explore how technological innovation is situated. These four technologies are: (1) *Automated milking systems* (AMS), robotic milking systems for cows, (2) *Nofence*, a digital fencing system for virtual herding of goats, (3) *Biodrone*, a technology for drone-based observation and management in agriculture and forestry, and (4) *Round baler silage systems*, which harvest, compress, and make silage.

The cases are different and are chosen strategically to highlight variations in types of technology, processes of innovation, and impact. They are at different stages of development and contain technological innovation, implementation by farmers, and societal discourse. Further, the innovations present a heterogenous array of past and present challenges of the material and immaterial kinds. The *AMS* case was chosen because it is one of the most known examples of robotization and new technology in contemporary agriculture and because it has had substantial structural effects on the sector. *Nofence* was chosen because it is a well-known and much-discussed technology start-up firm in Norwegian agriculture. We chose to include *Biodrone* because we wanted to add another technologically sophisticated innovation to the list of cases. The *round bale* technology was selected as a contrasting case. It is older and more established, and it is not in itself a technology based on digitalization. Furthermore, the cases vary in degree of impact. Arguably, AMS and the round bale technology have had a profound impact on Norwegian agriculture, while Nofence and Biodrone have had less impact so far. Thus, we have a set of cases that allowed us to study a wide range of innovation processes.

All four cases have been studied through interviews with users, mostly farmers. For case 1 (AMS), data is generated from two studies, one based on 29 interviews with farmers and eight experts from advisory services and suppliers, and one study with both qualitative and quantitative data. The latter was not directly applied, but was part of the context. For case 2 (Nofence), we interviewed the funder, two other people from the company, and eight farmers who used the new technology, for a total of 11 informants. For case 3 (Biodrone), we conducted one interview with the gründer. For case 4 (round baler), we conducted six interviews with advisors and farmers. In total, 55 informants were interviewed. For case 1, the interviews were structured with some open questions, while for the other cases, the interviews were semi-structured with open questions. The interviews were taped and notes were taken.

In addition, document studies of the technologies and their innovation processes were conducted. This mixed-method approach to both primary and secondary data was carried out for several years and through multiple research projects, which have been re-evaluated, reanalysed, and synthesized for this paper. To present the cases, we apply the method of narratives, which is well suited to presenting the processes in both heterogeneous and comparable trajectories. Interviews and document studies gathered narratives of development and use experiences for the respective technologies and were analysed after organization of the reported support factors according to the stages of innovation outlined in our sociotechnical framework (below). For more details about the method in three of the cases (1, 2, 4), we refer to Vik et al. (2019); Fuglestad et al. (2021); Søraa and Vik (2021); Kvam et al. (2022).

3. A sociotechnical framework for innovation

Technological development is the sum of many individual actions and processes. Only by having a far-sighted perspective on innovation can one see what social effect it has and could have. However, it is a challenge to connect concrete technological inventions to major societal changes. Our main approach is, thus, to connect such changes to phases in innovation processes by applying transition theory through a multilevel perspective.

By “technology,” we mean the physical aids used to perform an activity, the activity itself, and the knowledge and competence required to use the things or in some other way related to them – seeing how technology is socially constructed (Bijker et al., 1989). Agricultural technology includes machines, buildings, chemicals, mineral fertilizers, breeding, medicine, cultivation techniques, working methods, etc. in a wide network of human and non-human actors (Law and Hassard, 1999). The material aids and skills are connected and constitute technological systems or regimes.

A broad definition of innovation, inspired by Joseph Schumpeter, includes the development of new products and new production processes, the use of new raw materials or semi-finished products, new industrial organization, and introduction to a new market (Schumpeter, 1934). “The new” must also be realized, that is, implemented in real life; thus, innovation is more than just an invention. Several activities are part of innovation, such as scientific, technological, organizational, financial, and commercial steps towards implementing innovations. It is important to distinguish between different phases on the basis that they have different factors that are critical for moving forward in development.

The *invention* phase – that is, what we can call the first phase of innovation – is often a focus of studies. Inventions are frequently linked to individuals and their ideas for new solutions. Here, too, support and encouragement, both materially and mentally, have an important function. For an agricultural invention to be widespread, though, it must be *implemented* by farmers, first by pioneers as early adopters and later by various phases of adoption, such as how Rogers (1995 (orig 1962)) describes it. Many types of technologies can be regarded as innovations each time they are implemented on individual farms and not only the first time they are tried out in general, because they change the specific farms so drastically. Milking robots are an example in which the material robot has gradually become known, mature, and standardized, thereby selling well in commercial markets. However, its implementation on the individual farm (micro-level) is so complex that it is an innovation in itself on that specific farm. Such innovations contain more aspects of innovation than solely technical innovation, and the farmers' individual relations are crucial for the adaption (Kvam et al., 2022; Mrnuštík Konečná and Sutherland, 2022). For the milking robot, implementation on a dairy farm will entail both a new production process in the barn (loose farming with cows in circulation) and a new organization of both the production and the work tasks for the farmer and others working in the barn. It will also involve new actors in the supporting field (milking robot supplier, new advisers, and new use of services, e.g., from technical support and maintenance). Farmers are depended on how agricultural advisory organizations perform. Farmers can receive more updated and relevant services for their farms if the organizations can improve the incorporation of R&D and stimulate to continuous learning and networking. Adaption of new technology can be stimulated by systematic development in advisory organizations outside the farm (Stræte et al., 2022; Eastwood et al., 2019).

Finally, there is a third phase in the development of the specific technology in which the aggregated effects of the farmers' decisions become visible at the level of application and the level of societal *impact* (macro). These effects can, in turn, provide needs or opportunities for new innovations. To enter the third phase, the scope of the implementation must reach a certain level before effects can be observed at the societal level, which varies according to the type of technology being implemented.

When applying a long-term perspective on innovation, we also move between different societal levels, from micro to *meso* to macro. The multi-level perspective (MLP) provides a framework for understanding the structural dynamics of transition within socio-technical systems (Geels et al., 2016). It conceptualises systemic change as the result of cascading interactions between three levels – niche, regime, and landscape. The *niche level* is a locus of novel solutions that have the potential to alter regime dynamics, practices, inputs, and outcomes. The regime level is where established dominant producers and other actors in the actual system carry out their routine activities using certain technologies. The landscape level covers exogenous factors. In our study, technological innovation and diffusion in agriculture, industrial ambitions (value creation), and policy (regulation, stimulation for value creation) are important landscape factors, constituting much of the background for our research. However, regarding technology in farming, landscape is literally influenced, as the innovations also change the agricultural landscape, for example, by round bales as a visual impression, as do the number of cows and goats on pasture and the existence of physical or digital fences, which also change the vegetation in the landscape.

The three phases of innovation which we have outlined above are related to specific technologies, while MLP is a broader societal approach in which the technological development in agriculture is the sum of the development of several specific technologies. In what follows here, we look at the specific technologies and the associated innovation. Our phases of innovation are not equal to the three levels of MLP, but we regard our phases as an expression of relevant activities at the three levels. From this follows: The invention phase is at the level of niche, the implementation phase is at the level of regime, and the impact phase is at the level of landscape.

Developments here are not linear. This can be presented as three elements that are interdependent and mutually influential, as shown in Fig. 1. There is back and forth in the relationships and constant adjustments in technology based on trials and effects. In this sense, it is dynamic, but there are changes through these phases so that, over time, there are changes that constitute transitions. Technologies that have an impact over time will go through all three phases or conditions and form an element in the technological development.

Our claim is that each step or phase is more or less dependent on *support functions* to succeed. Here, to succeed means to achieve such widespread use that the invention has a social effect. Many inventions – perhaps most – do not achieve such an effect. The support functions can vary significantly, both tangible and intangible as well as intended and unintended. In this study, we consider the whole process, i.e., all three steps seen together. We also look at how the functions are facilitated in the various phases of development.

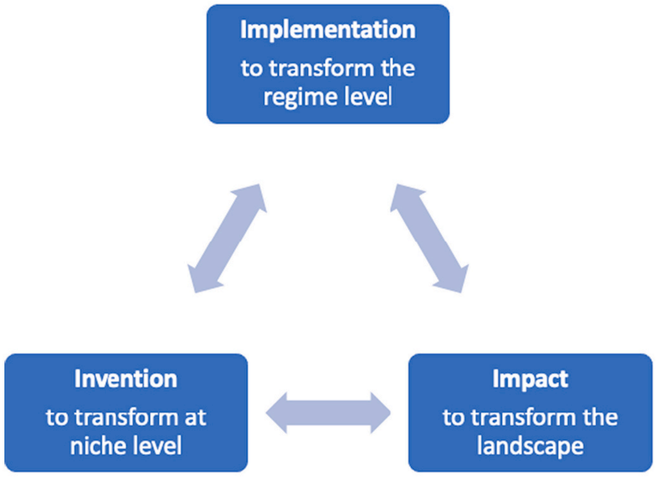

Fig. 1. Innovation and process of transition. Inspired by Geels et al., 2016.

Support for innovation can be categorized into functions, and several studies of functions in connection with innovation systems analyses have been performed (e.g., (Hekkert et al., 2007; Eastwood et al., 2017; Lamprinopoulou et al., 2014; Wieczorek and Hekkert, 2012). According to Hekkert et al., the functions of innovation systems emphasise “the most important processes that need to take place in innovation systems to lead successfully to technology development and diffusion“(Hekkert et al., 2007). In this article, we look at how various actors contribute to critical support functions in the process – covering the phases or stages – of innovation. Vik et al. (2021a) have developed a methodology for a Balanced Readiness Level assessment (BRLa) of new agricultural technologies. This balance supplements technology readiness (TRL) with market readiness, regulatory readiness, acceptance readiness, and organizational assessment to build the BRLa. In short, efforts from these dimensions must support the technology in being mature and ready for use and, in the end, successful. These dimensions constitute a relevant categorization of the supports.

Functions will vary over time and in different phases of innovation processes. Rarely can actors fill more than one function over time, but to the extent that some succeed, they are very important for an innovation network to work well (Hermans et al., 2013). It is of interest to know more about which actors are important at which stage.

Empirical studies can help shed light on what functions are important, which are not, and at which time. Previous studies have shown that access to knowledge, development of knowledge, learning, entrepreneurial activity, network, funding, market formation, resource mobilisation, and the creation of legitimacy are all examples of important functions (Eastwood et al., 2017; Lamprinopoulou et al., 2014; Wieczorek and Hekkert, 2012; Hekkert et al., 2007; Hermans et al., 2013).

4. Four cases of innovations

4.1. *Empirical context – Norwegian agriculture*

Technological development and innovation are context-specific. Norwegian agriculture has a high level of technological innovation and can provide a fruitful case study to illustrate our investigation of agricultural innovation in practice. Therefore, a glance at the Norwegian agricultural context is useful. Norwegian farming is of a relatively small scale. In 2020, the average farm unit was 25,5 ha and the average dairy herd consisted of 29,9 cows (Statistics Norway, 2021). Because of climatic and topographic factors, agricultural production in Norway is limited (Forbord and Vik, 2017). Only 3% of Norwegian land is used for agriculture (Knutsen, 2020) and the average patch or piece of land is one hectare (Vik, 2016).

The government-owned economic development organization and funding body Innovation Norway offers financial support for agricultural investments (Innovasjon Norge, 2022). The OECD has concluded that the Norwegian agricultural innovation system has well-developed institutions and that, despite the small size of the sector, the R&D system produces a larger share of agri-food patents and publications than in most other countries (OECD, 2021). However, according to the OECD, agricultural innovation needs more dynamic engagement by the private sector, focusing research and adoption at the firm and farm levels and on emerging areas of social interest. Notwithstanding, the Norwegian Agricultural Knowledge and Innovation System (AKIS) *has* moved from a governmental-driven strategy with an emphasis on farming and public goods into a commercialised business focusing on farmers (Grande et al., 2014; Klerkx et al., 2017).

In the analysis, we looked at how the support functions have affected development in the empirical case studies on specific technologies in the three main phases of technical material innovation, implementation, and innovation in the individual farmer and diffusion and societal change.

4.2. *Case – The milking robot*

Since the early 1980s, milk quotas have been used to regulate market supply in the dairy sector. For a long time, the quota system cemented the agricultural structure. However, gradually, the quota system opened for redistribution and structural change. Beginning in 1997, the state could buy out quotas from farmers who wished to quit dairy production and redistribute parts of the quota to expanding farmers (Partssammensatt arbeidsgruppe, 2007). From 2003 on, farmers could trade milk quotas within regional borders. From 2008 on, farmers were allowed to rent quotas, which accelerated the structural change in dairy farming. The average quota increased from 89,781 l in 2003 to 228,676 l in 2020 (NAA, 2022).

Technological development was imperative for the described development: the milking robot, or the automatic milking system (AMS). This technological development started in the mid-1970s, and the world's first commercial milking robot was installed in 1992 in the Netherlands (Meijering et al., 2004). The robot is placed in a loose housing barn where the cows walk inside a fence and can be milked when they feel like it. The robot can identify each cow down to the level of precision of being able to identify each individual teat of the cow's udder. The cow is locked in with the robot while milking. The milking itself is automated and takes place without the farmer being present. In connection with AMS, other types of robots and digital tools such as activity meters, automated feeding, and cleaning robots are often installed. Large amounts of data are associated with each cow in an AMS. Combined with data from the other technologies, this gives the farmer great opportunities to monitor and analyse milk production on the farm. Below, we will describe the transformation of the dairy sector within the model described in Fig. 1.

4.2.1. *Invention*

In Norway, the first milking robot was installed in 2000, eight years after the first one in the Netherlands. This means that the technology itself was known and that, in Norway, it was more about developing the value chain around the milking robot, working up competence, and convincing farmers that investing in AMS was a useful pursuit.

4.2.2. *Implementation*

The individual farmer has several motives to implement AMS. The most important one seems to be a wish to obtain a more flexible labour situation, to improve the quality of everyday life. When the farmer can choose when to go to the barn, it is also easier to adapt the farmer's life to family and social activities.

Although working days become more flexible with AMS, dairy farmers have not observed lower total workloads. Many have expanded production to finance the investment and optimize production capacity. This has increased the need for quotas and land and, consequently, increased the hours of labour (Hansen, 2015; Vik et al., 2019; Hårstad, 2019).

The first years of milking robot installations in Norway were characterized by pioneer farmers leading the way. The established advisory apparatus was not prepared for AMS and did not have much to offer the farmers in the first phase (Kvam et al., 2019). The suppliers of robots and other pioneers were the most important advisors to the farmers who assessed robots beyond the 2000s. In addition, we have seen that farmers who invest in milking robots discuss and learn from other farmers. Furthermore, suppliers offer service 24/7. This is important to reduce the perceived risks for individual farmers and to solve problems that arise in the implementation phase. Also, the dairy cooperative Tine SA developed a specialized advisory service for dairy farmers that made it easier for farmers to implement the robot technology.

4.2.3. *Impact*

Today, more than half of the milk in Norway is milked with an AMS. Compared to many other countries, Norway has a large share of AMS. Norway's unique political economy, with high labour costs, scarce land resources, and good access to capital, is an important background for this, but so are the regulative adjustments related to joint farming, quota regulations, and generous support schemes (Vik et al., 2019). For example, regulations gave a special advantage to joint farming by allowing for the combining of milk quotas from the joint farmers before the trade of milk quotas was allowed for all farmers in 2008. The material relationship between the structure before the introduction of AMS and the capacity of a milking robot is also essential: In 1999, the average dairy farm in Norway had 13.2 milking cows (Vik, 2016). A milking robot can handle 60–70 cows at the same time, day and night. Given the high costs of a robot, this relationship constitutes an incentive to adjust production to exploit the capacity of the investment. This seems to have created pressure to expand production on dairy farms. The impact has been significant. Because domestic markets do not rise, accelerating structural change is the result (Vik, 2020).

4.3. *Case – digital fences – Nofence*

The Norwegian agricultural landscape is segmented and often borders wild, overgrown, hilly, and mountainous areas. For farmers who work with grazing animals, fencing has, therefore, been an important task, but presented a significant cost in terms of time and resources. As the number of farmers declines and the use of marginal grazing areas has been phased out, interest in maintaining physical fences has decreased. In the last decades, several new types of electric fences and movable fences have been developed, but have had relatively limited impact.

Nofence is a digital fencing system for virtual herding. The first version – for goats – was put on the market in 2016. It was later adapted to cattle and sheep farming. The system consists of an app on the farmer's smartphone and a collar unit around the neck of the animal. The app and the collar unit are connected through a 4G network. The unit carried by the collar contains a GPS unit, a beacon for sending and receiving signals by satellite. The collar contains a beeper and a device to send an electric shock to the animal. The farmer may set a digital fence on the system's app, thus establishing a virtual boundary for where the animal may go. When the animal approaches the virtual fence, a beeping sound starts; it increases in volume as the animal gets closer to the border of the allowed area. If the animal continues and disregards the sonic warnings, it receives a small electric shock. This motivates the animal, if properly trained, to move back to the allowed area. The app on the smartphone stores information about the animal's activity.

4.3.1. *Invention*

The developmental process by which Nofence moved from a conceptual idea to a product available for farmers in Norway and a few other countries lasted about 15 years. In 2007, the inventor received his first funding to conduct a market analysis of the interest in virtual fences. The technological process involved many practical and material puzzles. What kind of sound signals were best? How should the electric shock be delivered when the sheep grew thick wool? How could the batteries be made to last long enough, and so on? Thus, the process involved a substantial amount of time as well as trial and error.

In this phase, the most critical support function is patient financial support. In the case of Nofence, the various public funding instruments under the umbrella of Innovation Norway were very important. Also, access to a network of sub-suppliers and manufacturers became important. Some of these were Norwegian companies, while others were abroad. A series of practical solutions had to be tried out before a combination of elements was found that worked well. This process continued even after the technology was adopted by farmers.

4.3.2. *Implementation*

The people who created Nofence live in a rural environment. Access to the users – and their animals – was critical in this phase. The technology had to be learned by individuals as well as their animals. Part of the initial idea was that farmers with grazing animals would be a core user group. What was more of a surprise was that a new way of using grazing animals became important – a new kind of goat farmer arose. These were farmers who did not use goats as milk or meat producers, but who started to supply grazing services as a kind of landscape maintenance service – precision grazing. The digitally fenced goats provided a solution to the problem of wild growth forestification of the open landscape qualities in many rural areas, or around roads, in the route of power grids, etc.

To access this new kind of customer, media attention was critical. Here, an unwanted controversy surrounding the animal welfare aspects of the technology may have been useful; because this technology gives an electric shock to animals if they go outside their defined borders, animal welfare authorities initially opposed it. This caused protests in the agricultural policy environment and some media attention that resulted in the technology becoming known in wider circles. The controversy was partly resolved through active intervention by the Minister of Agriculture and Food (Søraa and Vik, 2021). Thus, actors who can create attention and cut through political and regulatory hindrances were critical in this phase.

Another key element was the choice of business model. Nofence is supplied through a combined subscription approach. Farmers pay a one-time fee as well as a monthly subscription fee to use the services. This gives Nofence a regular income as well as a regular inflow of data and input on the workings of the technology, while the farmers get access to maintenance and help when needed. Thus, the implementation phase is characterized by farmers and customers binding together in a rather tight relationship. The ability to mobilize supporters of the technology during the troublesome early interface of the Norwegian Food Safety Authority also indicates the importance of a wider policy network.

4.3.3. *Impact*

Potentially, Nofence can play a significant role in the maintenance of pastures and outfields in Norway. The Nofence technology addresses a highly relevant issue in Norwegian agriculture – the combination of a significant need for fences and the substantial costs of both human and material resources of fencing. Now, only a small fraction of the rural population is involved in agriculture, and the number of people who have an incentive to build and maintain physical fences is low. At the same time, farmers who need to use the outfields must prevent their animals from wandering around in populated areas or on the roads. Nofence supplies a solution to this problem. However, this potential is not yet realized. To continue growing, Nofence needs a broader base of users within the farming community, especially among sheep and cattle farmers.

4.4. Case – Biodrone

Drones, or unmanned aerial vehicles (UAV), have a long history closely related to military purposes. Civilian drones became a reality with increased digitalization and the availability of miniaturized applicable general technologies. The technological development of drones for agricultural purposes is, therefore, more about combining and tailoring available drone technologies with potential market needs. Currently, a multitude of companies is developing drones and drone services for agriculture (Vik et al., 2021b).

Biodrone is an early-stage start-up company focused on drone-based approaches to forestry and farming applications. Thus, the company's technological basis includes drone technologies, with different sizes, carrying and flight capacities, and associated control systems (in combination with human operators) and software for managing aerial applications such as pesticides or seeds, as well as software for monitoring purposes like estimating growth in a given area or detecting wanted or unwanted elements such as disease or unwanted species. Forestry management applications include windfall damage surveying after storms, remote harvesting of branches for use in grafting, and efficient surveying of growth rates and harvesting readiness as an alternative to manual, time-consuming measurements in the field. Different tasks might require specialized equipment to be fitted onto drones, such as high-resolution, infrared, or other types of camera equipment, and different mechanisms for the aerial dispersion of substances onto fields or other areas. During in-flight operations, drone pilots can rely on footage from the drones themselves, observations from the ground, or a combination of these; some degree of autonomation of the drone task completion, or even operations based on groups or swarms of drones, is also conceivable.

4.4.1. Invention

Biodrone is a relatively new company. The technology consists of largely off-the-shelf products manufactured by the company DJI and already used in agriculture and forestry internationally. The company's innovation lies in software components combined with various adaptations to Norwegian and Scandinavian user needs. According to the entrepreneurs, the company is more engaged in developing methods than in developing material technology. Novel software focuses in particular on recognizing patterns, counting, and machine-based recognition of surveyed areas, which inform decisions about when and how to manage different areas.

Different forms of support or framework conditions have been critical so far. First, by being one of the first commercial actors in the market, the technology has received media attention, which has played a role in establishing recognition among possible users. Second, and relatedly, product demonstrations have proved to be highly effective and made a big impression on, e.g., forestry actors. Third, funding through Innovation Norway and other mechanisms supported the company financially during its start-up phase.

4.4.2. Implementation

Throughout the company's relatively short history, the entrepreneur describes significant learning on prospective technology users and customers. The initiator first targeted agricultural actors. However, a combination of prohibitive regulations concerning the use of aerial applicators in food production, together with a relatively easier path to scalable operations in forestry and a high potential for drone technologies to carry out previously cumbersome operations in difficult terrain far more efficiently than surveying and management operations conducted by humans, has shifted the company's attention to forestry.

Biodrone is not yet widely implemented, but a contract with one of Norway's few major forestry actors is the next likely implementation step. Thus, factors influencing Biodrone's implementation process include the Norwegian Food Safety Authority, which has granted limited exceptions to allow small-scale testing in partnership with an agricultural college in the region, and the parameters set by EU regulation. For this technology, then, regulations that were originally intended to limit aerial applications in general, and food production in particular, have had the effect of steering market expansion from food production to forestry, where regulations are less of a barrier.

4.4.3. Impact

The innovation could create significant productivity increases in forestry as laborious human operations are replaced by drone-based systems to save time and increase/maintain precision. On the other hand, this has workforce-related consequences. There might be other tasks that human surveyors/planters and others can carry out but that drones focused on monitoring and substance applications cannot carry out. If regulations are eased, similar scenarios could play out in agriculture. Moreover, technological learning and synergies across application areas, such as search and rescue and environmental and area monitoring, can be envisioned. However, the full impact of drone technologies in agriculture and forestry has yet to be seen.

4.5. Case – the round baler

Besides grain production, grass production as a part of meat and milk production comprises the largest portion of Norwegian agriculture. Due to Norway's short and wet summers, grass must be conserved by ensilaging after dried hay declined as the most important conservation method. From the late 1960s, this was done in-house in silos. Thus, all grass harvested had to be transported from the fields to the farm during a hectic harvesting season. Given the fragmented and small-scale structure of Norwegian farming, silo-based grass storage was a substantial limitation to farm growth. Furthermore, the silos were a substantial source of pollution to rivers and lakes. As it turned out, the round baler became a solution.

The first developments of the round bale technology are more distant, historically speaking, than the other technologies described here. It became mainstream in Norway during the 1990s and the early 2000s – and, thus, was not based on the recent revolution in information and communication technologies. Rather, the round bale technology represents the use of older technologies in a new way and entered Norwegian agriculture gradually and "quietly." Except for some early research activity, there were few incentives and little attention paid to stimulate the technology from the state or farmer organizations. Therefore, this is a somewhat deviant case (Fuglestad et al., 2021), representing a mechanical innovation with few digital components compared to the other technologies described.

The round bale technology is a machine that hangs behind a tractor. It can be described as a generic technical combination of three things: a grass cutter, a machine that compresses the harvested grass, and a solution that wraps the ball of compressed grass in a thin plastic film. The finished round bale, thus, is a plastic-wrapped ball of silage that can be stored outdoors until feeding.

4.5.1. Invention

From the 1970s onwards, several producers around the world began building round bale machines (Wilkinson and Rinne, 2018). In Norway, two well-known manufacturers of agricultural equipment, Kverneland and Orkel, started making round bale machinery. The market developed from a series of initiatives and advances initiated in the 1980s, originally aimed at cultivating new land in the farm's outfields. Later, agricultural advisor services played a role in advising farmers to choose baling rather than investing in new silos, for financial and environmental reasons.

4.5.2. Implementation

In Norwegian agriculture, the round baler developed from a solution discussed among researchers as a way to harvest marginal and newly cultivated land in mountain areas, to become the most common way to harvest grass (Fuglestad et al., 2021). New land in mountains was localised a long distance away from the farm, and there was no infrastructure to conserve and store the grass. Early in the process of technology implementation, research on the mechanization economy of grass harvest technologies compared various alternatives (e.g. Hilmersen (1981)), and the potential for rationalization – especially in the use of newly cultivated and marginal land – was emphasized. Flexibility and mobility were recognized as advantages of the round baler. Thus, research done both by researchers at the Norwegian Agricultural College and by actors in the agricultural extension services provided supporting functions. Actors in the industry were also important. Additionally, Norsk Fôrkonservering (NOFO), which produced conservation additives (acid) for the silage process, played a key role (Prestrud et al., 1982). During the early 1980s, they experimented with silage baling (NOFO, 1983). In the following years, NOFO published a series of reports and educational leaflets on the round bale technology, as did several other research stations, agronomists, agricultural economists, etc. (NOFO, 1983; Kjus et al., 1996; Valberg, 1994; Bardalen, 1993).

The key support system at this level may, therefore, be identified as the working of a larger structure of research and industry actors. For the farmers, the technology became a preferred harvesting technology: It was flexible, had high capacity, reduced the need for labour in the silo, reduced the need for investments in expensive building, and, most importantly, enabled the farmer to use land more distant from the farm unit and, thus, allowed for growth through the use of rented land. Another key factor contributing to use of the baler was the presence of old concrete silos on most farms. These were either damaged or too small to store more silage. Building new ones or fixing old ones was an expensive investment, and using baling equipment was cheaper. The opening for growth is the single factor that first and foremost led to the major impact of the round baler.

4.5.3. *Impact*

Before the round baler entered the scene, growth beyond the borders of nearby land was difficult for Norwegian farmers, as grass had to be transported to a silo at the farm during the short and hectic harvesting season. Thus, the main impact of the round baler is that it made farm growth possible to a significantly higher extent than before. However, in a restricted market, and when access to agricultural land is restricted, the growth of one farmer means that another farmer must reduce her production or quit farming. Farm growth, therefore, implies farm concentration or agricultural restructuring (Vik, 2020). The baler was key to this process in the Norwegian context, but an important point here is that the process seems to have been an unintended consequence of the implementation of the baler. For individual farmers, the baler was a rational technology for grass harvesting in the existing geographic and economic conditions, but for the agricultural sector as a whole, it became a transformative technology. However, the round baler cannot, on its own, be held responsible for the restructuring of the agricultural sector. Yet, it is clear that the round baler did help to facilitate the process towards larger farms with a high use of rented land, which is now a distinct feature of Norwegian agriculture (Forbord et al., 2014). Here, technological developments work in concert. The interplay between the round baler and the milking robot is particularly stunning. In Norwegian agriculture, automated milking systems have become the new normal (Vik et al., 2019), though they require larger herds of cows and, thus, more grass than that needed by the former standard milking farm in Norway. The round baler was ideal in supporting the transformation towards a dairy sector where milking robots are a key feature, as the round baler made it possible to harvest additional fields of grass far from the farm itself. As Vik et al. (2019) point out, the development of the new AMS-adapted dairy sector required a set of political and social adaptations in addition to technological ones.

In terms of support systems, we can also speak of a series of interrelated actors and processes that have paved the way for the impact of the round bale technology.

4.6. *Technology support schematic for the four cases*

In Table 1, we extract, from the case narratives, the kind of support or factor that was important at what stage in the innovation process for each technology.

5. Discussion

The four cases we have described above are diverse in many ways. They range from rather simple mechanical machinery (the round baler) to advanced digitalised, sensor- and information-heavy technologies (AMS, Biodrone, and Nofence). Some are examples of imported technologies, others are developed nationally, etc. Some require cooperation

Table 1

Four case analyses: Critical support for improving readiness in different stages of innovation.

Case Critical Support in	Milking robot Automatised milking system	Nofence Electronic tracking and digital fencing	Biodrone Drones for use in farming and forestry	Round bales Grass harvesting, pressing, packing and conserving
Invention	(Not relevant in the Norwegian context)	- Funding from Innovation Norway - Access to technical solutions through network of suppliers - Testing by frontrunners among farmers	- Funding from Innovation Norway - Media attention - Support from R&D partners	- Early research by governmental research institutions - Experimentation with harvesting practices and silage quality using baling technology
Implementation	- First movers/pioneers necessary to demonstrate utility - 24/7 service from suppliers - Funding for farmers - Advisory service to farmers from TINE	- Interest among a network of users/farmers - Media attention - Social acceptance - Regulative acceptance and support from core politicians	- Access to and support from actors in forestry industry - Exceptions from regulatory constraint (granted by the Norwegian Food Safety Authority)	- Activity on research and information from research and industry actors on e.g. feed quality, and additives - Machinery cooperation between farmers
Impact	- Adjusted regulation (of e.g. quotas) and support schemes	Limited impact so far. Potential for larger impact requires: - Access to more partners and markets - Broader base of users in the agricultural sector	No significant impact yet. - Potential for impact requires regulatory change for use in food production - Automation has high workforce implications in both forestry and agriculture	- No specific support for impact, but: - Small and fragmented farms was fertile ground for the technology - Increased requirements and costs of the alternatives made the technology attractive

and learning by animals, e.g., goats understanding the concepts of digital fencing and cows getting in line to be milked by machines. Thus, the technologies we have chosen constitute fertile ground for showing and analysing a wide variety of (pre)conditions and support functions important for the invention, implementation, and impacts of new technologies.

The narratives of the cases and the overview in Table 1 can reveal a structure in the supporting functions, which varies according to what we indicate in the long-term innovation process.

In short, in the *(1) invention* stage, we can observe from our cases, unsurprisingly, that technical support is crucial. This includes, for example, technological and biological knowledge and sometimes also research. However, we also see that, in some cases, funding is needed to develop the technology. When funding is needed, the question of market is raised. The network to potential customers or producers is a very important supporting function.

The next stage, *(2) implementation*, is, of course, dependent on the character of the technology. Some technologies are rather complex, like the milking robot, while others are more straightforward, like the round baler. The supporting function at the micro-level will vary depending on the complexity. However, along with the other dimensions of readiness, we observe several supporting functions that are non-technical. In particular, regulations, social acceptance or opinions, media, the business model, supporting services, etc. influence the degree of implementation. This is a transition at the regime level. We saw, for example, that the round baler was an easier technology to buy and use for farmers, as it was not regulated in terms of the strict animal welfare perspective that, e.g., electric shocks from collars would assert – as in the Nofence case.

Finally, supporting functions at what we label the *(3) impact* stage, in the long-term innovation process, may be of another kind. Still, while the functions at the implementation stage are important, market demand, regulation, and social acceptance are crucial to achieving societal impact and stimulating the transition of the system.

In these cases, we can observe a fluctuation of supporting functions through the three stages of innovation. Fuglestad et al. (2021, 176) sum up this development related to the round baler case:

This shows us traces of an expert system located at the nexus between state, industry and farmer organizations that facilitated agricultural transitions by way of research and information directed to farmers and farmer organizations.

All cases show the interplay between factors at the different levels to continue the innovation process from the invention stage. As the round baler and the milking robot cases are the most mature ones, in time, we can best observe the interplay or duality here. The technology can open up the possibility of – and even bring about – transition and structural change in agriculture, but the technology is also dependent on various regulations that support any potential transition. Clearly, though, the complexity of the causal relationship between technological development, political regulation, and structural change prevails.

The above-presented narratives also suggest that there is a relationship between the critical support an innovation receives at various phases and the development of its “balanced readiness”. In the invention phase, we saw that the technological readiness level was developed without any critical support in the case of AMS and the round baler, while Nofence received substantial critical funding for the development of the technological readiness. Biodrone also received support for integrating the various technologies it uses. Market readiness may be developed early in the invention phase, but we have seen, in both the Nofence case and the Biodrone case, that market readiness depends heavily on regulatory readiness and acceptance readiness – which, in terms of phases, stretch out to both implementation and impact. Funding and support from key actors were critical for the development of market and regulatory readiness for Nofence and Biodrone. For AMS, regulatory readiness in the form of quota easings, etc. was critical for its spread and impact. This illustrates that the balanced readiness assessment and the three phases of innovation are closely interlinked.

In addition, the case studies presented here illustrate how the ambitions of RRI must be tailored to the structuring factors that influence innovation within individual sectors. Such ambitions include goals for early, inclusive, and meaningful dialogue about the effects that innovation may or should have on different societal groups (Owen et al., 2012). As the technologies discussed above indicate, the role of public and centralised support such as R&D funding has been limited, while factors such as media attention, investment capital, existing regulation, and the needs of industry actors all have been part of shaping the innovation trajectories of agricultural technologies. Agricultural innovation may include the introduction of developed technology into a Norwegian context by early-stage entrepreneurs, where the direction and possibilities of technical development are, thus, largely defined before its market adoption. This is evident in both the milking robot case and several components of Biodrone. In other cases, technology may be developed for a relatively modest purpose, but have its more transformative potential recognized only later, as other groups become involved in its use. This was evident in the story of round baling, which originally – in the Norwegian context – was thought to be a means of assisting in utilizing distant outfields, and only later transformed Norwegian silage use after agricultural advisors recognized and communicated the technology's potential in that area to farmers (Fuglestad et al., 2021). Moreover, in several cases, we see that the uptake of technologies was triggered or redirected by bursts of media attention, focusing critical attention on animal welfare concerns in the case of Nofence or helping to attract capital investments in the case of Biodrone. Finally, with regard to activities by early-stage entrepreneurs in the cases of Biodrone and Nofence, both cite economic development assistance from Innovation Norway as a critical support factor at the earliest stages of invention.

While the factors identified here are doubtless at play in innovation in other sectors as well, their recognition in relation to agriculture is necessary as part of an effort to incorporate RRI within that sector. The more practical question then becomes: At what point in these trajectories might there have been scope for RRI ambitions to be incorporated – and by whom and in what forms? One insight from the application of BRLa to these cases is that RRI could be more effectively introduced to agricultural innovation by targeting support mechanisms at play in different stages of the innovation process. Unlike activity areas funded by the Research Council of Norway (which operates with its own RRI framework), Norwegian economic development efforts funnelled via Innovation Norway have yet to formulate RRI guidelines that accompany its support mechanisms for innovative start-up companies. Moreover, we see that different advisory services play an important role in technologies' wider uptake and impact, suggesting that these actors, too, are in a position to engage more explicitly with RRI in the Norwegian agricultural innovation context. Debates surrounding animal welfare, the displacement of human labor by automation, or the role of technology in enabling the centralization of agriculture are examples of issues on which these groups could facilitate engagement guided by RRI.

Technological innovation will not necessarily have only positive societal effects. Often, the effects will be positive for some and negative for others. This interpretative flexibility of the technology, as Bijker et al. (1989) call it, has not been the focus of our article, but could be an interesting next step of inquiry. We have first of all looked at how innovations contribute to positive societal effects. However, for a technology to achieve societal impact, there is a need to have reached a high Balanced Readiness Level on all dimensions in addition to a high Technological Readiness Level.

6. Implications

The support functions are linked to key aspects of the technology and its development in order to have a significant social effect. Through transmission at the different levels (niche, regime, and landscape), we can observe that a technology's success in achieving diffusion is more complex at a higher level. The sociotechnological system, like the farming systems we have studied in this paper, transforms through a complex mix of supporting functions that are technologic-specific, but the social and organizational dimensions of support become more important when the impact is to be reached. From this, it follows that supporting invention to stimulate innovation is important; supporting implementation is also important, but identifying the supporting functions that can have an impact is crucial to stimulating the transition of the system at the landscape level. These supporting functions are not always obvious or easy to predict, as shown in this paper. Research must also include these aspects. This is particularly relevant for challenges related to the Green Deal and climate challenges where transitions are demanded. To succeed here, supporting functions must embrace all relevant dimensions for readiness and all stages of the long-term innovation process.

7. Concluding remarks

Through this study of four distinct agricultural innovations, we have investigated how innovation practices can be understood in the transition to smart farming. Our main findings show that each phase of technological development benefits from specifically targeted support and that support functions should not be underestimated in order to raise technology to a higher level of acceptance. The heterogeneity of agricultural technologies should also not be underestimated; what works well for technologies for goats follows different development trajectories than that for cattle, or round bales, for that matter. Likewise, farmers specializing in different produce have different pains and gains from using different technologies. Technology developers, policymakers, researchers, and farmers can benefit from seeing technology as a socio-technical construction of multiple stakeholders negotiating how, when, and what a technological innovation could be, and what it should be, to stabilize.

For a new technology to have an impact on the sector, it must reach a certain level of readiness along several dimensions: technological, marketwise, regulatory, social acceptance, and organizational.

Each phase of the innovation process will most likely benefit from specifically targeted support. That means supporting functions might have different meanings in different phases of the process. The supporting functions will have different effects depending on the technology in question. A technology high in market value and low in regulatory acceptance would need extra support in overcoming that specific barrier, whereas a technology that is perfectly fine with regard to regulatory acceptance but that is low in market value would need support in becoming more attractive to the market.

We have also observed that unintended factors should not be underestimated as supporting functions. Especially at the impact level, i.e., the last step in the long-term innovation process, a complex set of factors might be facilitating the diffusion of technology. From the perspective of the readiness level, there must be a high level of readiness along all relevant dimensions. This is how technology influences the transition of farming, from the niche level, through the regime level, to the landscape level. However, it is also a mutual dependency – functions supporting transition also stimulate technology development.

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Statement of author contribution and declaration of competing interest

EPS has worked on the case of the milking robot, written parts of the introduction, methods, and data, concept, and discussion in particular, edited the paper, and been responsible for the writing process. JV has worked in particular on the case of digital fences and the round baler, written parts of the context, results, and discussion, and edited the paper. EMF has worked on the case of the round baler and commented. MDG has worked on the case of Biodrone and written in other parts. AMM has contributed text about context, in general and for all cases. RAS has worked on the case of digital fences and round balers and contributed by editing the paper. All six authors have contributed to the paper and are equally responsible. The order of authors reflects the work done for EPS and JV, while for the others the order is alphabetical.

None of the authors have competing interests with regard to the topic of this paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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