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Balanced readiness level assessment (BRLa): A tool for exploring new and emerging technologies.

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ABSTRACT

In this paper a methodology for a balanced readiness assessment of novel agricultural technologies is developed and presented. The methodology expand on the well-known Technology Readiness Level (TRL) assessments, with a method for assessing TRL as well as Market Readiness Level (MRL), Regulatory Readiness Level (RRL), Acceptance Readiness Level (ARL), and Organizational Readiness Level (ORL) in concert. In the article the Balanced Readiness Level assessment (BRLa) methodology is employed and illustrated on 1) a set of 36 novel agricultural technologies, and 2) on the development of a technology for virtual agricultural fences. The empirical applications in this article indicates that the BRLa- methodology may serve as a fruitful approach for a compound assessment of emerging technologies. The methdodology is relevant for actors involved in advisory services, funding, investment and technology development.

1. Introduction

A series of developments have paved the way for what may seem like a new technological revolution in agriculture across the globe. First, the food price peak back in 2007–2008 (Rosin 2013), increased awareness on the crisis of climate change (Bjørkhaug, Almås et al. 2012; Rickard 2015), and the anticipated population growth led to an increased interest in agricultural productivity and sustainable intensification (OECD 2019; Rockström 2017), as well as new or re-occuring productivism in agriculture (Wilson 2001; Almås, Bjørkhaug et al. 2010; Burton and Wilson 2012; Lawrence, Richards et al. 2013; Moreno-Pérez 2013; Forbord and Vik 2017). A high-level forum appointed by The United Nations Food and Agricultural Organization (FAO) predicted a need for a 70 percent increase in food production worldwide (FAO – High-Level Expert Forum 2009). While this estimation has been challenged (Tomlinson 2013; Mitchell 2017), the sense of urgency when it comes to increased global food production has remained. It seemed like the long-lasting concerns with the problem of agricultural over-production was replaced with an attention to food security (Burton and Wilson 2012). Still, technological developments in agriculture are closely linked to structural, political and societal changes for the farmers and in rural communities (See e.g. Vik 2020; Vik et al., 2019).

The new interest in food security and increased production has partly coincided with what has been described as a shift towards "smart" farming practices, "precision farming" (Daberkow and McBride 2001; Gebbers and Adamchuk 2010), or "data driven farming" (Bolman 2016). Much of this has a common feature in the use of sensor and monitoring technologies. We have seen a leap in the availability of technologies related to sensors, visual diagnostics, robotics, satellite communication, drones and the "Internet of things" (Krishna 2017). Smart farming may potentially contribute to optimizing farm practices (Carolan 2018a), but also holds the risks of surveillance, data storage and privacy issues (Klauser 2018). There are also concerns of a growing divide between the "smart farms" and the "not-so smart" farms of the past (Salemink, Strijker and Bosworth 2017). The Covid-19 pandemic has both re-actualized the food security issue around the world, and, in Norwegian agriculture, raised the question of how technology can become an alternative to a seasonal workforce, which became significantly less mobile due to travel restrictions during the pandemic.

However, even though new technologies may be promising and create new possibilities, the developments and implementation of new technology is complex. It is un-even, non-linear, potentially disturbing and hard to grasp (see e.g. Bijker, Hughes and Pinch 1987). The term technology itself is also compound. It includes the material constructs as

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well as the necessary connections and knowledge associated with the implementation and use of the technology – what Bijker et al. (1987) terms the social construction of technology.

Exploring the uneven and non-linear character of technology development, adaption and implementation can be done in several ways. In this article, a conceptual tool for assessing the development of new agricultural technologies, that take the complexities of technological development and implementation into account is presented and demonstrated. The concept of "Technology Readiness Level" (TRL) is taken as our *starting point* (Mankins 2009; Héder 2017). However, as has been noted by many, the development of new technology is not linear and cannot be grasped by the readiness of the material technology alone (Hasenauer, Gschöpf et al. 2017; Dent and Pettit 2011). New technologies in agriculture need a market, and the "Market Readiness Level" (MRL) does not necessarily converge with the TRL (Hjort & Brem 2016; Dent and Pettit 2011). Furthermore, new technologies may conflict with organizational, societal and/or political regulations and understandings (Kobos, Malczynski et al. 2018; Innovations Fund DK 2018). So, even if technologies have a high TRL and MRL, this does not tell us if and how a new technology is being *domesticated* by its users (Lie & Sørensen 1995) – as users bring it into their own sphere of daily practices and socio-technical structures. Therefore, to approach a better understanding of whether or not a new technology is close to implementation – and the reasons why (not) – this paper aims to suggest and test a set of concepts and a methodology for assessing the combined readiness level of new agricultural technologies, including five aspects of the technology: the (material) technology readiness; the market readiness; the regulatory readiness; the organizational readiness; and the (socially) acceptancy readiness levels.

The main contribution of this article is a methodology – or a tool – for a balanced readiness level assessment of new technologies. We present the methodology and show how it can be used to describe and categorize upcoming agricultural technologies. Thus, our development and exploration of the balanced readiness assessment methodology also serves as a plausibility probe (Eckstein 1975; Levy 2008) for this novel way of assessing new and emerging technologies. The novelty of the approach lies both in the composite assessment of the readiness of emerging technologies, and in the construction of the conceptual tool for the assessment. The tool is relevant for actors involved in advisory services, funding, investment and technology development.

The paper is structured as follows. First, we present the methods and data that we build upon in the paper. Second, we review some of the literature on technology readiness level. Thereafter we investigate what research has previously been done on market readiness level and societal readiness levels respectively. Based on this, we move on to present our readiness level measures and methodology and the resulting tool. To explore the usefulness of the tool, we apply it in two different empirical settings. First, we present an overview of new agricultural technologies of possible relevance for Norwegian outdoor agriculture on which we have applied the balanced readiness methodology. Thereafter, we apply the tool on the historic development of one particular technology – a virtual fencing system for digital herding of livestock called "Nofence." Finally, we sum up the paper by discussing the strengths, weaknesses and prospects of the balanced readiness methodology.

2. Methods and data

This article is written as a part of the research project "SmaT – Smart technologies for a sustainable agriculture", where we aim at exploring the development and implementation of new technologies for a more sustainable agriculture sector. The project focuses on outdoor technologies relevant for Norwegian agriculture.

The data we utilize in this article can be separated in two types. First, we have generated a database of new agricultural technologies that may contribute to a sustainable Norwegian agriculture. The list contains information on 36 different technologies. The selection of these is based on a technology screening done by searching through a wide range of online technology presentations, project webpages, etc. Our inclusion criteria were that the technologies should be i) outdoor technologies; ii) technologies of relevance to Norwegian agriculture; iii) technologies that are novel to the market or not yet available, and finally; iv) technologies with a physical material element. That means we have excluded computer programs, advisory tools, mobile apps etc. that are software-only based.[1] The screening was done, not to get an exact picture of all new technologies, but rather to get a grasp on approximately where the current technological development stands, and what the agriculture sector of tomorrow may potentially look like. The screening of the market for new technologies – and the resulting list – has served a double purpose. On the one hand, it has helped us to identify aspects of new technologies that have to be considered to get an overview of a new technology's overall readiness. On the other hand, the list has served as a pool of technologies on which we could test balanced readiness assessment methodology. Based on public available information on the technologies we have assigned all the technologies scores on the Balanced Readiness Level assessment tool to test its applicability.

The second type of empirical data stems from an in-depth study on the historical development of the virtual fencing system *Nofence* (Søraa and Vik, 2021). Data were gathered partly by interviews with key person in the company, farmers using the Nofence technology, observations of the technology in use, and some secondary data on news articles regarding the technology, as well as technology forum observations. These data are used to illustrate how the tool may cover how a technology develop in readiness over time. The technology is described below, in section 5.2.

Seen together our data are well-suited for performing a probability probe of the usefulness of our approach to a balanced readiness assessment of new technologies.

3. Literature review – from rocket science to the societal realm

"Technology readiness level" (TRL) is a conceptual measurement tool that estimates technological maturity on a scale ranging from *idea* to *functional product*. The concept and evaluation framework were introduced by the National Aeronautics and Space Administration (NASA) in the 1970s (Mankins 2009). In 1995, Mankins provided definitions and examples of the nine levels (Mankins 1995). Since then, the scale has been refined and elaborated by many (Sadin et al., 1989; Heslop, et. al. 2001; Mankins 2009; Hèder 2017; EARTO 2014; CloudwatchHub, n.d.), and several operationalizations and adjustments have been made (DoD 2009; 2011; US GAO 2016). The interest for the concept has gradually risen and is now incorporated and employed worldwide in a variety of organizations (Mankins 2009; CloudwatchHub, n.d.; Bakke 2017). Mankins (2009) holds that technology evaluation can, if done thoroughly and at the right points of time, be a crucial ground for decision-making. This includes performance objectives of the technology, current technology readiness level and an assessment of the hindrances for further development (Mankins 2009).

Even though the TRL scale has become a widespread tool, there are limits to its usefulness. The European Association of Research and Technology (EARTO 2014) describes different limitations of the use of TRLs as being: i) too much focus on product development and not enough on manufacturability, commercialization and organizational changes, ii) negligence of maturity setbacks, iii) focus on single technology readiness, and iv) failure to adjust the scale to specific purposes. Furthermore, the widespread use and cross-sector implementation of technology readiness assessment has led to adjustments and new variants (Nolte 2008). Hèder (2017) argues that mutations and a wide range

[1] This is a practical demarcation line stemming from the project purpose, and does not imply that we discard e.g. software, apps and algorithms as technologies.

of readings and an employment of the TRL-scale in several non-similar (non-commutable) sectors and disciplines, poses a problem for the applicability of the scale. Technology is a multi-faceted subject and assessing technological readiness does not offer a comprehensive understanding of a product's maturity (Nolte 2008), nor what is necessary for successful technology transition (Doerry 2010). Li and Kassem (2019) point out that TRL does not consider the surrounding environment in the implementation of new technology, and Dent and Pettit (2015) hold that a more holistic approach to assessing a product's maturity by introducing market readiness as an additional aspect, will prove useful.

Dent and Pettit (2011) argue that just as developers and dealers of technology try to handle the "technology risk" by monitoring and controlling the technology readiness level, the "market risk" should be considered equally important through evaluating the "market readiness level" (MRL). MRL is a more recent concept, and definitions and operationalizations of market readiness are therefore far less widely accepted and cemented than TRL. Paun take a similar approach and argue for the combination of TRL and the use of what he calls "Demand readiness Level" (Paun, 2011).Recently, however, the focus on market readiness has become increasingly prevalent, as e.g. expressed by Horizon2020s sharpened focus on the market aspect of product development (CloudwatchHub, n.d. –b). Hasenauer, Gshöpf and Weber (2017) argue that MRL can be summarized with four questions: i) To what extent are competitive products available? ii) How is the demand for the product? iii) Is the customer ready to use and adopt the product? iv) Is the product available for widespread use? Kobos et al. (2018) also point out that the value of the product depends on whether it offers something new, better or cheaper than other products. Assessment of market access, financial capital, manufacturing possibilities and users' profits in the form of higher returns relative to the use of resources is necessary for a good understanding of the product's potential. New technology in the agricultural sector may necessitate relatively substantial investments for the farmer.

Yun and Lee (2015) stress, in their study of renewable energy diffusion, the need to include a societal focus in order to overcome barriers of implementing alternative technologies. There have been attempts to address various aspects of what may be termed societal readiness, but this is an even newer and less elaborated term than TRL and MRL. Yet, there are a few studies that do address these themes; Kobos et al. (2018) for instance build upon the TRL method when developing what they call the "Regulatory Readiness Level" (RRL). Whilst TRL focuses on the technological aspect of a product, the RRL addresses the regulations affecting the commercialization of new technology. They argue that even technology that is fully operational and ready for market may fail without regulatory support. The underlying factors of RRL are the access to, and understanding of, the regulatory process, effectiveness and security of regulatory support, the "do no harm"-principle, and the political and social acceptability of the project or technology. In line with this, Hjort and Brem (2016) find that companies appear to lack an understanding of legislation as a constraining factor. Furthermore, the Australian Renewable Energy Agency (ARENA 2014) uses what they call the "Commercial Readiness Index", where regulatory conditions are amongst the factors, as well as several more market-oriented aspects. What they refer to as regulatory matters are divided into six levels, from the point when regulations are unknown and undefined, up to the point when regulations and permits are documented and approved. Also Sartas et.al. address these issues while suggesting a method for assessing a technology's "scaling readiness" (Sartas et al., 2020).

Authorities renew and adapt regulations as innovation pushes forward (Vik et al., 2019), and in some cases, regulatory conditions may also hamper the introduction of new technology that improves current practices (Søraa and Vik, 2021) . Regulatory support for new technology represents an institutionalized approval, where the support ultimately lies in the hands of the people electing lawmakers (Kobos et al. 2018). Furthermore, Munir et al. (2018) argue that a public disapproval of new technology due to for example safety issues will lower the motivation for authorities or companies to allow and develop this. Yet, the resistance to new technology may also be institutional of nature, as e.g. when the infrastructure surrounding the technology favours one technology over another (e.g. gas stations vs battery chargers). Thus, technology use is to some degree path dependent (Urry 2004).

The literature on readiness levels is, as we have shown, uneven. There is a rich literature on TRL, some more on MRL - partly in combination with TRL - , while literature on readiness assessments regarding regulation, social acceptance, and organizational issues of new technologies is scarce. Nevertheless, new technologies have the potential to create new practices as well as unforeseen consequences. Thus, assessing the implementation of new technologies depends on market readiness, regulatory readiness, societal acceptance, and organizational readiness. Therefore, the need to take theese aspects of new technologies into account is apparent. Acknowledging the need for a wider approach to a technology's readiness implies a more holistic understanding of technology development and implementation. We now turn to the methodology for creating such a balanced readiness assessment.

4. A new balance readiness approach

This article holds that a multi-dimensional assessment of technology readiness is necessary in order to get a good grasp of technology development and implementation. How well developed is the technology? How ready is the market? Are the legal aspects taken into concern? Will society welcome the technology? How are the end users supposed to integrate the new technology in their current practices? These are questions that a balanced approach to readiness needs to address. The line of thought concerning the existing readiness levels often follows a linear timeline, with logical transitions from idea, to the development of individual components, to the development of an integrated prototype, to the finished product. This need not always be the case (Hjorth and Brem 2016). Due to the large variation in a product's journey from idea to market, we consider that one single integrated scale that addresses all the mentioned dimensions, is not feasible. We therefore suggest, based on our literature review and analysis, a five dimensional readiness assessment. The dimensions we explore are i) TRL – technology readiness level; ii) MRL – market readiness level; iii) RRL – regulatory readiness level; iv) ARL – acceptance readiness level; and v) ORL – organizational readiness level.

A balanced readiness approach links these five dimensions of a technology's readiness together in a five-dimensional description. This gives an overall assessment of a product`s development, where to expect eventual barriers, and where the technology developers need to focus their attention.

Inspired by the literature on readiness measurements presented above, our balanced approach also builds upon the 9-point scale, on five different dimensions, and hence scales. For each readiness scale, the methodology includes a numeric readiness level, a general description of what the level means, and an additional comment on what the levels will imply in practical terms. For each scale we have also developed a questionnaire in order to ease the categorization of actual technologies and products. Below, we go through the five dimensions and scales:

TRL – technological readiness level – is about technological *development*, build on a large literature on TRL (Héder, 2017; Heslop, 2001; Mankins, 1995, 2009; Sadin et al., 1989; EARTO, 2014) and consists of the nine following levels: Level 1 is a situation where a specific technological idea is formulated; level 2 is when the idea is explicitly described; level 3 is when experimental proofs of concepts are produced; level 4 is when the elementary technology has been tested and validated in the lab and/or simulated environment; level 5 is when technology is tested in a relevant environment; level 6 is when a prototype is tested in natural environment; level 8 is when the product has been finally tested, validated and the functionality is being optimized, and finally; level 9 is when the actual system is being proved functional in use.

MRL – market readiness level – is about *commodification* of a technology. The theme is adressed in the literature (Paun, 2011; CloudwatchHub, 2020; Dent and Pettit, 2011; Hasenauer et al., 2017) and address how well-developed is the process of adapting the product to the market. Yet, there is little concensus on how to deal with the issue. Here, the emphasis has been on building the same type of scale as in TRL: level 1 is a hunch regarding a need in the market; level 2 is when a description of a product and a market has been formulated; level 3 is when the market needs and the products are explicated or concretized; level 4 is when the market is validated by e.g. a small pilot campaign; level 5 is when a business model is clarified; level 6 is when the product has been launched to small groups; level 7 is when customers confirm satisfaction and/or progress; level 8 is when a stable sale makes a prediction of income possible, and; level 9 is when market is stable or growing.

RRL – regulatory readiness level – is about the *legalization* of a product. The term has been used by others (Kobos et al., 2018), although in a somwhat different vein. Here, level 1 describes a situation where the legal or regulatory aspects of a new product is unpredictable; level 2 is if the product demands changes in current law; level 3 is when use or production require changes in regulation and/or reinterpretation of regulations; level 4 describes a situation where use of the technology will require hard-to-get certificates or approvals/concessions; level 5 is a situation where certificates etc. also are required but are more easily accessible; level 6 describes a situation where approvals are necessary, but likely to be obtained; level 7 is when approvals are mandatory but are "just around the corner"; level 8 is when general conditions for use are fulfilled, and; level 9 is situations where use and production are regulatory approved or unproblematic.

ARL – acceptance readiness level – is about the *legitimization* of a new product or technology. The dimension seeks to capture the social acceptance of a new technology. Kobos et al. (Kobos et al., 2018)address the issue in relation to their discussion of the regulatory readiness and Sartas et al (Sartas et al., 2020) discuss social and political qacceptance in relation to their term, scaling readiness, Here, level 1 describes a situation where the technology is, or will be seen as illegitimate or socially unacceptable; level 2 is when the technology is seen as controversial in large portions of the population; level 3 is when the technology is seen as unwanted by groups of the population: level 4 is when the technology is seen as questionable by groups of the population; level 5 is when use of the technology is seen as inappropriate by important groups in the sector; level 6 is when the technology is seen as inappropriate or unwanted by some actors in the sector; level 7 is when the technology is seen as questionable by groups within the sector; level 8 is when use of the technology is seen as unwanted by marginal interest groups, and; level 9 is the situation when use and production of the technology is generally accepted or not questioned at all.

ORL – organizational readiness level – is mainly about the *domestication* of technology, and the degree of how compatible the new technology is to existing technologies. Sauser et al. (Sauser, 2006) use the term system readiness to describe how well individual technologies are integrated. This is related to the term ORL used here, but ORL is more about how a technology is integrated with existing social and organizational practices. , work routines or practices. Level 1 is when the technology clearly breaks with existing practices in the field; level 2 is when it is open or unclear how the technology is to be merged with existing work processes or technologies; level 3 is when there is a formulated idea regarding how the technology is to be used in relation to work processes or existing technologies; level 4 is when the integration/merging/replacement is explicitly described; level 5 is when there exists a concrete plan for how to integrate or use the technology in relation to, or instead of, work processes and/or existing technologies; level 6 is when substantial organizational changes are needed in order to make use of the technology; level 7 is when minor organizational changes are needed; level 8 is when the technology is adapted to, or ready to replace, existing processes or technology, and level 9 is when the new technology works seamlessly together with other technologies or in existing work processes.

The categories for each of the five dimensions of readiness are summarized in table 1. Corresponding to the scales for the five different readiness level assessments, a questionnaire to help the classification of each of the technology readiness dimensions is developed. The questionnaire is presented in table 2. The tool is a series of nine questions for each readiness level type, where each question corresponds to a level on the scale above. The questionnaire is logically structured in a fixed sequence: For each of the five dimensions, the evaluator must start from the top and work his/her way downward until he/she can answer "Yes". Then s/he stops. A yes on question 1 corresponds to TRL 9, question 2 corresponds to TRL 8 and so on. Following this sequence, when a question is answered with "Yes", it means that the level of readiness is found – on that measure. If for instance – on TRL – there is "No" on the first two questions and "Yes" on the third: the TRL level is 7 for this technology.

In addition to the presented tables, there is a need for a way to picture the result. This may be done through a variety of diagrams or bars. Here, a a pentagon is chosen. Thus, when the questionnaire procedure is done for the five different dimensions of readiness, the result may be illustrated on a five cornered form – the pentagon. If a technology is fully matured on all five scales, it will follow the outer line. The less ready or mature a technology is, the closer the score will be the center of the figure. Se Fig. 1.

The methodology presented above is primarily an initial mapping tool. It is meant to supplement market studies, elaborate research on social conditions in relation to new technological solutions or legal investigations of various fields. However, as an initial and combined approach to readiness assessments it is useful in situations where there is a need to get an early grasp of the prospects and challenges of new technologies. However, as always, it is necessary to exercise discretion when making technology assessments.

5. Balanced readiness level assessments of new agricultural technologies

In the following section, the practical use of the tool is illustrated in two steps. First, the tool is employed on 36 different agricultural technologies, thereafter the use of the methodology is illustrated in some more detail on a virtual fencing system.

5.1. A screening and assessment of 36 emerging technologies

For the identified technologies, the readiness in terms of technologically, market, regulatory, acceptance, and organizationally readiness were rated using the above-described methodology. The findings are reported in table 3.[2]

The technologies were diverse, but the new technologies could be sorted in six groups: i) Agricultural robots with specific tasks; ii) All-round agricultural robots; iii) Drone technologies; iv) Sensor-technologies; v) Technologies for livestock tracking and handling, and finally; vi) "Other" technologies. They were in different stages in all the five dimensions, but typically technologies on very early TRL stages were not captured by the screening method in the project.

[2] It must be emphasized that the scores put on the various technologies are done by us as external researchers based on publicly available information at the time of writing. Developers may have information or views that are out of line with our evaluation. The scores we use are based on our best discretion regarding our current knowledge per October 2020.

Table 1
Five dimensions of readiness level assessments.

Level	TRL «Development»	MRL «Commodification»	RRL «Legalization»	ARL «legitimization»	ORL «domestication»
1	Specific technological idea is formulated	Hunch of a market need	The legal and/or regulatory aspects of the technology is unpredictable or unknown or unpredictable	The technology is or will be seen as illegitimate or unacceptable	The technology represents a fundamental break with existing work processes or organizing
2	The technology idea is explicitly described	Market and product are described	Use or production will require changes of laws.	The technology will be seen as controversial in large parts of the population	Unclear how the technology might be adapted to existing work processes/organization
3	Experimental proof of concept	Market need and market supply are explicated.	Use and/or production will require change or reinterpretations of regulatory framework	The technology is seen as unwanted or inappropriate among groups of the population	An idea about integration domestication exist
4	Technological elements are tested and validated in lab or simulated environment	Validation of market/small pilot campaign	Use and/or production will require demanding permissions or approvals	The technology is seen as controversial among groups of the population	Integration with work processes/organization is formulated
5	Integrated technology tested and validated in lab or simulated environment	Business model described	Use and/or production will presuppose accessible permissions or approvals	Use of the technology is seen as unwanted or inappropriate among key actors in the sector	A concrete plan for integration with existing work processes is formulated
6	Technology demonstrated in relevant environment	Products are being launched in limited scope	Necessary approvals are likely	Use of the technology is seen as unwanted or inappropriate among a few actors in the sector	Large/fundamental organizational changes are needed in order to use the technology
7	System prototype demonstrated in natural environment	Customers confirm progress/improvement	Necessary approvals for use or production are "just around the corner"	The technology is seen as controversial in parts of the sector	Small organizational changes are needed in order to use the technology
8	Product tested and validated, and the functionality is being optimized	Stable sale makes income predictions possible	Use or production fulfill general conditions	The technology is seen as controversial among marginal interest groups	Technology is adapted to work processes and/or existing technology
9	Actual system proven functional in natural environment	Market confirms stability/growth	Use and production are regulatory unproblematic	The technology is generally accepted/applauded	The technology works seamlessly with existing technology

5.2. *The nofence technology*

"Nofence" is the name of a virtual herding technology developed by a small Norwegian company called Nofence AS that started in 2011. The Nofence technology consists of a collar attached around the neck of an animal (goats, sheep or cattle), with a beacon that sends and receives 4G satellite signals. The collar contains a battery (sun-charged) as well as a Bluetooth unit as a backup-solution should the battery run out. The system is connected to a farmer's app, where the farmer can set digital boundaries on a map, in order to control where the equipped animals can walk. Animals that walk outside of the designated virtual fenced area will start hearing a beeping sound from their collars, increasing in volume, until it reaches a point where a small electric shock is given as a last resort. After some training, the animals learn to run back the way they came after receiving sounds and the potential shock. The farmer's app, on e.g. her mobile device, gives an overview of where the animals are, what their battery level is, and what number of sound and shock triggers the individual animal has received. This novel technology has received substantial media attention and has led to negotiations with national and local governing actors. We will in the following section show with the five respective Readiness-Levels how the No-Fence technology has moved on the scales. The history of the development of the virtual fencing technology is based on the brief history available on the company's home page (Nofence 2020), and an interview performed by two of the authors (see also Søraa & Vik, forthcoming).

5.2.1. *TRL-development*

The idea of a virtual fencing system developed with the founder Oskar Hovde Berntsen during the 1990s. How this could work became clear later on and the first patent application was submitted in 2009. So, during the 1990s and the early 2000s, the TRL moved from TRL 1 to TRL 2. The company was established in 2011, and in the years between 2012 and 2015 they did intensive product development and testing of the technology. Thus, they moved from TRL 3 to TRL 5. In 2016 they did a pilot testing on 850 goats, indicating that they took the step further to TRL 6 and TRL 7, where 7 is described as "System prototype demonstrated in natural environment". According to interviews, they continued to improve the technology throughout 2017 and 2018, indicating that they moved on to TRL 8 and 9. In 2019, 4000 goats used the Nofence technology. From 2017 and 2018, Nofence was modified to be used on sheep and cattle. This application of the technology can be said to start on TRL 5 or 6 since the basic elements of the technology was the same as for goats. What was needed was modifications and permissions to test the technology on other animals. A pilot test on sheep and cattle was performed in 2019. In 2020, Nofence was authorized for use on sheep and cattle, by the Norwegian food safety authority (NFSA). Then, Nofence reached TRL 9 also for those animal types: "Actual system proven functional in natural environment".

5.2.2. *MRL-development*

To some extent, the market readiness level developed together with the TRL. The basic idea of the technology coincided with a hunch that there was a market for it. The background was that, according to the founder, he realized that outfields increasingly fell out of use – partly due to the cost of maintaining the traditional fences, and partly due to the difficulties of practicing grazing in a changing agricultural structure. The basic idea was therefore just as much a market hunch as a technological idea. However, more explicit descriptions of the market and the market need – indicating MRL 3 – weren't developed before Nofence started to apply for public funding support around 2011. Here the founders also met difficulties as their way of seeing market development didn't match the more standardized market studies that they were required to do in order to receive funding. However, in 2016 a pilot study was performed – indicating a MRL at 4. Later on, Nofence developed a business model where the costs are partly paid by prices per animal collar, chargers, extra batteries etc., and partly by a cost per animal per grazing day. They have also developed a price calculator to help customers find the annual costs of implementing the system (https://www.nofence.no/priser). This indicates that they had reached an MRL level at 5. The next step in MRL development came after the approval by the NFSA in 2017. Then, the product was made available to waiting customers, who in turn, through their feedback, contributed to the rapid development of MRL from 6 to 9. For sheep and cattle, the NFSA approval came in 2020, opening for a broader marketization also for those animal groups.

Table 2
Questionnaire for the five dimensions of technology readiness level assessment.

Question	TRL	MRL	RRL	ARL	ORL	If Yes. level
1	Is the technology fully developed and ready to use?	Is the product available in a market through a defined business model?	Is use and production of the technology regulatory unproblematic?	Is use and production of the technology socially accepted in general?	Can the technology be used seamlessly together with existing technologies?	9
2	Is the technology tested and validated in a broad scale?	Is product demand stable or growing?	Does use and production of the technology fulfill general requirements?	Is use of the technology seen as questionable within marginal interest groups?	Is the technology adapted to work processes and/or other technologies?	8
3	Is the technology tested and validated in natural environment?	Has there been demand for the product in the market?	Are the necessary approvals/ permissions close to be given?	Is the technology seen as questionable in parts of the sector?	Are only minor organizational changes needed?	7
4	Is a prototype tested and validated in a relevant environment?	Has the product been sold in small amounts?	Are needed approvals/ permissions likely?	Is the technology seen as questionable by a few actors in the sector?	Are major organizational changes needed for the technology to be used?	6
5	Are core components tested together and validated in lab/simulated environment?	Is there a described business model?	Will use of the technology require easily accessible permissions?	Is the technology seen as questionable among key actors in the sector?	Is there a plan for integration of the technology with existing work-processes?	5
6	Are the core technological elements tested and validated one by one?	Is the market demand and the idea confirmed by customers and market actors?	Will use of the technology require demanding permissions/approvals?	Is the technology seen as questionable among groups of the population?	Has a potential integration and domestication of the technology been described?	4
7	Is a concept clearly demonstrated and described?	Has a market demand and a product been explicated?	Will use of the technology require regulatory changes?	Is the technology seen as very questionable among groups of the population?	Has an idea regarding integration/domestication been formulated?	3
8	Is the idea explicitly described?	Has an idea regarding a need and a technological solution been formulated?	Will use of the technology demand legal changes?	Is the technology controversial among large part of the population?	Is the integration with existing work processes unclear or problematic?	2
9	Is a specific technological idea formulated?	Does an idea regarding a market need exist?	Are the legal and regulatory aspects of the technology unpredictable/unknown?	Will the technology be seen as illegitimate or socially unacceptable?	Will the technology represent a fundamental break with existing work processes?	1

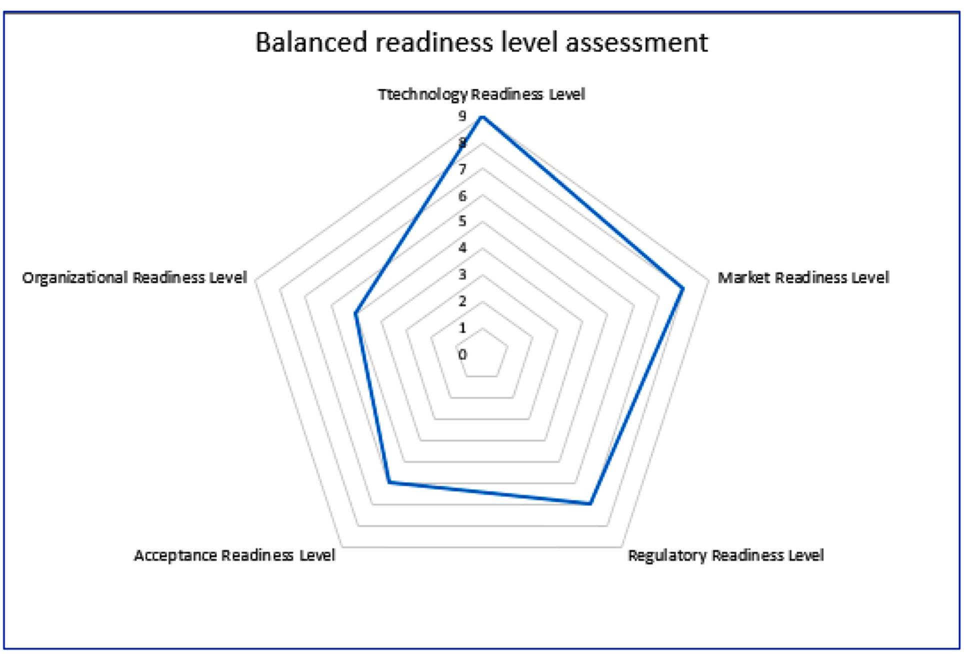

Fig. 1. Balanced Readiness Level assessment illustrated.

5.2.3. RRL-development

As is clear from the presentation so far, a controversy with NFSA was a defining element in the development of Nofence. NFSA – which is obliged to take animal welfare considerations – was reluctant to open for the new technology. This must be seen in relation to the idea of giving the animals an electric shock. Nofence, on the other hand, wanted to open for more use of outdoor grazing while reducing physical fences in the outfields. The controversy arose as the authority of approval was moved from the "Animal-Experiment-Committee" (AEC, NO: *Forsøksdyrutvalget*), which had the responsibility to approve animal experiments and tests, to NFSA. AEC had quite a good relationship with the Nofence developer team; the team viewed them as both fair in their treatment of experiment applications, while at the same time ensuring that animal tests were carried out in a proper manner. However, this committee was dissolved in the middle of the approval process, and their responsibility was transferred to NFSA, which had a much stricter approach. Eventually though, the Minister of Agriculture and Food intervened personally and "proposed" for the NFSA to reconsider their

Table 3
Technology screening with balanced readiness level score estimates.

Agricultural robots with specific tasks	TRL	MRL	RRL	ARL	ORL
FarmBot Genesis (Farmbot, u.d.)	9	9	9	9	9
FarmBot Express (Farmbot, u.d.)	9	8	9	9	9
Agrobot (Agrobot, u.d.)	8	6–7	6	9	5–6
Asterix (Adigo, u.d.)	6	7	6	9	8
Ecorobotix (Ecorobotix, u.d.)	6–7	4	8	9	8
Franklin Robotics – Tertill (Tertill, u.d.)	9	9	9	9	9
Naio Technologies – Dino (Naio Technologies, u.d.)	9	7–8	9	9	5–6
Earthsense – TerraSentia (Earthsense, u.d.)	8	4–5	9	9	6
All-round agricultural robots	**TRL**	**MRL**	**RRL**	**ARL**	**ORL**
AutoAgri (AutoAgri, u.d.)	4–5	4	4–5	8	5–6
Thorvald (NMBU, 2020)	7	5–6	4–5	8	5–6
AgriBot (Agribot, u.d.)	6	4–5	4–5	8	5–6
AgroIntelli – Robotti (AgroIntelli, 2020)	9	8–9	4–5	8	5–6
Small Robot Company – fleet (Small Robot Company, u.d.)	8	5	4–5	8	6–7
John Deere – GridCon (Koerhuis, 2020)	5–6	4–5	4–5	8	4–5
Ztractor – Bearcub 24 (Ztractor, 2020)	9	8	4–5	8	6–7
Drone technologies	**TRL**	**MRL**	**RRL**	**ARL**	**ORL**
AgEagle (AgEagle, u.d.)	9	9	9	9	9
Delair-Tech (Delair, u.d.)	9	9	9	9	9
GriffAviation (GriffAviation, u.d.)	5–6	4	4	4	9
Nileworks (Nileworks, 2020)	9	7–8	4	4	9
Rantizo (Rantizo, 2020)	9	8	4	4	9
SenseFly (Sensefly, u.d.)	9	9	9	9	9
PrecisionHawk (PrecisionHawk, 2020)	9	9	9	9	9
Sensorics	**TRL**	**MRL**	**RRL**	**ARL**	**ORL**
Dimensions Agri Technologies – DAT-sensor (Dimensions Agri Technologies, u.d.)	9	8–9	9	9	9
TopCon CropSpecs (Topcon Positioning, u.d.)	9	9	9	9	9
N-sensor Yara (Yara, u.d.)	9	9	9	9	9
Augmenta (Augmenta, u.d.)	9	6–7	9	9	9
7Sense Products (7sense, 2020)	9	7–8	9	9	9
Technology in livestock agriculture	**TRL**	**MRL**	**RRL**	**ARL**	**ORL**
NoFence (goat) (Nofence, 2020)	9	9	9	8	7
NoFence (cattle and sheep) (Nofence, 2020)	9	9	9	8	7
FindMy (Findmy, u.d.)	9	9	9	9	9
Telespor (Telespor, u.d.)	9	9	9	9	8
Other technologies	**TRL**	**MRL**	**RRL**	**ARL**	**ORL**
Orkel Dens-X Compactor (Orkel, 2020)	9	7–8	9	9	9
Visionweeding – Robovator (Visionweeding, u.d.)	9	9	9	9	9
Kverneland Exacta CL GeoSpread (Kverneland, 2020)	9	9	9	9	9
Soil Steam International – Soilprep 400 (Soil Steam International, u.d.)	8	5–6	9	7	9
Quicke – Q-Companion (Quicke, u.d.)	9	9	9	9	9
Avant Tecno e-series (Avant Tecno, 2020)	9	9	9	9	9

position, which they did in 2017 (Søraa & Vik, fourthcoming). Regulatory readiness is about legalization of production and use of the technology. In the Nofence case, the critical point was the approval from NFSA. Before 2017, though, the scoring on the RRL scale was uncertain, but in the range between 3 through 7. With the acceptance from NFSA, the RRL reached RRL 9 for goats in 2017, and sheep and cattle in 2020. In this case, we also see that this is a condition for the development of MRL from 6 to 9.

5.2.4. ARL-development

When it comes to acceptance readiness level, the *legitimization* of Nofence has bounced back and forth on the scale. In relation to the RRL controversies as described above, the technology could easily have been framed in an unwanted "animal-cruel" way, with negative media portrayals leading to a potential level ARL at 4. However, as the RRL-issue of governing was resolved, the technology ARL has stabilized on level 8, which is when the technology is seen as controversial only among marginal societal groups.

5.2.5. ORL-development

ORL is about the domestication of the technology – how are the users adapting and implementing the technology? Nofence is partly an alternative to using physical fences. Permanent physical fences have been kind of a "dying" technology in Norwegian farming for several years. Thus, there is not a conflicting situation between farming with Nofence and farming with traditional fences. Grazing-based farming with the use of Nofence is made easier – although it may be costly. However, Nofence also opened for new ways of grazing and utilizing grazing animals. For several of the farmers that used Nofence in the first years, landscape cultivation was the main purpose. Starting to use Nofence involves a learning process, both for the animals and the farmer. The farmer gets support through the Nofence support service. Thus, at least in an early phase of technology implementation, organizational changes are required. The organizational connections that are built between the users and the Nofence organization is part of the business model of Nofence. For some farmers this may be seen as an obstacle in taking up farming with the use of virtual fencing, and thus, we suggest that Nofence is given an ORL score of 7.

By using Nofence as an example, it is demonstarted how movement on scales is dynamic and relational. A technology can achieve high levels on one scale, while struggling to meet higher level demands on other scales. The balanced readiness assessment methodology allows users to elaborate on this dynamic and to explicate both the promising and the challenging dimensions of technology development.

6. Concluding comments

In agriculture, the relationship between technological development and societal change is substantial, but largely understudied. However, the renewed interest in food security, sustainable intensification, and smart farming has led to a renewed interest in studies of technology from a societal perspective.

The close relationship between agricultural and rural development and technological change implies that from entrepreneurial and innovational, as well as analytical perspectives, tools and methodologies for assessing new technologies are in demand. What does it take to move from an invention to an implemented technology? What should funding organizations, market actors, and advisory services look for when assessing new products and ideas? What are the critical factors in the overall development and implementation of a new agricultural technology? These are questions that a methodology for a balanced readiness assessment may contribute in answering.

TRL has become an international standard for evaluating technological readiness and serves as a language for discussing technological development. Trying to develop a methodology for a more balanced and broader assessment of technology readiness must therefore, on the one hand, build on the established terminology of technology readiness, stemming from decades of TRL studies, and, on the other hand, build on a critique of the same tradition. In this article, we have tried to do just that. We have adopted the idea of technological development moving through scales of readiness or maturity, but at the same time expanded this from the somewhat narrow focus on technical aspects of TRL to the fields of market, regulation, societal acceptance and organizational adaptation.

The ambition with this article has been to contribute to the ongoing debate concerning the development of readiness assessments. Moving beyond TRL is challenging though. First, because the routes towards implementation of new technologies are diverse, and second, because the concepts of TRL, and to some degree MRL, have been defined and refined over time, while ARL, RRL and ORL are addressing more novel dimensions of readiness assessments.

Notwithstanding, the methodology for balanced readiness levels assessment developed and presented in this article is a fruitful attempt to both build on, and expand beyond, materially oriented studies of technology development. Further studies are needed to explore the applicability and usefulness of the approach.

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