Managing testbeds for accelerating a sustainable transformation of the agri-food system

A multiple case study about the management of two Swedish testbeds for digital farming technologies

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Abstract

Digital farming technologies are predicted to contribute with solutions to some of the grand challenges the agri-food sector is currently facing, such as feeding a growing population, ensuring food safety and improving sustainability performance in food production. While testbeds are identified as important sites where digital technologies are developed, a paucity of research considers the management of testbeds for digital technologies in the food and farming sector. This study aimed to contribute to understanding the management of testbeds developing digital farming technologies and management implications for the upscaling of digital farming technologies beyond testbeds. A qualitative multiple case study was performed on two testbeds for IoT solutions, one focused on dairy farming and one on pig farming. 4 open-ended, semi-structured interviews were conducted. Further data was collected through documents, web pages, and reports. The findings showed that external funding for testbeds is short-term, fragmented, and projects based, leading to limited resources in terms of capital, time, and workforce. Furthermore, the testbeds are used for demonstration purposes to showcase emerging technologies rather than for learning about the technology. Moreover, the plans to scale up technology beyond the testbed involve contradicting expectations between project stakeholders. Thus, managing the multiple and sometimes diverse expectations among stakeholders is an important management practice. In conclusion, coordination of testbed initiatives with more long-term timeframes should be a management priority to give the testbeds a more strategic role in testing emerging technologies that can resolve sustainability challenges in the agri-food industry. In such instances, it is also important to include a more diverse group of participants in testing and learning about emerging technology. This means that it is not only researchers who should participate in testbeds, but also farmers, agricultural advisors, and other relevant industry actors that can make valuable contributions to the research in testbeds and thus shape the innovation trajectory closer to applicable innovation.

Keywords: Digital farming technologies, Agriculture 4.0, Testbeds, Transitions theory, Multilevel Perspective, Strategic niche management.

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Abbreviations

AI	Artificial Intelligence
CSEM	Centre Suisse d'Électronique et de Microtechnique
DFT	Digital Farming Technologies
IoT	Internet of Things
MLP	Multi-level Perspective
PPG	Photoplethysmogram
RISE	Research Institutes of Sweden
R&D	Research and Development
SLU	Swedish University of Agriculture (Swedish: Sveriges Lantbruksuniversitet)
SNM	Strategic Niche Management
SVA	Swedish National Veterinary Institute (Swedish: Statens veterinärmedicinska anstalt)

1. Introduction

In chapter one, a background to the topic and a problem statement is provided. Moreover, the aim, the research questions, as well as the scope and delimitations of the study are specified.

1.1 Background

The agri-food system is facing several challenges. Firstly, the increasing global population creates a severe challenge of how we will provide food to all people in a food system that is already characterized by food inequality and lacking food security (UN, 2021). Also, with a growing middle-class, the demand for animal products will increase. At the same time, there are growing concerns among consumers about the negative impacts of livestock farming on the environment, public health, and animal welfare (Ellison et al., 2017). Secondly, the farming community suffers from other societal challenges, such as an aging population and depopulation in rural communities, failure to attract labor, difficulty in reaching markets, lack of public and health services, etc., which also negatively affects sustainable food production (Rolandi et al., 2021).

With these issues in concern, digitalization has become the biggest driver of transformation and offers ways to improve nearly every industry imaginable, not least the agricultural (Andersen et al., 2021; Rijswijk et al., 2021; Rose & Chilvers, 2018). The digitalization of the agricultural sector is referred to as the fourth agricultural revolution, where digital farming technologies (DFT), namely big data, biometric sensors, Internet of Things (IoT), and artificial intelligence (AI), are integrated with farm production systems (Lioutas et al., 2021). Some of the expected benefits are better decision tools, increased farm efficiency and productivity, reduced use of antibiotics, and improved sustainability (ibid.). Thus, the use of DFT in livestock farming is expected not only to meet the growing demand for animal protein, but also to address concerns about environmental sustainability, public health, and animal welfare (Ellison et al., 2017).

While DFTs are already available in the market, challenges to their broad diffusion still exist (Giua et al., 2022). This is explained by several factors. Firstly, the agricultural sector is less digitized and connected than other industries, and the technologies used differ radically from those traditionally used within the agricultural context. Secondly, deployment has been slow since the impact of DFT has not been sufficiently proven (Goedde et al., 2020). Similarly, Ingram et al. (2022) state that farmers are unsure of the value DFT brings, both in terms of economic benefit and sustainable value (economic, environmental, and social value). Thirdly, farmers are concerned about data ownership, e.g., who will benefit from accessing and using farmers' data.

Moreover, Jakku et al. (2019) argue that the social implications of technological innovations are largely neglected by those who promote them, which makes it difficult for DFT to contribute to the expected benefits. These innovations are intrinsically a socio-technical process, as their development and deployment are a product of social interactions between people, institutions, regular settings, and the technology itself. In other words, there are not only technological factors to consider but also many social dimensions that must mature simultaneously to make the new solutions fit the existing world, such as user's preferences, legal standards, planning requirements, and social practices (Bocken et al., 2021; Geels & Raven, 2006).

Traditional modes of governing through national and international policy or a so-called 'technology-push' are perceived to be insufficient for the diffusion of radical innovation (Turnheim et al., 2018). It is argued that these modes lack the agency needed to act upon the complex, situated, and uncertain characteristics of problems such as climate change, and more decentralized, bottom-up, experimental activities are better at mitigating these challenges. Hence, path-breaking technologies and solutions need to be developed in experiential settings, where they can be tested in a collaborative environment where the technologies' techno-economic performance can be improved while learning about the social and institutional dimensions concerning the technology. (Kemp et al., 1998).

A growing stance of literature is arguing for the role of experimentation in accelerating transformation (Kemp et al., 1998; Hoogma et al., 2002; Smith and Raven, 2012). As a result, testbeds and living labs have become an integral part of government and industry actors' innovation strategies (Turnheim et al., 2018). The Swedish government has established the initiative Testbädd Sverige (eng. Testbed Sweden), which aims to encourage the testing and experimentation of new innovations to stimulate investments in the Swedish research and innovation environment (Regeringskansliet, 2016). While there is no coherent definition of what a testbed is, Vinnova's (2021) definition 'physical or virtual environment in which companies, academia, and other organizations can collaborate in the development, testing and introduction of new products, services, processes, or organizational solutions in selected areas' is often used in the Swedish context. Testbeds have also become a strategy to bring research at universities closer to the industry to conduct more applicable research. In the agricultural context, universities such as SLU and Linköping University collaborate with funding bodies and organizations such as RISE, SVA, Lantmännen, etcetera to test and develop new technology in close connection to the industry (RISE, n.d.).

1.2 Problem statement

DFTs are perceived to play a crucial role in transforming the agri-food systems towards sustainability. Digital technologies are developed in testbeds, as these settings are considered to accelerate the development and deployment of new radical innovations. Research on the role of testbeds as experimental settings to induce sustainable transitions has been carried out in contexts such as urban development (Bulkeley et al., 2018; Carvalho, 2014), energy sector (Geels, 2014; Ruggiero et al., 2018), transport sector (Sushandoyo & Magnusson, 2014) and health care sector (Cramer et al., 2014). However, research investigating the role of testbeds for sustainable transitions in the agricultural context has been largely neglected until recently (Toffolini et al., 2021).

Furthermore, research has mainly focused on informing policymakers on how to support the development of testbeds. However, a paucity of studies considers the management practices within testbeds from a business perspective (Cramer et al., 2014). More insight is needed into the management of testbeds to understand the development and uptake of DFT and explore what enables and hinders technologies developed in testbeds to move from an experimental stage to the upscaling and deployment in agricultural business practices.

1.3 Aim and research questions

The aim of this paper is to contribute to the understanding of the management of testbeds to develop digital technologies in the context of the food and farming sector. As such, the paper contributes to an important field within business administration that considers innovation management with a particular focus on testbeds. In addition, the paper will explore conditional factors that enable and hinder DFT from moving beyond experimental stages to deployment in agricultural business practices. The study focuses on actors involved in testbeds projects where DFT is developed. This will be done by answering the following research questions:

- *What are the motives for developing digital farming technologies in testbeds?*
- *How are digital farming technologies developed in the testbeds in terms of management practices?*

- *What are the management implications for scaling up technology from testbeds?*

1.4 Scope and delimitations of the study

This study is methodological limited to a qualitative method, where a multiple case study is conducted. The case study will focus on two Swedish testbeds initiated partly by SLU researchers. The testbeds develop DFT within livestock production. Particularly, they focus on using big data and sensors in IoT solutions to support data collection about farm management. Both testbeds have been financed by grants directly from the university or other research funding bodies. The projects have or had an established testbed with interdisciplinary actors involved. The study will focus on actors involved in the projects to get insight into the experiences of the activities and relations within the testbed. Furthermore, as this thesis project is limited to a period of approximately five months, the study provides a snapshot of the current situation in the testbed perceived by the respondents rather than perceptions from different phases of the testbed development.

Moreover, this study will explore the operations of a testbed through the lens of transitions theory, particularly Strategic niche management. However, the goal is not to anchor the processes of testbeds to the SNM framework, nor to present a framework or model for how a successful testbed should be organized. Instead, the goal is to explore management practices that facilitate the deployment of DFT and what barriers testbeds projects experience in the agricultural context. Also, it is important to note that strategic niche management considers the process of experiments with new radical innovations becoming a niche that later competes in or changes the mainstream market. This study will focus on the early stage and why DFT initiatives are struggling to form a niche.

2. Conceptual framework and literature review

Chapter two comprises a literature review and theoretical background as well as the analytical framework that was used in the analysis of this study. Firstly, an overview of the literature concerning the digitalization of the food and farming sector, testbeds, and testbeds in the food and farming sector is provided. This is followed by a depiction of previous literature in the field of transitions studies. Secondly, the framework of Strategic niche management is presented, which is used to build the analytical framework. Lastly, the analytical framework is presented.

2.1 Agriculture 4.0 and digital farming technologies

Digitalization is considered a key driver for sustainable food and farming. Digital farming, also known as digital agriculture or smart farming, is broadly defined as the application of big data and precision technology systems in agriculture (Ingram et al., 2022). It comprises a range of practices that together have the potential to transform the current agri-food systems. The changes in the agricultural production system are perceived to be profound and will emanate from multiple points at the time rather than one top-down initiative. Data-supported forms of precision agriculture and field-specific data have been available for a while to *support* farmers in the decision-making process around production management, referred to as the *digitization* of agriculture (Giua et al., 2022; Ingram et al., 2022). However, in the new era of DFT, smart devices and intelligent systems supported by networks of interconnected things and facilitated by cloud computing make decisions *for* the farmer, which is referred to as the *digitalization* of agriculture (ibid.). Consequently, DFT, namely big data, IoT, and AI, has the potential to transform traditional, manual agricultural systems into smarter, data-driven systems (Ingram et al., 2022).

These developments in the agricultural sectors are often referred to as 'the fourth agricultural revolution' with the narrative to increase the efficiency and productivity of food production while improving sustainability (Rose & Chilvers, 2018; Klerkx et al., 2019; Giua et al., 2022). It implies that digital technologies and big data will benefit both food production and ecosystem services and are perceived as foundational for the future of sustainable agriculture. However, some critics mean that there is an over-optimism in the assumptions and expected benefits formulated by research and policy that only favors a few innovative firms and large-scale farms, causing the risk of reinforcing the existing economic, spatial, and social divides (Bronson, 2019; Carolan, 2017; Ingram et al., 2022).

2.2 Experimentation and Testbeds

A central part of the innovation process is the testing and demonstration of technologies, products, or processes before scaling up. This is often done in firms' internal R&D facilities but can also be done in external test and demonstration environments that are open for firms and others to test their technology prototypes (Kjellgren & Ståhl, 2019). Several concepts are used to describe test and demonstration environments, for example, 'testbed', 'test site', 'living lab', 'open lab', 'pilot sites', and 'incubators' (Tillväxtanalys, 2017). Though these concepts possess different characters and orientations, 'testbed' has come to be used as an umbrella term to cover these concepts.

While used heavily in policy and business reports, there is no established or unambiguous definition of what a testbed is. However, Vinnova (2021), the Swedish innovation agency, has formulated a definition that is often used in Swedish contexts: "physical or virtual environment in which companies, academia, and other organizations can collaborate in the development, testing and introduction of new products, services, processes, or organizational solutions in selected areas." Furthermore, Vinnova distinguishes between three different types of testbeds: testbeds as laboratories, testbeds as constructed/virtual user environments, and testbeds as real user environments (Kjellgren & Ståhl, 2019).

Testbeds are used in several different contexts, ranging from urban planning and renewable energy production to health care. What motivates testbeds are often the complexity of the world's current grand challenges (Kjellgren & Ståhl, 2019), such as population growth, climate change, and depopulation of rural areas. While solutions have been proposed, such as digitalization which is the subject of this paper, the implications of their diffusion are yet unknown. Thus, experimentation and testing are a way to learn about the possibilities and challenges of new solutions. Testbeds are characterized by uncertainty, and an important note is that tests always bear a risk of failure. Kjellgren & Ståhl (2019) argue that challenges of knowledge and analysis on practices, the constellation of actors and financial models, etcetera, about what works well and less well are still missing, which are crucial for testbeds to contribute to lasting change.

2.3 Experimentation in the food and farming sector

While a paucity of studies exists on testbeds in the agri-food context, a few studies have started to elaborate on their characteristics. McPhee et al. (2021) propose three components of agri-food testbeds: (1) transdisciplinary approaches, (2) co-design and co-development with participants, and (3) monitoring, evaluation, and research on working landscapes. Thus, agri-food testbeds encourage the involvement of multiple stakeholders (farmers, food industry companies, researchers, governmental institutions, advisory services, etcetera), where the end-users are described to play a central role. In a collaborative approach, these actors "co-create, explore, and evaluate innovations within the users' real-life context" (McPhee et al., 2021) which makes it an extension of traditional agricultural system innovation processes and promotes "on-field experimentation".

Similarly, Lacoste and colleagues (2022: p. 12) highlight that more open approaches to the agricultural innovation process are needed where agricultural stakeholders are brought together around "mutually beneficial experimentation to support farmers' own management decisions". Moreover, they state that these experimental constellations can help fill the current gap between the research community and practitioners, build bridges between social and technical sciences, and become a vehicle for transformational change. Furthermore, Cook et al. (2013) state that experimentation is a regular activity within agricultural management. However, the research field perceives it as a 'process for demonstration purposes only' rather than an opportunity for adaptive management that needs to be investigated further.

More research is needed to investigate the management of testbeds that goes beyond demonstration of technology to accelerate innovations that help transform the agri-food system towards sustainability. To investigate this, a theoretical approach is needed. Thus, the next section will explore theoretical approaches to transitions as well as the management of innovations with the potential to transform society.

2.4 Understanding socio-technical transitions

The multi-level perspective (MLP) was introduced as a concept to understand socio-technical transitions, particularly sustainability transitions (Geels, 2019). The concept of MLP is used to understand the dynamics of stability and change in terms of multiple levels, which are described as niche, regime, and landscape levels. Rather than conceiving innovation as a linear process that proceeds from idea to implementation, innovation is a complex and dynamic process. While antecedent concepts, such as ‘technological paradigm’ (Dosi, 1982) and ‘technological regime’ (Nelson & Winter, 1977), have predominantly focused on the engineers’ and investors’ perception of which technology should be developed, MLP takes multiple societal factors in regard when evaluating a technology (Geels, 2002).

In MLP, the ‘regime’ is described as socio-technical instead of technological, as it constitutes the prevailing institutional, social and organizational structure that, through its stability and well-established rules and norms, shapes the technological trajectory (Geels, 2004; Grin et al., 2010). Geels (2019: p. 189) explains that this process evolves over decades as “the system elements are reproduced, maintained, and incrementally improved by incumbent actors, such as firms, engineers, users, policymakers and regulators, and special-interest groups”. This creates various lock-in mechanisms, resulting in an inert system characterized by incremental and path-dependent developments where radical innovations are disadvantaged due to infrastructural, institutional, political, and social mechanisms shaped by the technologies in the dominant regime (Geels, 2019). Thus, not only a good solution is required for the implementation and diffusion of radical innovation, but it also needs to overcome the dominant regime’s inherent inertia and compete with established technologies that have been a part of the regime for a long time.

The socio-technical landscape constitutes the regime’s external context and involves aspects the regime actors do not have direct influence over, which includes both slow-changing developments, such as demographics, cultural repertoires, societal concerns, geo-politics, macro-economic trends, climate change, and external shocks, such as natural disasters, oil price shocks, financial crises, and wars (Geels, 2002; Geels, 2019). External stress at the landscape level can create changes in the dominant regime, which causes instability hindering the regime from working effectively. Consequently, a window of opportunity is created for radical innovations to be established (Grin et al., 2010). Thus, according to MLP, these innovations need to be protected in niches where they can go through experiments and development before a window of opportunity appears. In this way, the implementation and diffusion can be accelerated when the right time comes, protected from the dominant regime’s selection processes.

Due to the inertia of the socio-technical regime and the support for existing solutions, MLP emphasizes the role of niches to encourage the development and diffusion of radical path-breaking innovation (Shot & Geels, 2008, Kemp et al., 1998). The niche acts as a place where innovations can be tested, developed, and improved until they are ready or when the opportunity emerges to be implemented and diffused. A burgeoning stance of literature studies the importance of niches for innovation, particularly with a focus on how policymakers should support these initiatives to stimulate radical innovation (Grin et al., 2010). The role of niches is developed further in SNM, described in the section below.

Socio-technical transitions evolve over several decades and are described in four phases: experimentation, stabilization; diffusion or disruption; and institutionalization or anchoring. In this paper, the focus will be on the first phase, experimentation. Here, niche innovation is initialized in R&D laboratories, real-world experiments, and demonstration projects where necessary learnings about the innovations' techno-economic performance, socio-cultural acceptance, and political feasibility is taking place (Geels, 2019). Common struggles in the experimental phase are uncertainty, competing claims and promises, and high failure rates and burn-out among the participants (ibid.). Another critical challenge is to "overcome the current fragmentation of initiatives, and their tendency to remain isolated and short-lived, which ultimately reduces their potential for lasting and wide-ranging change" (Turnheim et al., 2018: p.237).

2.5 Strategic Niche Management

While MLP provides the big picture of how socio-technical transitions occur, it does not describe the micro-processes that lead to niche formation. More specifically, to reach the purpose of this paper, the investigation should focus on the management activities that testbed adopts to protect and fine-tune its innovation before it is mature enough to fit in the socio-technical regime or even change it. The concept of strategic niche management (SNM) describes this process and aims to "understand and influence the early adoption of new technologies with high potential to contribute to sustainable development" (Shot & Geels, 2008: p. 1). The concept implies that through the creation of technological niches and protected spaces, actors can test and experiment with new technologies to enable and accelerate the diffusion of sustainable, transformative innovation (Kemp et al., 1998; Hoogma et al., 2002; Smith and Raven, 2012).

In other words, radical innovations need to be developed in an experimental setting that is relatively protected, as the technology needs to mature before it can compete in a market. Thus, learning is an essential part of SNM, which is why the notion of 'experiment' is used rather than demonstration or pilot projects (Hoogma et al., 2002). Learning in SNM goes beyond learning about technological performance but also aims to align the innovation with its social context, that in an early-stage act as a barrier to the wider diffusion of radical innovation. These barriers consist of infrastructures, networks, regulations, user preferences, and expectations that favor the dominant regime. Smith and Raven (2012) have proposed that the process of taking a radical innovation from the protected space to broader processes of transformation can be understood through the processes of *shielding, nurturing,* and *empowering*, which will be described further in the next section.

2.5.1 Shielding

Shielding is an activity that focuses on preventing radical innovation from being 'killed' by selection pressures from the socio-technical regime. Instead, the niche creates its own selection environment with advocates which allow space for experimentation. Smith and Raven (2012) distinguish between two types of shielding: active and passive. In *active shielding,* the creation of protective spaces is strategically initiated by advocates and through targeted support of radical innovation. Examples of active shielding processes are support through financial resources, the creation of subsidies or rule exemptions for the technology, and tolerance or justification of its poor technical and/or economic performance (Verhees et al., 2012). In *passive shielding*, there is a pre-existing deliberate mobilization by advocates of a specific innovation, thus providing some form of protective shield to it (Smith & Raven, 2012; Verhees et el., 2012). For example, it can be done by mobilizing pre-existing generic research subsidies or locating experiments in favorable geographic locations where selection pressures are different (Verhees et al., 2012).

2.5.2 Nurturing

The processes of *nurturing* are about ensuring that the created space is used to support the development of radical innovation (Smith & Raven, 2012). From an outsider's perspective, the goal is to improve the innovation's socio-technical and/or economic performance in the protective space to reduce the dependence on shielding gradually. Shielding is constituted by three internal processes for successful niche development: *articulating expectations and visions*, *the building of social networks*, and *the organization of learning processes* (Kemp et al., 1998 in Grin et al., 2010). The process of articulating expectations and visions is important to attract attention and resources to innovation when it is still in its early stage, as the functionality and performance are still unclear. Moreover, positive expectations build acceptance and credibility for the future outcomes of the innovation. Articulating expectations is also necessary to provide a direction for learning processes and the creation of tangible goals.

The second process, the building of social networks, is important as niche formation requires that new actors get together from a broad set of domains. Moreover, the regular interactions between the actors are essential to facilitate learning and drive change (Mourik & Raven, 2006). The third, the organization of learning processes, is crucial for successful innovations, as it enables adjustment of the technology and societal embedding to increase the chance of successful diffusion (Smith & Raven, 2012). It should not only focus on techno-economic optimization but also the alignment of technical and social aspects, e.g., user preferences, regulations, and cultural meanings, referred to as first-order learning. One other important factor is that the learning should be reflexive, namely by questioning the underlying assumptions and a willingness to change course if there is a mismatch between the innovation and these assumptions, referred to as second-order learning (ibid.).

2.5.3 Empowering

The third process, *Empowering*, is the function that enables the innovation to move from the protective niche to the regime level through the gradual removal of its support (Smith & Raven, 2012). On the one hand, one stance of literature argues that the processes of nurturing (e.g., building of social networks, expectations, and learning processes) enable the gradual removal of the protection (ibid.). On the other hand, another stance argues that more is required to realize the innovation's 'path-breaking' potential. Particularly, for upscaling of radical innovations, interactions with existing socio-technical systems and regimes are needed, such as established industry structures, dominant technologies and infrastructures, mainstream markets and user practices, existing policies and power structures, and socio-cultural frames (Turnheim & Geels, 2019). Thus, radical innovation needs to be empowered, not only through 'inward-oriented' system building within protective spaces but also in 'outward-oriented' activities aimed to influence or change the mainstream contexts (Verhees et al., 2012). Smith and Raven (2012) distinguish between two ways of empowering an innovation, *fit-and-conform* and *stretch-and-transform*. Fit-and-conform implies that protection is only temporarily necessary, and that the competitiveness of innovations can be increased under existing rules (Turnheim & Geels, 2019; Verhees et al., 2012). Stretch-and-transform implies that shielding is not (fully) removed, but that parts of it become institutionalized through regulations or incentives, thus changing the conventional selection criteria (Turnheim & Geels, 2019; Verhees et al., 2012).

2.5.4 Shortcomings of Strategic Niche Management

Along with the growing popularity of the SNM framework, several shortcomings have been identified in the literature. Hoogma et al. (2002) state that there is an overoptimism among advocates about the potential of individual experiments. The experiments are often isolated events with difficulties in building bridges to other initiatives. As a result, most of them fail to sufficiently influence or change the strategic direction of the socio-technical regime. As socio-technical transitions typically unfold over several decades, niche formation is rather a process of multiple networked experiments across multiple spatial dimensions (Sengers et al., 2016). Secondly, the shielding, nurturing, and empowering processes are not necessarily consecutive as previously suggested, but can also be developed simultaneously (Verhees et al., 2015).

2.6 Analytical framework

To fulfill the research aim, as well as answer the research questions, the management practices of the testbeds are explored through the lens of the 'shielding, nurturing and empowering' framework as depicted in the SNM. While SNM usually is used as a policy tool or an analytical framework to understand innovation processes, this thesis will focus on the latter. Particularly, the focus is on understanding the management practices adopted to *initiate the testbed, support the development of DFT in testbeds*, and *scale up the technology from the testbed*. As such, the analytical themes of shielding, nurturing, and empowering have been modified to explore management practices accordingly (see Table 1). Shielding refers to the management practices that make the testbed possible. Shielding includes both active and passive shielding. Active shielding relates to management practices to attract resources, for example, financial support, facilities, or competence, and/or applying for substitution or rule exemptions. Passive shielding refers to management practices to mobilize pre-existing resources and/or locate the testbed in a favorable location where there is already sufficient support for the technology, such as a university campus.

Nurturing refers to management practices that support the development of DFT in the testbed. Nurturing includes articulating expectations and visions, the building of social networks, and the organization of learning processes. Articulating expectations and visions imply management practices to build acceptance for the digital farming technology and to provide a direction for the future. The building of social networks entails management practices to build a broad network with a diverse set of actors representing farmers, researchers, tech developers, governmental institutions, industry companies, advisory services, etcetera. Furthermore, network building concerns the type of interactions that take place inside the testbed. For example, if the interactions are based on informing, consulting, or involving the social network in decision-making processes. Organization of learning processes refers to the learning processes cultivated within the testbeds. First-order learnings are focused on improving the technology's techno-economic performance and learnings about user preferences and the institutional context. Second-order learnings are more reflexive, focused on questioning and improving underlying values and norms.

Empowering refers to management practices that support the upscaling of the technology or branching to another application domain. Empowering is divided into fit-and-conform and stretch-and-transform practices. Fit-and-conform implies increasing the DFT's competitiveness under existing rules, which decreases the need for shielding. It can be done by collaborating with regime actors, which can help improve the technology's techno-economic performance with their resources. Stretch-and-transform implies activities to change the conventional selection criteria where parts of the shielding become institutionalized, for example, through lobbying and negotiating for regulations and incentives.

Table 1. Analytical framework

Theoretical concept	**Dimensions**	**Description**
Shielding - creating a testbed for developing DFT	Active shielding	• Attract resources (financial support) or negotiate legislation (rule exemptions)
	Passive shielding	• Mobilize pre-existing resources or locate the testbed in a favorable location
Nurturing - management practices to support the development of DFT in a testbed	Articulating expectations and visions	• Building acceptance and credibility • Provide a direction for the future
	Social network building	• Broad and diverse set of actors • Interactions inside the testbed
	Organization of learning processes	• First-order learning (broad learning, techno-economic optimization, technical and social alignment) • Second-order learning (reflexive learning, questioning and improving underlying values and norms)
Empowering - management practices to scale up DFT from a testbed	Fit-and-conform	• Increase competitiveness under existing rules
	Stretch-and-transform	• Lobby activities and negotiation to change the conventional selection criteria

3. Methodology

Chapter three will describe the methodological choices that have been made regarding research design, data collection, data analysis, quality criteria, ethical considerations, and methodological reflections of the study.

3.1 Research philosophy

Research philosophy is the belief and assumptions the researcher has about the way in which data about a research topic should be collected, analyzed, and used (Bell et al., 2019). Ontology is our understanding of reality, and the ontological standpoint of this thesis will be on social constructivism (ibid.). Social constructivism argues that the world contains multiple complex realities and depends on how people perceive the world (Creswell, 2003). The scientific viewpoint of this thesis was of an interpretive epistemological nature. Interpretivism contradicts the objective view of positivism, suggesting that facts are dependent on people's values and cannot be generalized or studied by definite laws (Bell et al., 2019). Instead, the truth lies in 'socially constructed agreements' (Slevitch, 2011). Thus, it allows the researcher to draw upon subjective contexts and experiences to explore different nuances of the topic researched (Guba & Lincoln, 1994). Saunders et al. (2009) state that research philosophy influences the choice of research strategy, ergo, the data collection approach.

3.2 Research design

The research design refers to how the study is structured as well as how the choice of design affects the use of the method, and the way data is collected and analyzed. The choice of research design indicates the standpoint that the research has and how priorities are made (Bell et al., 2019). Based on the philosophical assumptions of this thesis, a qualitative study with inductive reasoning has been chosen. Inductive reasoning aims to explore and develop a theory rather than testing an existing one and proving its hypotheses (Creswell, 2003). Commonly, qualitative studies apply an inductive approach to investigate if connections exist between research questions and the theory in question (Bell et al., 2019). Therefore, the research question has been formulated in an exploratory way, and the relation between theory and research is of inductive nature.

Because of the exploratory nature of the aim and research questions, a case study research design was adopted. Usually, case studies examine one specific case but can also examine smaller communities or organizations (Bell et al., 2019). Moreover, case studies can be of both qualitative and quantitative characteristics but are more commonly associated with qualitative research strategies. A case study approach allows the researchers to get a clear and detailed picture of the study object by answering questions such as how and why, rather than measuring something (ibid.). It is common for researchers who apply case studies as a research strategy to use qualitative observations or qualitative interviews, as these allow the researcher to deep dive into the case or the organization (ibid.).

In this thesis, a multiple case study was conducted. A multiple case study is used to understand the differences and similarities between the studied cases (Baxter & Jack, 2008; Stake, 1995). Furthermore, it allows the researcher to analyze the data both within each situation and across situations (Yin, 2003). As multiple cases can contribute with evidence from several empirical investigations, the results are often strong and reliable (Baxter & Jack, 2008), allowing a comprehensive investigation of research questions and theoretical evolution (Eisenhardt & Graebner, 2007). Thus, the multiple case study helped to detect similarities and differences in the management practices of the two testbed projects, which can give an indication of best practices and what needs to be improved. Furthermore, it enables to detect if the testbeds face similar constraints, as well as differences in enablers and constraints that can have implications for future testbed projects.

3.3 Sampling strategy

As a qualitative case study was conducted, the sampling logic is not the same as in quantitative studies, which aim to provide statistically significant outcomes and conclusions (Yin, 2003). Conversely, the focus of a multiple case study design should be on concluding how many replications of the case are required to provide the same outcome. Since the study concerns a complex subject, a smaller number of cases allows for getting an in-depth understanding of each case while still being able to compare the cases to find contrasts and similarities. Thus, the cases were chosen based on a replication logic where expected outcomes are similar for each case. Consequently, the unit of analysis needs to fulfill several requirements based on the delimitations of this study. Namely, the testbeds operations should primarily be based in Sweden and develop DFT for primary production purposes. Thus, the unit of analysis is testbeds for DFT, and the unit of observations will be actors involved in the testbeds.

Hence, snowball sampling was used to find relevant participants. Snowball sampling is a non-probability sampling technique, where the researcher identifies a few participants relevant to the research topics, which in turn provides contact with other participants (Bell et al., 2019). Taking this surge of local testbed initiatives for the digitalization of agriculture in Sweden as the motivational point of departure, initial e-mails were sent to the testbed project leader or coordinator at the five identified cases, of which two responded. Secondly, these testbed actors provided contact details to people relevant to the research topic.

The two cases identified are initiated by researchers at SLU and refer to themselves explicitly as testbeds. Moreover, since one of the testbeds is inactive (FITPIG) and the other is active (Gigacow), a comparison will be made to explore the differences in activities on what is important for the long-term operation of a testbed.

3.4 Data collection

3.4.1 Semi-structured interviews

The interviews followed a semi-structured approach to allow flexibility and let the informants express themselves freely and in-depth (Bell et al., 2019; Farquhar, 2012). Thus, all interviews were based on an interview guide connected to the research aim, while supplementary questions varied depending on the respondents' answers. A summary of the interviews can be found in Table 2.

With the consent of the informants, the interviews were recorded and transcribed for several reasons. Firstly, it allows the researcher to actively listen and observe how the informant responds to the questions (Bell et al., 2019). Secondly, it allows the researcher to ask complementary questions instead of concentrating on writing down and memorizing the answers (ibid.). Thirdly, it allows for repeated and thorough examination of the answers, allowing other researchers to examine the same data (ibid.). As a result, a more objective examination of the data can be performed, which reduces the risk that the researchers' biases will influence the analysis. The interviews were performed face-by-face physical on-site, or digital through communication platforms, such as Zoom, Skype, or Microsoft Teams, depending on the geographical location of the respondents.

Table 2. Information regarding the conducted interviews

Role, Firm/Organization	**Name**	**Date**	**Validation**	**Duration**
Project leader, FITPIG (SLU)	Anders Herlin	2022-03-18	Video meeting, recorded & transcribed	51 minutes
Project coordinator, Gigacow (SLU)	Tomas Klingström	2022-03-21	Video meeting, recorded & transcribed	56 minutes
Researcher, SLU, working with Gigacow	Lars Rönnergård	2022-04-27	Video meeting, recorded & transcribed	42 minutes
Advisory, VÄXA Sverige, working with Gigacow	Annica Hansson	2022-05-03	Video meeting, recorded & transcribed	44 minutes

3.4.2 Secondary data collection

The semi-structured interviews were complemented with a review of secondary data, particularly articles, press releases, and reports that can be of value to get a broader understanding of the research context. Moreover, the secondary data contributed to an increased understanding of the cases prior to the interviews, which resulted in more effective interviews as the focus was on the information the author could not attain through the collection of secondary data.

While the collected secondary data contributes to triangulation (Bell et al., 2019), the researcher should be aware that information found on websites can be biased or incorrect, to favor the interests of the organization which governs the website.

3.5 Data analysis

Qualitative data collection generates a substantial amount of data, which creates a need for structuring it to be comprehended (Bell et al., 2019). In this study, a qualitative content analysis was conducted to understand the unit of analysis in-depth. The goal of qualitative content analysis is to "understand social reality in a subjective but scientific manner" (Zhang & Wildemuth, 2009: 318). In qualitative content analysis, the researcher divides the text into units of meaning by coding, structuring, and simplifying the collected material to define different themes and patterns (Hsieh & Shannon, 2005; Patton, 2014). The process of content analysis is divided into three phases: preparation, organizing, and reporting of results (Elo et al., 2014).

The preparation phase starts with transforming the data into text to be able to perform the analysis (Zhang & Wildemuth, 2009). Thus, the recorded interviews were transcribed directly after they were conducted to ensure that potential impressions and memories from the interview were fresh. The verbalizations were transcribed literally, as well as pauses, laughs, and other sounds, to capture both descriptive and latent content. Moreover, the preparation phase includes selecting the unit of analysis, which can be a word or a theme.

In the organization phase, the goal is to interpret and code the data in a valid and reliable way (Elo et al., 2014). Firstly, the transcribed interviews were carefully read through to get a holistic perspective of the data. Secondly, the transcribed interviews were read through again, where codes relating to the analytical framework as well as other codes interesting to the research questions were selected and grouped into categories that reflect the central message of the interviews. While qualitative studies usually use an inductive approach, where codes are derived directly from the data, this study has chosen a more abductive approach where initial codes were derived from the conceptual framework. These themes can be modified if new categories could emerge inductively during the course of the analysis (Zhang & Wildemuth, 2009).

In the presentation phase, the empirical findings are categorized according to the descriptive themes that were identified to provide a rich, transparent, and interesting demonstration of the data (Zhang & Wildemuth, 2009). The analysis is structured according to the analytical concepts *shielding*, *nurturing*, and *empowering* derived from SNM, where the data is compared with the theoretical framework.

3.6 Ethical considerations

The study was conducted with ethical principles in business research to ensure scientific integrity and protection of human rights and dignity. Thus, the author considered the four areas of ethical considerations provided by Diener and Crandall (1978): *protection of the participants from harm*; *informed consent*; *right to privacy*; and *exclusion of depletion*. These considerations were ensured by informing the participants prior to the interviews about the intention of the research. The participants were asked for their consent about recording and transcribing the interviews, which all participants agreed upon. Moreover, the participants were informed that only the researcher would handle the recorded and transcribed versions of the interviews to ensure confidentiality. The participants were offered to be held anonymous, but all participants have given their consent to partake with their names. Also, the participants were informed that they could refrain from answering questions or discontinue the interview if they wished. The participants were allowed to read the study prior to its publication, and changes according to the participants' requests were accepted until the publication.

3.7 Quality assurance

Demonstrating credibility is important in both quantitative and qualitative research. While quantitative researchers do this through the instrument construction, in qualitative research, “the researcher is the instrument” (Patton, 2002 in Golafshani, 2003: 600). Thus, since this is a qualitative study, reliability and validity, which are used to measure credibility in quantitative studies, become difficult to use. Reliability and validity refer to how well research measures something, while credibility in qualitative studies is more about the ability and effort of the researcher (Golafshani, 2003). Thus, rigor becomes vital in qualitative research. The application of rigor in qualitative research refers to establishing trust and confidence in the research findings. Lincoln and Guba (1985) propose four alternative criteria for ensuring qualitative rigor and trustworthiness: *credibility*, *transferability*, *dependability*, and *confirmability*.

3.7.1 Credibility

Credibility refers to the confidence that can be placed in the truth of the findings (Lincoln & Guba 1985). Credibility is upfilled by ensuring that the research findings represent information collected from participants' original data or that the researcher has correctly interpreted the participants’ original views. The author ensured credibility through respondent validation, allowing the participants to read the study and confirm that the researchers’ interpretations correspond with the participants’ perspectives (Bell et al., 2019). Furthermore, triangulation is applied by combining multiple data collection methods (Golafshani, 2003), namely by using both interviews and secondary data sources.

3.7.2 Transferability

Transferability is the degree to which the results of qualitative research can be applied to other contexts with other respondents (Lincoln & Guba, 1985). As qualitative research often entails an in-depth study of a small group to find unique aspects of the studied context, which makes it difficult to generalize findings to the broader population. Instead, this is done through a process described as ‘thick description’, meaning that the researcher should provide a broad description of the research process and the participants. In this way, the reader can assess if the findings are transferrable to his or her own context. As a consequence of the small and somehow heterogeneous sampling group, it is difficult to assess the transferability of this study. However, the author has provided a thick description of the case as well as used secondary data that offered more breadth to the findings and confirmed that some of the experiences from the interviews were also found in the secondary data collection.

3.7.3 Dependability

Dependability entails the stability of the research findings over time (Lincoln & Guba, 1985). Particularly, it is about acknowledging the inherent risk of subjectivity and ensuring that biases and errors are minimized. This was done by documenting the procedures of the study, recording and transcribing the interviews, as well as letting peers and a supervisor act as auditors during the course of the research. However, to ensure the confidentiality of the collected, the auditors did only access the data that was used in the report.

3.7.4 Confirmability

Confirmability is the degree of neutrality that the research findings possess (Lincoln & Guba, 1985). While complete objectivity is perceived to be impossible in business research (Bell et al., 2019), Confirmability can be ensured by other researchers confirming the findings of the study. Particularly, confirmability is about ensuring that the researcher derived the findings from the collected data and did not allow personal values or skewed interpretations to affect the findings. Thus, the author has, with transparency, described the research path and was conscious of her own experiences and reflections during the research process.

4. Empirical background and findings

Chapter four will present an empirical background about the current situation for testbeds in Sweden and innovation in the food and farming sector. It will also present the findings from the semi-structured interviews.

4.1 Testbeds in Sweden

Sweden has been a global frontrunner when it comes to research and development (Regeringskansliet, 2016). However, the competition is getting tougher, and the country has experienced a weakening of the research and innovation system compared to other prominent countries. Thus, the Swedish government decided to launch the initiative Testbädd Sverige (eng. Testbed Sweden) in 2016, which is a strategic coordination program to accelerate the Swedish research and innovation system. In the initiative, the Swedish government offered a grant worth 500 million SEK and assigned the Swedish innovation authority Vinnova the task of establishing a coordinating function for the strengthening of the Swedish test and demonstration activities. Thus, the aim is not only to develop more test and demonstration environments, but also to increase the knowledge and accessibility of the testbeds, as well as increase the cooperation between actors in the currently fragmented testbed infrastructure.

4.2 Innovation in the food and farming sector

In 2022, Sweden food arena issued a pilot study about innovation in the context of the food and farming sector. The study was aimed to propose initiatives for how to utilize and make research available, as well as suggestions on how to increase collaboration between national and regional actors within research and innovation in order to enable sustainable transition (Sweden food arena, 2022). The Swedish food and farming sector experience the same trends as the Swedish innovation landscape at large. While there are many incremental innovations, the sector lacks the radical innovations that are required to accelerate a sustainable transformation. Sweden Food Arena (2022) explains this with several factors. Firstly, the food and farming sector consists of 95 percent 160 000 companies spread across the country, whereas 95 percent have less than ten employees. While small companies are the most innovative in the system, they face larger challenges than larger companies in implementing innovation processes due to limited internal resources (e.g., such as personnel, capital, competence, time, etcetera) (ibid.).

Secondly, research and innovation in the food system are underfunded and short-term (Swedish food arena, 2022). While the public sector invests several billions of SEK in innovation both on the national and regional levels, the implementation is short-term, fragmented, and often project-based. Uncoordinated innovation support results in fragmentation of how to spread knowledge to companies, as the channels and formats are many. Consequently, companies have it difficult to find and take part in the offers that exist, and public resources are not used optimally. Furthermore, while funding is granted for research, the gap between academia and industry is large. Much of the produced knowledge stays in academia and never becomes applicable to farmers. If it does, it often stays in the region where the research is conducted. The projects are often performed by actors isolated to different stages in the chain and seldom connected. Management activities, role divisions, and priorities are often vaguely defined. Sweden food arena (2022) suggests that cooperation and acceleration of activities are required to utilize and research more available. Furthermore, organization on the regional and national level is needed to enable a sustainable transformation of the food and farming system (ibid.)

4.3 FITPIG

4.3.1 Background

Farm Internet Tracking of Pigs (FITPIG) was a testbed project focused on IoT solutions in the pig industry. More specifically, FITPIG is a testbed that has developed a decision support application with connected IoT sensors, which are integrated into the pigs' ear tags to measure the animals' heart rate and activity to determine their health state and farrowing. The purpose of FITPIG, is to "help the farmer to get useful and simple information for decision support. This includes health alerts and indications of the start and duration of farrowing. We think the farmer will feel safer with this, instead of guessing and instead use the time and efforts on the animals that really need assistance or treatments" (Herlin, n.d.). The outcomes include improved animal health while the use of preventive medication can be reduced, as well as increased productivity and lower economic risk for farmers. FITPIG was a part of the project Internet of Food and Farm (IoF2020), a project funded by the EU's Horizon2020 program, with the goal "to accelerate adoption of IoT for securing sufficient, safe and healthy food and to strengthen competitiveness of farming and food chains in Europe" (Cordis, n.d.). FITPIG was a collaboration between the Swedish University of Agriculture (SLU), the Swiss research institute Centre Suisse d'Électronique et de Microtechnique (CSEM), and the Spanish firms HopU och DigitAnimal. The project ended when the funding for two years was terminated.

4.3.2 The technology

The technology that was developed in FITPIG was an IOT-sensor designed as an ear tag for pigs, with both an activity meter and a PPG sensor that measures resting heart rate. While it can be used on all pigs, they saw the most value in using it on sows:

> In the testbed, we started to evaluate what this could be used for, and there are many slaughter pigs, so it is a quite big market, but at the same time, the probability that you cannot make it work as good as intended, or that the value is not big enough, or well, there is very little added value in one pig. […] The pig category that is most sensitive here is the sows, especially around farrowing. That is why we chose to focus on them. So, we talked with a farm within animal welfare about how this could be used in practice.

Anders describes two uses for the sensor. The first one is the activity meter which can predict whether the sow is about to pig or not because the sows build nests prior to it and are intensive when doing it. The other one is a PPG-sensor, which can help the farmer to detect diseases that occur during farrowing. Anders describes that the resting pulse increases at least 10 percent when we are sick and can thus be used to find sick sows. However, Anders describes it as complex since it can be several different diseases with similar symptoms, and the treatment differs between the different diseases.

> The interesting thing is that we did not have full technology, but we could still show that the heart rate went up for those we had seen were sick. Usually, it is not easy to see what is normal and what is not. (Respondent Anders)

4.3.3 Initiating the testbed

FITPIG's project leader Anders Herlin is an agronomist and disputed in the 80s with a dissertation about comparisons of milking systems. How FITPIG was initiated is described by Anders as a coincidence. He was contacted by a woman from Switzerland that worked at an institute for medical technology, CSEM, who wanted to collaborate on a call from IOF2020:

> They had found a call from IOF2020, it was one of those giant calls from the EU, and those are a bit strategic, you should have partners from different parts, and Sweden did not have anyone there. (Respondent Anders)

Anders, who usually works with cattle and milking cows rather than pigs, forwarded the questions to his colleagues in Uppsala, who had a test facility for pigs. However, they already had too much work. But after some discussions, one of them decided to join as well as a former colleague who is a pig farmer who could act as a host for the experiments.

> We saw that they do not need a super experimental project with a very strict experimental design. What was important here was to test technology and see if you got a signal from the pigs' ear and that it could move to a central unit in the stable and out to the router and out in cyberspace and with the ultimate goal of being able to move it back to a smartphone. (Respondent Anders)

The role of SLU in the project was the organization of test farms and the data collection concerning the production and health, which was the basis for the analysis (SmartAgriHubs, n.d.). It also included the installation of the sensors and cameras. HOPU was responsible for the architecture of the system, CSEM for the manufacturing of the ear tags, and Digitanimal for the smartphone application in which the end-user was supposed to view the processed data (ibid.).

When FITPIG received the grant from IOF2020, they spent the first year building the ear tag. Following that year, they could have a first practical test on a sow. However, it took another four months before they had made ten ear tags and could perform tests with several sows. Also, the implementation of the system in real-life conditions confronted the researchers with technical problems with receiving the signal from the sensors. Thus, it was not until the third test round they managed to receive data. Although some connectivity issues on the way, they managed to complete several rounds of tests. In 2019, FITPIG organized a demonstration activity on a test farm in Spain, where they focused on showing and informing the public about how the technology works and the advantages of monitoring the health, behavior, and state of farrowing of pigs (IOF2020, 2019).

4.3.4 Expected benefits and outcomes

Looking at the general benefits of the sensor, Anders states that it helps the farmer to get instant alerts about the health of each animal, which otherwise is information that is only obtained through observing the pigs several times a day. Thus, the user can instantly identify which animals that require help and perform the treatment needed. Moreover, Anders believes that the efficiency gains DFT delivers will have other positive consequences:

> It becomes indirect when you have a little bit more efficient production, maybe less waste, and so on. But it is a lot about economics, that the technology provides a return on investment but also a kind of sustainability work, for example, better-perceived benefit and safety in production, as well as reduced animal suffering. (Respondent Anders)

Another consequence of efficiency gains in the production is time savings, and exemplifies the technological developments in the dairy industry:

> Did we need milking robots? The first pioneers came around 20 years ago, and suddenly, these farmers said that they for the first time could go to Copenhagen

> and watch the opera. […] They were not slaves to milk at five o'clock in the morning and get up the same time the next day to milk again. Suddenly, this social value was made so much greater for them. You move time from manual parts to work more strategically. (Respondent Anders)

Furthermore, it contributes to a more modern agricultural industry, which he thinks might attract new employees as well.

> It is no longer about driving a wheelbarrow in mud or running around and dragging a lot of things or doing everything with paper and pen. These are young people that do everything with their smartphones.

FITPIG was terminated after the funding from IoF2020 was over, and the system never became market-ready. However, Anders states that one of the most important outcomes was the learnings they received from working in FITPIG. Firstly, the project actors learned from each other:

> CSEM knew nothing about farm animals. Digitanimal works with technology for grazing animals, so they knew a lot about that. (Respondent Anders)

Secondly, they worked until the end of the project to improve the technical performance of the ear tag as well as explore an extension of the system to other livestock:

> I have contacts within this because I think the sensor would be affordable in series production, which means that you could find other applications, for example, to find sick calves. […] When we have been in contact with practitioners, for example, veterinarians, they see the need for methods to find sick animals, so there is a demand for this kind of technology. (Respondent Anders)

4.3.5 Challenges

One of the largest challenges is to demonstrate the added value in pig production. While dairy farmers possess a certain technical readiness and already using new technology to detect problems, pig production has largely been based on efficient work and management routines, for example, synchronized insemination. Furthermore, he describes that there are some concerns that precision livestock farming is only for large-scale farms, while he believes that FITPIG's technology provides more value for small farmers, as there is more value in every animal in small-scale production.

Describing how the challenges of demonstrating value can be solved, Anders explains that he thinks the only way is to test it in the field and show some form of improvement potential. While tangible improvements are important, he also thinks that intangible improvements are at least as important. Thus, he suggests that in-depth interviews about the experience and how the technology works would be a good way for both the farmer to understand the value and for FITPIG to understand the farmer's demands. Furthermore, he believes that FITPIG could have demonstrated the value better with more extensive experiments.

> If this technology had gone ahead and we could have made 10 000 ear tags with this and applied it to several farms, of course, we would have followed them closely and followed up with an advisor to find out how we could use this data. (Respondent Anders)

To be able to perform larger tests is not only a matter of money but mostly a matter of time:

> It was a relatively large amount of money, we got 100 000 euros, but it took time. […] if we had done it properly, we would have done a slightly larger series, tested it for a longer period, got it fully built into a platform with algorithm development, and transferred it to a smartphone. Then we could have run it as a testbed, but we did not get to the point where we drove the testbed fully to the end-user. It was a test done by researchers. (Respondent Anders)

4.4 Gigacow

4.4.1 Background

Gigacow is a project initiated by SLU focused on creating a research infrastructure with a testbed functionality. More specifically, Gigacow has created a platform for data collection, where the participating farms' own management systems and digital tools are integrated. Moreover, new technology such as sensors or cameras can be tested and connected to the platform. The data is primarily available to researchers at SLU, but external stakeholders can access it on agreement, as the knowledge produced is also valuable for both farmers, advisory organizations, and technology developers to improve productivity, profitability, and sustainability of the dairy farming industry (Klingström et al., 2021). The aim is to increase the knowledge exchange between farmers and researchers while contributing to a more sustainable and competitive agricultural industry where farmers get rewarded for the added value created.

Currently, 17 dairy farms and two research farms are involved in the project to collect data from over 5000 cows. While farmers already have access to a lot of data through the technology they use, the platform will contribute to the integration of different types of data. The focus has been on genomic breeding assessment, which later is supplemented with an automated collection of animal characteristics, feed intake, diseases, and other information about the animals' living conditions (Nordic Testbed Network, n.d.).

Gigacow is a part of Sustanimal, a center for research on the role of animals in future food production, which is led by SLU together with RISE and SVA. Gigacow will contribute to the project with their network of farms as well as with the platform to generate data that will be used in the research (SLU, 2020).

4.4.2 The technology

As mentioned above, Gigacow has developed a platform for data collection from multiple systems, which makes it possible to compare and find relations between different datasets more efficiently. Moreover, it makes it possible to compare different farms, which will be useful both at the local and industry levels.

> The basic problem is that modern agriculture collects a lot of data, which is because the technology companies that develop equipment have been extremely quick to take digital technology and use it to make equipment better, such as digital control of milking systems, automated milking robots, and activity measurement. […] What happened then is that everyone uses digital technology to build better machines. However, the agricultural industry has been slow with the access and integration of data from different machines. (Respondent Tomas)

Tomas continues to describe that every single machine or system has its set of data, as well as the farmer possesses its own information, manual or digital.

> If all our research projects would collect this data individually, then all our researchers would only be engaged in data collection and IT issues. So instead of accelerating this, we decided to build an infrastructure for automated data collection and then support many different projects with data from the same infrastructure. (Respondent Tomas)

4.4.3 Initiating the testbed

Gigacow started as a research infrastructure rather than a straight-out testbed, but currently, Tomas defines Gigacow as a research infrastructure with a testbed function. Tomas describes how Gigacow became a testbed:

> Since I, as a coordinator and de facto project manager, constantly investigate what information that can be gathered from farms, we also become a source of knowledge about what information is currently available at farms and what information could be attractive to collect for the future. As a result, various camera and AI companies and researchers have turned to us with questions about whether we have this specific technology, if the technology could be used to solve something in the agricultural industry, or if we have technical suggestions on how a specific information need could be solved. So that is how we became a testbed. (Respondent Tomas)

One of the researchers that initiated Gigacow is now a researcher at VÄXA Sverige, which is an advisory organization for farmers and one of the most important partners in the project. Another project member is himself a farmer and runs the farm that was first to join Gigacow. Tomas became a participator in the project because of his engineering background.

> We were rejected on the application the first year, and then we wrote a new one, and that was when I entered the whole, as we were rejected because the technology part was too weakly described. (Respondent Tomas)

Gigacow received a 4-year grant from SLU to develop the platform and establish the testbed, but it got extended for a fifth year since the competence created in Gigacow was needed in other projects. Consequently, Tomas’ role in Gigacow has changed during the duration of the testbed project. There are currently several large initiatives with actors such as RISE, the Swedish Board of Agriculture, SVA, VÄXA and Lantmännen, etcetera, are involved, working on the integration of different data sources where he acts as a technological expert.

> As we are the first independent actor to dig into various IT systems from a non-commercial and holistic perspective, I have been included as an external expert in these projects. So, we will review my role because it is not research, but it is to assist with technical expertise that has sprung from research. But there is currently no assignment or funding for that work, but it is a job that we see that must be done. (Respondent Tomas)

While the platform is mainly aimed to facilitate research with automated data collection, Tomas describes that the interest is large from tech companies as well.

> At present, we have mainly worked with researchers to carry out studies, while the technology companies have mainly been interested in the competence we have built up in the infrastructure. That is, either you have pieces of equipment and say: “I know that Gigacow works with data collection, and we think our sensor could be interesting. What problems do you think you can solve with this sensor? And would it be worth selling it to farmers, would they make a profit on it?” Those kinds of questions have been raised in the industry. (Respondent Tomas)

Tomas continues to describe why his role as a technological expert within the agricultural industry is important:

> Sweden is one of the world’s leading countries in information and communication technology (ICT), and if you take animal health into account, we also have the world’s highest production per dairy cow. But we have been very slow in bringing the two worlds together. That is why Gigacow has entered the testbed section to collaborate with players who want to solve this. (Respondent Tomas)

Lars is a researcher who has a research project that was granted in collaboration with Gigacow. He looks at how social interactions affect the spread of diseases and the welfare of cows, as well as how it affects production. In the future, it is planned to connect this with breeding goals. The data from Gigacow will be used in this research. Currently, the knowledge exchange is mainly between researchers, but they want to involve farmers and other agricultural actors in the future. VÄXA is also involved in the project.

> VÄXA will arrange meetings with farmers this autumn where we will discuss our research results, how it affects agriculture in the future, how to improve milk production, and how important they think research on social interactions is. (Respondent Lars)

4.4.4 Expected benefits and outcomes

The largest benefit of Gigacow is that it increases the knowledge exchange between researchers and farmers, which in turn brings research closer to the industry. Gigacow facilitates research projects with connections to farmers and makes sure to find farmers that think the project's aim is attractive. In this way, both researchers and farmers receive value. Annica, an advisor who is involved in Gigacow, describes that the diversity of skills and professions is important so to create a rich experience and knowledge exchange.

> The foreman, the vet, the owner, the advisor, and the researcher note and reflect on different things or solutions. […] different competencies will come with different feedback on Gigacow's outcomes. […] sometimes, it is an exchange of experience in itself. But if you have a discussion, they can come up with ideas and research questions on topics that need more attention. (Respondent Annica)

Similarly, Lars states that in a project where several different competencies are represented, it is important to get to know each other and find out what different researchers think is important in research.

> It requires that you meet regularly […] it is really important to get a group to work together. (Respondent Lars)

Furthermore, Annica explains that there is optimism for initiatives such as Gigacow in contributing to research that generates more applicable knowledge, which farmers perceive as lacking today.

> It is more difficult for [farmers] to feel that basic research is directly applicable, although basic research often is a prerequisite for developing applied research. So, there is a hope for initiatives such as Gigacow that a larger proportion of research will be useful to farmers. (Respondent Annica)

At the same time, Lars explains that some of the research ideas could be spin-offs and become tools developed by tech companies but that his research team currently does not has such a focus.

> I am not used to work like that. Or if we come up with something hypersmart, maybe. (Respondent Lars)

When discussing more general what value IoT-solutions contribute, Annica mentions that the economic benefit is central but also several other important aspects:

> Increased job satisfaction, increased security in the stable, and you feel that you have control over your animals. Both that you feel that the animals are well, or animal health linked to that you deliver the best quality to the dairy trader, both as a health and animal welfare assurance. (Respondent Annica)

Tomas anticipates two alternative trajectories for the future of Gigacow. Either it will continue as a passion project where Tomas and his colleagues will do whatever it takes to keep Gigacow running because they truly believe in it, or that will have the possibility to scale up and become a long-term research infrastructure where SLU and other funding bodies jointly pays for a collective infrastructure for the whole food and farming industry.

> Then we cannot only do this as a small infrastructure for SLU, but it will be a national strategic interest where we test new agricultural technology, provide feedback to researchers, and drive Sweden's agricultural industry forward in the right direction. (Respondent Tomas)

If this becomes real, Tomas sees several other applications of infrastructure and testbed.

> The area that I think we can really contribute to is partly to have environmental analysis, because if you look at how Gigacow is built, in addition to testing agricultural equipment, which is actually in a way a small part of Gigacow, but what we basically do is that we collect baseline data on how things are going from Swedish agriculture and information about the animals on the farm and information about the agriculture itself so that researchers can do studies. (Respondent Tomas)

Tomas explains that he has both a 5- and 15-years plan for Gigacow. But he does not want to be perceived as the 'rockstar' of Gigacow.

> My goal as the project coordinator is not to be the star but to attract people that lead their own projects with the help of Gigacow and that we are the support function. […] it is my job to be an enabler of as many projects as possible. (Respondent Tomas)

4.4.5 Challenges

In the long-term perspective, the plan is to be financed by the institutions on SLU, external actors, and the research projects Gigacow contributes to being granted. However, Tomas also states that many of the challenges lie in the financial model.

> I would say that the biggest obstacle we have right now is how the funding systems for research on technology and development are designed because there are no strategic resources for investing in technology. (Respondent Tomas)

In addition to not having resources to invest in technology to test, it also creates problems in establishing a long-term organization and workforce.

> Although the universities have a low wage level, we are able to motivate people to start working with us because we do very interesting things, but when you cannot promise employment that lasts more than one or two years, people will not leave other workplaces for this sector. So, to be able to build great technical infrastructures, we must, even if we can get the money, have a financial model that is enough long-term so that we can recruit the right competence to the testbeds. And that is a knot we are trying to solve right now. […] Currently, we are dependent on my competence because we do not have money to duplicate my competence. I prefer to have at least two people in one position, because if I am on paternity leave or get run over by a car, then it will be a challenge. (Respondent Tomas)

When trying to solve a better financial model, they use lobbying activities, trying to partner up with projects that have a more long-term financial model to work with that is not research projects.

> If you gave testbeds a more strategic role in the research funding system, then you could get around many of the problems we have today. […] If we could have a strong base structure on maybe 2.5 or 3 million, then we could absorb an unexpected profit on 1 million upon that. But if we constantly lie on the minimum, maybe 1 million, it will be difficult to scale up the organization so that we can use the short-term grant in a pleasant way. (Respondent Tomas)

Regarding how they manage to operate with the financing models existing today, Tomas states that it is dependent on his and his colleagues' willpower and commitment. They manage to be independent of funding through being flexible and managing to balance research projects with the work with the infrastructure.

> In order to be able to serve the industry with the needs that exist with the skills we have built up, it may even be relevant that I reduce my work within SLU because I am needed as a consultant in the industry, and that work is outside the activities we are funded for and aim to perform. Therefore, you must first review the purposes you have and then also the business model. (Respondent Tomas)

Annica discusses another challenge regarding data ownership. While farmers generally are positive about DFT, they are protective of how their data will be used.

> Companies that sell, for example, management tools have insight into the data at the farm, but there is nothing that is released in public. The farmers who have been involved in Gigacow and those who may have refused to join, then there was some fear of activists and the uncertainty about who will have access to the data in the future and use it without the farmer's consent. […] They did not feel safe with what will happen to Gigacow's data and what they would do with it, although it is on a server at the university. They feel that you cannot guarantee that, for example, fatalities at my company, end up in the hands of some newspaper or something which then name and shame you. (Respondent Annica)

Concerning how to get more farmers involved in testbed activities, Annica believes in local meetings with a specific focus, where there is a mutual exchange of experience and knowledge.

> If there is a specific topic that the farmer is interested in and engaged in and wants to influence future research on, it is more likely that the farmer wants to participate. […] If it is only that the researcher wants to inform the farmers about their research results, then farmers expect to have a link to a teams- meeting instead. (Respondent Annica)

4.5 Summary of empirical findings

In table 3, a summary of the empirical findings is described. The rows describe the themes identified in the data analysis, and the rows describe the empirical findings divided by the two testbeds, FITPIG and Gigacow.

Table 3. Summary of the empirical findings

	FITPIG	**Gigacow**
Purpose	• To provide a platform for farmers to receive information for decision support, which will increase productivity while improving animal health.	• To provide a research infrastructure with testbed functionality for automated data collection. Possibility to become a collective infrastructure for data collection for the whole industry.
Initiating the testbed	• Funding from IOF2020 • Partners from the research institute in Switzerland and start-up firms from Spain • Unique product offer	• Funding from SLU and financial flows from researchers using the infrastructure • Committed researchers both within and external to the testbed • Large interest from industry actors
Expected benefits/ outcomes	• Helps the farmer to get instant alerts about the health of each animal, as well as the time and duration of farrowing, which will contribute to efficiency. May results in financial gains, reduced waste and better safety in production, and reduced animal suffering. • Time savings contributing to both more leisure time for the farmer, as well as time to work more strategically. • Contribute to a more modern agricultural industry which might attract labor. • Learnings from testing technology and about possible future applications.	• Facilitate the data collection for researchers about farms, which in turn will bring research closer to the industry, increasing the knowledge flow between farmers and researchers. • Possibility for farmers to be more included in the research and development of new technologies while helping researchers explore important research topics. • Building a competence portfolio that can be useful in other settings, for example, advisory and tech developers.
Challenges	• Demonstrate the added value in pig production • The limited resources (e.g., time and capital) to fully run the testbed.	• Fragmented and short-term funding • Dependent on the current participators • Gain the trust and engagement of farmers

5. Analysis and discussion

In chapter five, the empirical data is analyzed with the support of the analytical framework, followed by a discussion of the implication for the management of testbeds in relation to the research questions.

5.1 Shielding – creating a testbed for developing digital farming technology

Shielding are the management practices of creating the testbed, which implies building up enough support and resources to prevent the technology from 'premature death' due to a misfit with the existing socio-technical configurations (Verhees et al., 2012). The literature on shielding suggests that the process takes two forms, active and passive shielding. Active shielding is when a protective space is created, in the form of receiving resources, such as funding or other types of financial support, or legalizations, for example, rule exemption or subsidies. In passive shielding, the protected space can be a geographical location or institutional context where the selection pressures are less apparent. When looking at the two cases through the shielding lens, we see both active and passive shielding, through both creating new protective spaces and mobilizing existing ones.

FITPIG was a research project which was granted by IOF2020, which in turn is a project within Horizon2020. The funding is perceived as active shielding, as it was external financing support that FITPIG applied for to develop and test its technology. The features of the sensor are unique, and nothing similar exists in the current market. Nevertheless, the application on pigs has never been tested before, which indicates a logical need for shielding to learn about and improve its technical, economic, and socio-institutional performance, as proposed by Smith and Raven (2012). The composition of the project team also performs as a form of socio-cognitive protection, as sufficient competence is necessary to develop the technology both from a technological and institutional perspective (Smith & Ravens, 2012). CSEM, who initially found the research call from IOF2020, had no experience in developing technologies for livestock production and teamed up with researchers and firms with the agricultural knowledge they were missing.

Gigacow received initial funding for four years from SLU to develop the research infrastructure, which also can be perceived as a form of active shielding (Verhees et al., 2012). When the funding from SLU was terminated, Gigacow applied for grants on basic research, where a part of that amount goes to building and running the infrastructure. Also, research projects that use the infrastructure ‘pay’ to use it with their funding. This could be perceived as Gigacow mobilizing pre-existing financial resources, which is passive shielding (Verhees et al., 2012). The geographical location in Uppsala is near the SLU campus, as well as commercial dairy farms in the local area. This is perceived as a favorable location since SLU is a prominent agricultural university with credibility among both farmers and other actors in the industry (Smith & Ravens, 2012).

While shielding has been provided for both cases, challenges exist with the financial models. In both cases, the respondents perceived the limited time of the funding as a constraint to running the testbed in a desirable way. Gigacow has managed to work independently of active funding as they mobilize additional funds to build their infrastructure. However, Tomas describes that Gigacow currently operates on minimum resources and faces several challenges. Firstly, Gigacow cannot recruit staff as they need, which also makes it hard to upscale the organization. In turn, they are dependent on the actors currently involved in the testbed, and these actors need to take on multiple roles to continue the development of the infrastructure.

FITPIG only received funding from IOF2020 for two years, and the project was terminated after that. The data indicates that it was terminated because of both scarcities of financial resources as well as a lack of time to develop the technology into a market-ready product. The lack of financial resources and time has consequences for both nurturing and empowering activities, which will be discussed further below.

5.2 Nurturing – management practices to support the development of the digital farming technology in a testbed

Nurturing is about the management practices to improve the sociotechnical and/or economic performance of the innovation to reduce its dependency on shielding (Smith & Raven, 2012). In this section, the testbeds’ management practices are discussed through the lens of the following three areas: articulating expectations and visions; the building of social networks; and the organization of learning processes (Kemp et al., 1998 in Grin et al., 2010).

5.2.1 Articulating expectations and visions

The activity of articulating expectations and visions is about providing a direction for the learnings and outcomes from the testbed, as well as attracting attention and legitimizing the continuing protection of the testbed activities (Grin et al., 2010). The data indicates that the expectations in FITPIG are aligned with a broader social concern regarding improving animal welfare as well as farm profitability, as well as being shared with actors connected to FITPIG, such as researchers, farmers, and veterinarians. To communicate these expectations to project stakeholders, FITPIG organized at least one demonstration to showcase the value of their solution. The purpose of the demonstration event was to stimulate the acceptance of the technology among intended users.

Gigacow articulate a vision to bring their research closer to the industry. However, while the outcomes of the digital infrastructure are generally positively received by industry stakeholders, their expectations seem to be fragmented. While the researchers such as Lars expect that Gigacow will facilitate the conduct of fundamental research through data collection, farmers expect to get more applicable research, and tech providers expect to find out possible extensions of their products. Furthermore, larger governmental and industry actors, such as RISE, the Swedish Board of Agriculture, SVA, VÄXA, and Lantmännen, who are developing aggregated platforms for agricultural data, are requesting the competencies and knowledge about digital infrastructure developed in Gigacow. Therefore, the testbed is not only a new form of infrastructure for doing research, but it can also provide a basis for developing a common research infrastructure for the whole industry. This may cause conflicts between its stakeholders on what the infrastructure should be used for in the end. While all actors may be able to unite in this common direction, it is important to acknowledge possible contradicting expectations and interests. For example, Annica mentions another expectation from farmers about ensuring the security of their data, which is a highly demanded resource in commercial organizations. It will be important to consider expectations on data ownership and farmers' right if commercial interests get involved in Gigacow.

5.2.2 Building of a social network

Social network building is important as niche formation requires that new actors get together from a broad set of domains and that regular interactions occur (Mourik & Raven, 2006). FITPIG comprises a network of partners from Switzerland, Spain, and Sweden and is part of IOF2020. CSEM is a private non-profit research organization, and Digitanimal and HOPU are both tech companies. IOF2020, in addition to the different professions represented in the project, provides a somewhat heterogeneous network, which is described as desirable by McPhee et al. (2021). However, the end-user, i.e., farmers, are not represented more than having a consulting role in addition to providing the test facilities for the technology. Involving users in the development process can provide important lessons about user' experience and behavior (Hoogma et al., 2002).

Gigacow being a testbed within SLU, does not only provide shielding of their protective space but also provides an extensive network of researchers and university alumni working in agricultural businesses and organizations. One of the project members is a farmer himself, which can be seen as an important factor in both fostering positive expectations and facilitating mutual exchange between researchers and farmers. The researchers using the infrastructure to perform fundamental research contributes to the building of a social network of researchers dedicated to learning about the implications of DFT. Also, Gigacow exchanges information with colleagues outside academia, which contribute to both important insights from other stakeholders as well as further legitimization of what is developed within the testbed (Smith & Ravens, 2012). For example, the connection to VÄXA, the largest farming advisory organization in Sweden, has an influential position in influencing farmers' attitudes.

5.2.3 The organization of learning processes

Learning processes are crucial for successful innovations, as it enables adjustment of the technology and societal embedding to increase the chance of successful diffusion (Smith & Raven, 2012). It includes both first-order learnings (e.g., user preferences, regulatory context, and techno-economic performance) but also second-order learnings (Schot & Geels, 2008). This usually means a practice-based and interactive learning style with intended users and other stakeholders.

In Gigacow, the use of the platform contributes to learning in several ways. Firstly, researchers are the primary intended user, who contributes to learnings about user preferences and technological performance. Secondly, since the project members also are involved in the research projects, they are building a unique knowledge and competence base about DFT. More specifically, they get an overview of the research strand about the digitalization of agriculture and future directions, which may contribute to second-order learning. Nevertheless, it could be reinforced by involving farmers in the research activities in Gigacow, contributing to mutual learning where farmers get the chance to influence the research agenda. In turn, the research might become even closer to the farmers, and unintentional consequences of technology can be reduced.

In FITPIG, much effort has been on first-order learnings such as user preferences, infrastructure requirements, and techno-economic performance. Already at the beginning of the project, FITPIG consulted with an animal welfare farm about valuable uses for the sensor, which provided the way for specialization on sows and farrowing. However, the involvement of farmers in decision-making has been limited. Moreover, the demonstration of the ear tag was focused on showing and informing about the value of the innovation for the stakeholders rather than starting a dialogue, which could be a way to facilitate second-order learning. FITPIG planned to have tests where the farmers could explore the technology by themselves (learning-by-doing) but did not reach that point. Thus, during the two years of development and testing, much focus was put on improving the technical performance of the product due to technical issues.

Learning processes are perceived as one of the most crucial parts of SNM (Grin et al., 2010). While the focus was primarily to prove the concept of the technology, FITPIG did not manage to build a market-ready do during the time span of the project. However, they continued exploring opportunities for improvement and alternative applications until the very end, and the lessons are stored in SmartAgriHubs' platform (n.d.). Currently, neither one of the project actors are currently officially applying the lessons in other projects to improve the technology they developed.

5.3 Empowering – management practices to scale up technology from testbed

The third management process, *Empowering*, is the function that enables the innovation to move from the protective niche to the regime level through the gradual removal of its support (Smith & Raven, 2012). There are two ways to empower radical innovation: 'fit and conform', which implies that the protection is gradually removed when the innovation is ready to compete under mainstream selection pressures, and 'stretch and transform', which implies the protection is partly institutionalized and changes the mainstream selection pressures (Verhees et al., 2012). While neither FITPIG nor Gigacow have reached a state where there the experiments have been stabilized, the empowerment lens will be used to explore the cases' approaches to scaling and the interactions with the dominant regime.

In the case of FITPIG, the result suggests that the project's lack of shielding resulted in limited nurturing that was required to facilitate stabilization and growth towards maturity. Also, it indicates that it was difficult for FITPIG to demonstrate the value for the intended user, pig farmers. Moreover, FITPIG emphasized benefits such as efficient production and lower economic risk in this problem, rather than other benefits such as animal welfare and the social value of more spare time. This indicates that FITPIG focuses on dominant selection criteria, which may favor the regime trend of increasing large-scale commercial farms (Bronson, 2019). Despite the attempts to prove the value to pig farmers, FITPIG explored other possibilities to scale by extending the technology to other livestock animals where the demand for exploring sick animals is greater, such as dairy farming.

In Gigacow, the protection is currently based on the mobilization of funding for fundamental research projects and the willingness and motivation of the current members. However, it is described that with the existing resources, it will be challenging to scale. Gigacow will continue to be a research infrastructure exclusively for SLU if nothing else happens. Nevertheless, the knowledge base built in Gigacow is not only attractive to researchers and farmers but has also gained attention from advisors and tech firms. Through being a technological expert in large industry projects, Gigacow does not only build a network of powerful actors but also creates a narrative on how Gigacow has built the infrastructure that actors in these projects aim to develop. This could be perceived as a niche interaction described by Verhees et al. (2012: 5), where "innovation champion will have to develop narratives that are acceptable and make sense to potential funders, decision-makers and the like". It opens the possibility for Gigacow to scale up the infrastructure to cover the whole food and farming sector through the fusion with these actors. Consequently, Gigacow has started to test the institutional conditions for such infrastructure to be transferred beyond the research context.

Another possible path is to unite with other actors who already are in Gigacow's social network or bring new actors in, which could lead to Gigacow scaling up, becoming a large strategic initiative for a shared agricultural research infrastructure. The vision is to create a more extensive research infrastructure where many kinds of data are incorporated, such as the example with environmental analysis, to accelerate the transformation of the agri-food system. This could help overcome the fragmentation of current initiatives and release the potential for wide-ranging change (Turnheim et al., 2018). However, bringing more actors in will result in shifting interests, norms, and values and may cause unintended consequences, which result in issues of power and governance. Hence, it becomes even more important to consider the initial expectations from farmers and researchers.

5.4 Summary of the analysis

The main findings from the analysis are summarized in table 4. The rows represent the management practices and challenges connected to the analytical categories shielding, nurturing, and empowering. The columns represent the two cases, FITPIG and Gigacow. A discussion of the findings from the analysis will be discussed in the next section.

Table 4. Analytical summary

Analytical categories	**FITPIG**	**Gigacow**
Shielding	• Applied for funding from an EU-supported project • Short-term funding causing pressure on succeeding • Dispersed geographical location of project members	• Applied for funding from SLU and mobilized existing funds for research •Short-term project-based funding causing difficulties in managing the testbed optimally
Nurturing	• Creating positive expectations shared among stakeholders • Lack of user involvement • Focus on demonstration rather than learning	• Building of heterogeneous network • Learning activities involving both first-order and second-order lessons • Contradicting expectations • Lack of clear direction
Empowering	• Opportunity to scale out to other application domains	• Scaling within SLU vs. scaling out to other contexts

5.5 Discussion

The aim of this paper was to contribute to the understanding of the management of testbeds to develop digital technologies in the context of the food and farming sector. The first question in this research sought to determine *what the motives are for developing digital farming technologies in the testbeds.* The result suggests that both testbeds are developing digital technologies that are expected to contribute to solving some of the challenges facing the food and farming sector, somehow in different ways. FITPIG aimed to develop a technology for improving animal welfare and farm profitability, which are described as important challenges by Ellison et al. (2017) and Rolandi et al. (2021). Gigacow aimed to build a research infrastructure to facilitate exchange between researchers and the industry, which is important both in building bridges between researchers and practitioners as well as social and technical sciences (Lacoste et al., 2022). Thus, the testbeds' purposes are perceived as important vehicles to legitimize funding and protection during the development phase of digital farming technologies.

The second question aimed to understand *how digital farming technologies are developed in the testbeds in terms of management practices.* 'Develop' in this sense does not only refer to technological improvements but also technical and social alignment. Considering management practices to articulating expectations and visions, both FITPIG and Gigacow have managed to foster positive expectations about the expected benefits and outcomes of the technologies. While the expectations are aligned in the case of FITPIG among the social network, it seems like the expectations of different actors in the case of Gigacow are more contradictory. It is important that those visions and expectations evolve in response to learning processes (Grin et al., 2010), which suggests that the various expectations may be a result of learnings in the experiments. However, it is important that the articulation of expectations is done continuously with all involved partners to ensure cooperation of partner activities (Hoogma et al., 2002). Thus, it is vital to consider the implications of conflicting expectations. It may create alternative ways to scale up the technology, but it can also be devastating if actors with different values, interests, and degrees of power should agree on the specific direction of the technology. In the end, Gigacows intended users are researchers, and the outcomes will serve farmers, and thus these actors' expectations might be important to be kept central, although fulfilling the aim of more powerful actors such as industry actors may generate continuous support in terms of financial resources and legitimizing the infrastructure.

The result indicates that the testbeds have a relatively heterogeneous network of actors. However, only a small number of them are involved in decision-making processes. Moreover, there are few established tasks or formalized responsibilities for other stakeholders than the researchers and technology developers. Users and other relevant stakeholders are consulted in varying phases of the development of technologies, but their ability to influence decisions made in testbeds may be limited. This indicates that the focus primarily has been to inform and demonstrate the value of the technologies, which is important to create expectations (Kemp et al., 1998 in Grin et al., 2010). However, deeper interactions with users and other stakeholders also provide learning opportunities, both first-order learnings in terms of user preferences and second-order learnings that could help the testbeds to be more reflexive (Hoogma et al., 2002).

The third question in this study aimed to explore *the management implications for scaling up technology from testbeds.* The result from both the secondary data from Sweden food arena (2022) and the interviews indicates that funding for testbeds is fragmented, short-term, and project-based. This causes a lack of resources in terms of money and time, resulting in several organizational challenges such as difficulties attracting project members, long-term planning, and performing more extensive testing. Furthermore, Sweden food arena (2022) suggests that, while the number of testbeds and innovation arenas for DFT is growing, there is fragmentation between different initiatives, which indicates that the niche development is limited. While it is hard for the testbed management to control external financial models, coordination with other testbed projects is possible since many of these already exist in their social networks. More coordination between different projects would result in access to more resources (e.g., capital, knowledge, competence, etcetera) and facilitate learning (Smith & Ravens, 2012).

One surprising finding is that FITPIG, which was backed up by a project funded by the EU, did not manage to survive, while Gigacow, mainly financed by mobilized research funds, still is running. One possible explanation is offered by Hoogma et al. (2002), who suggest that projects receiving external funding have higher expectations of proofing the performance of the technology. Thus, FITPIG may have felt pressure to prove its techno-economic performance, while Gigacow, with its flexible yet uncertain financial structure, can work more autonomously from outside expectations. FITPIG's focus on demonstration and learning about technical aspects might have caused them to neglect other important learnings. It does not mean that they engendered important learnings, for example, that the decision support may work better in other domains, such as dairy production, where farmers are more used to deploying technological tools in their practices. However, there was no transfer mechanism to transfer the lessons to follow-up projects. In line with Hoogma et al. (2002), it is suggested that the testbed outcomes not only should be evaluated on the basis of their performance and success but on the basis of what has been learned concerning technical and social alignment. In this way, negative learning becomes something useful that can be used as lessons for future testbeds.

6. Conclusions

Chapter six concludes the study by summarizing the key research findings in relation to the research aims and questions and will provide a discussion of the value and contribution. Furthermore, it will review the limitations of the study and propose suggestions for future research.

6.1 Implications for the management of testbeds

This study was aimed at understanding the management of testbeds in the context of the food and farming sector. It contributes to the understanding of what is required to initiate a testbed and what management practices are applied to develop DFT in terms of both techno-economic performance and social and technological alignment. It also discusses management implications for scaling up technologies beyond the testbed. Thus, it provides important lessons for future testbeds for digital farming technologies.

DFT is predicted to play an important role in ta sustainable transformation of the food and farming system. DFT differs radically from traditional agricultural technologies as well as the practices linked to them. Thus, the diffusion of DFT implies not only technical change but also social change. SNM suggests that through experiments with new technologies and new socio-technical arrangements, the co-evolution of technology and social practices can be stimulated. Hence, SNM provides a tool to get a better understanding of not only the technological factors of new DFT but also the social and institutional dimensions that need to mature simultaneously with the innovation.

The findings of this research are in line with critics of SNM about the limited power of individual experimental projects to induce sustainable transitions. It is thus suggested that coordination between similar testbeds is required for the new DFT to have a real and lasting influence on the conventional agricultural regime. Thus, coordination of testbed initiatives with more long-term timeframes should be a management priority to give the testbeds a more strategic role in testing emerging technologies that can resolve sustainability challenges in the agri-food industry. Nevertheless, it is important to consider the implications of expanding the social network since it is likely that conflicting interests and views will arise. Though conflict can be necessary for reflexive learning and questioning underlying assumptions, it is important to continuously consider the expectations of all involved partners, regardless of power position. This is likely to both improve the chances of success as well as reduce the risk of unintended consequences.

This thesis contributed to important insights into the management of testbeds for DFT. SNM proved to be a fruitful management theory to understand how to initiate and manage testbeds for technologies that have the potential to provide solutions to some of the challenges that the food and farming sector is currently facing. Thus, SNM is not only a useful policy tool but may also be used as a framework for testbed managers to identify management practices beyond demonstrating the technological performance, as the social and institutional alignment is at least as important.

6.2 Limitations

This thesis study was not without limitations, which will be considered in the following section. Firstly, the methodological choices were largely based on the suggestions from previous research on how to explore the micro-processes of SNM (see Ballon et al., 2018; Cramer et al., 2014). A common problem with a qualitative research approach is the high degree of subjectivity, in the sense that the interpretation of the collected data is influenced by the researcher's judgments and preferences (Bell et al., 2019). As a result, the data analysis was based on the researchers' interpretations of the information provided from interviews and secondary data sources. However, since the study is conducted from the viewpoint of interpretivism, subjectivity is viewed as a natural consequence of data collection since reality is composed of multiple perspectives. Thus, the consequence of subjectivism is not perceived as negative in this study since it also results in more diverse and rigorous research contributions (ibid.).

Furthermore, the data was collected from a small sample with unique characteristics, making it hard to generalize the findings to the broader population. While generalizability is not required in qualitative studies (Bell et al., 2019), trustworthiness could have been enhanced by including viewpoints from additional testbed project members or/and users such as farmers and researchers. While a larger number of actors were asked to participate, those that were not included in this study declined due to the increased workload during this time of the year or did not reply.

6.3 Suggestions for future research

This study focused on the management practices and processes of testbeds preparing digital farming technologies for business adoption, as well as enabling and constraining factors in scaling the testbed operations. As testbeds are a considerable new concept in academia, particularly in the agriculture area, more research is needed to understand the management of testbeds and their potential to accelerate innovation and sustainable transitions. While SNM has shown to be a useful theory to explain the importance of testbeds for emerging technologies, it is primarily developed as a policy tool with limited insights on the management processes within testbeds. Thus, it is proposed for future research to combine SNM with theoretical concepts that explicitly focus on management practices. While testbeds as an organizational form are new, there exists literature on project management that could be useful to extend SNM.

Moreover, the result suggests that more coordination between testbeds is needed for them to be able to contribute to real and lasting change. Thus, it is proposed that future research focus on the network of testbeds and how coordination between them can be enhanced. Also, a broader set of actors should be considered to understand the different sets of expectations and interests that exist in these types of interdisciplinary collaborations.

References

Andersen, A. D., Frenken, K., Galaz, V., Kern, F., Klerkx, L., Mouthaan, M., Piscicelli, L., Schor, J. B., & Vaskelainen, T. (2021). On digitalization and sustainability transitions. *Environmental Innovation and Societal Transitions*, 41, 96-98. https://doi.org/10.1016/j.eist.2021.09.013

Baxter, P., & Jack, S. (2008). Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report*, 13(4), 544-556. https://doi.org/10.46743/2160-3715/2008.1573

Bell, E., Bryman, A., & Harley, B. (2019) *Business research methods* (Fifth ed.). Oxford, United Kingdom: Oxford University Press.

Bocken, N., Weissbrod, I. & Antikainen, M. (2021). Business experimentation for sustainability: Emerging perspectives. *Journal of Cleaner Production*, Volume 281. https://doi.org/10.1016/j.jclepro.2020.124904

Bronson, K. (2019). Looking through a responsible innovation lens at uneven engagements with digital farming. *NJAS – Wageningen Journal of Life Sciences*, 90-91, 100294. https://doi.org/10.1016/j.njas.2019.03.001

Bulkeley, H., Marvin, S., Palgan, Y. V., McCormick, K., Breitfuss-Loidl, M., Mai, L., von Wirth, T., & Frantzeskaki, N. (2019). Urban living laboratories : Conducting the experimental city? *European Urban and Regional Studies*, 26(4), 317-335. https://doi.org/10.1177/0969776418787222

Carolan, M. (2017). Publicising food: Big data, precision agriculture, and Co-Experimental techniques of addition. *Sociologia Ruralis*, 57(2), 135-154. https://doi.org/10.1111/soru.12120

Carvalho, L. (2015). Smart cities from scratch? A socio-technical perspective. Cambridge *Journal of Regions, Economy and So*ciety, 8(1), 43-60. https://doi.org/10.1093/cjres/rsu010

Cohen, D., & Crabtree, B. (2006) *Qualitative Research Guidelines Project*. Retrieved February 10, 2022, from http://www.qualres.org/HomeRefl-3703.html

Cook, S., Cock, J., Oberthür, T., & Fisher, M. (2013). On-farm experimentation. *Better Crops*, 97(4), 17-20. http://www.ipni.net/publication/bettercrops.nsf/0/AE0A720181C570A585257C28007A4A8E/$FILE/BC%202013-4%20p%2017.pdf

Cordis (n.d.). *Internet of Food and Farm*. Retrieved April 27, 2022, from https://cordis.europa.eu/project/id/731884

Cramer, H., Dewulf, G., & Voordijk, H. (2014). The barriers to nurturing and empowering long-term care experiments - lessons learnt to advance future healthcare projects. *International Journal of Healthcare Management*, 7(3), 165-184. https://doi.org/10.1179/2047971913Y.0000000064

Creswell, J.W. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches*. (2nd ed.) Thousand Oaks: Sage.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2(3), 198-209. Doi: 10.1038/s43016-021-00225-9 https://doi.org/10.1038/s43016-021-00225-9

Diener, E., & Crandall, R. (1978). *Ethics in Social and Behavioral Research*. Chicago: University of Chicago Press.

Dosi, G. (1982). Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. *Research Policy*, 11(3), 147-162. https://doi.org/10.1016/0048-7333(82)90016-6

Eastwood, C., Klerkx, L., Ayre, M., et al., (2017a). Managing socio-ethical challenges in the development of smart farming: from a fragmented to a comprehensive approach for responsible research and innovation. *J. Agric. Environ. Ethics.* https://doi.org/10. 1007/s10806-017-9704-5.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *The Academy of Management Journal*, 50(1), 25-32. https://doi.org/10.5465/AMJ.2007.24160888

Ellison, B., K. Brooks, and T. Mieno. (2017). Which livestock production claims matter most to consumers? *Agriculture and Human Values*, 34:819–831. https://doi.org/10.1007/s10460-017-9777-9

Elo, S., Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, 62, 107-115. https://doi.org/10.1111/j.1365-2648.2007.04569.

Elo, S., Kääriäinen, M., Kanste, O., Pölkki, T., Utrainen, K., & Kyngäs, H. (2014) Qualitative Content Analysis: A Focus on Trustworthiness. *SAGE Open*, 4(1), 215824401452263–. https://doi.org/10.1177/2158244014522633

Farguhar, J. D. (2012). Data collection. Chapter 5 in Farquhar, J. D. *Case study research for business* (pp. 65-83). London: SAGE Publications Ltd.

Goedde L., Katz, J., Mernard, A., & Revellat, J. (2020). Connected future: *How technology can yield new growth*. McKinsey & Company. Retrieved February 18, 2022, from: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, 31(8), 1257-1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6), 897-920. https://doi.org/10.1016/j.respol.2004.01.015

Geels, F. W. (2014). Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. *Theory, Culture & Society*, 31(5), 21-40.

Geels, F. W. (2019). Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability*, 39, 187–201. https://doi.org/10.1016/j.cosust.2019.06.009

Geels, F. W. & Raven, R., (2006). Non-linearity and Expectations in Niche-Development Trajectories: Ups and Downs in Dutch Biogas Development (1973–2003). *Technology Analysis & Strategic Management*, 18(3-4), pp. 375-392. https://doi.org/10.1080/09537320600777143

Giua, C., Materia, V. C., & Camanzi, L. (2022). Smart farming technologies adoption: Which factors play a role in the digital transition? *Technology in Society*, 68, https://doi.org/10.1016/j.techsoc.2022.101869

Golafshani, N., (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report*, 8, pp.597–607. https://doi.org/10.46743/2160-3715/2003.1870

Grin, J., Rotmans, J., & Schot, J. W. (2010). *Transitions to sustainable development: New directions in the study of long term transformative change* (1st ed.). Routledge. https://doi.org/10.4324/9780203856598

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In E. G. Guba, Y. S. Lincoln, & N. K. Denzin (Eds.), *Handbook of qualitative research* (2 ed.) (pp. 163–194). Riverside County: Sage.

Herlin, A. (n.d.) *FITPIG – Farm internet tracking of pigs.* Nordic Testbed Netwowork. Retrieved April 27, 2022, from: https://nordictestbednetwork.se/fitpig/

Hoogma, R., Kemp, R., Schot, J., Truffer, B., 2002. *Experimenting for sustainable transport: the approach of strategic niche management*. Spon Press, London, New York.

Hsieh, H., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9), 1277-1288. https://doi.org/10.1177/1049732305276687

Ingram, J., Maye, D., Bailye, C., Barnes, A., Bear, C., Bell, M., Cutress, D., Davies, L., de Boon, A., Dinnie, L., Gairdner, J., Hafferty, C., Holloway, L., Kindred, D., Kirby, D., Leake, B., Manning, L., Marchant, B., Morse, A., . . . Wilson, L. (2022). What are the priority research questions for digital agriculture? *Land use Policy*, 114, https://doi.org/10.1016/j.landusepol.2021.105962

IOF2020 (2019). *Interoperable Pig Health Tracking - Murcia, Spain*, Retrieved March 18, 2022, from: https://www.iof2020.eu/latest/demonstrations/2019/07/ interoperable-pig-health-tracking1

Jakku, E., Taylor, B., Fleming, A., Mason, C., Fielke, S., Sounness, C., & Thorburn, P. (2019). "If they don't tell us what they do with it, why would we trust them?" trust, transparency and benefit-sharing in smart farming. *NJAS - Wageningen Journal of Life Sciences*, 90-91, 100285. https://doi.org/10.1016/j.njas.2018.11.002

Kemp, R., Schot, J., & Hoogma, R. (1998) Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management, *Technology Analysis & Strategic Management*, 10:2, 175-198, https://doi.org/10.1080/09537329808524310

Kjellgren, F. & Ståhl, B. (2019) *Studie inför skapandet av nationella funktionen Testbädd Sverige*, Vinnova Rapport VR 2019:01

Klerkx, L., Jakku, E., & Labarthe. P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS - Wageningen Journal of Life Sciences* 90-91: 100315. https://doi.org/10.1016/j.njas.2019.100315

Klerkx, L., & Rose, D. (2020). Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways*? Global Food Security*, 24, 100347. https://doi.org/10.1016/j.gfs.2019.100347

Klingström, T., Petersson, K-J., von der Lehr, N., Persson, H., & de Koning, D-J. (2021). Precision dairy farming ‑ A Phenomenal opportunity with SLU Gigacow. *EMBnet.journa*l 26: e966. https://www.researchgate.net/publication/353111796_Precision_dairy_farming_-_A_Phenomenal_opportunity

Kochevar, D. & Werneck, G. (2021, Nov 3). Preventing future pandemics starts with recognizing links between human and animal health. *The Conversation*. https://theconversation.com/preventing-future-pandemics-starts-with-recognizing-links-between-human-and-animal-health-167617

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna, B. A., & Lombi, E. (2019). Soil and the intensification of agriculture for global food security. *Environment International*, 132, 105078-105078. https://doi.org/10.1016/j.envint.2019.105078

Lacoste, M., Cook, S., McNee, M., Gale, D., Ingram, J., Bellon-Maurel, V., MacMillan, T., Sylvester-Bradley, R., Kindred, D., Bramley, R., Tremblay, N., Longchamps, L., Thompson, L., Ruiz, J., García, F. O., Maxwell, B., Griffin, T., Oberthür, T., Huyghe, C., … Hall, A. (2021). On-Farm Experimentation to transform global agriculture. *Nature Food*, 3(1), 11–18. https://doi.org/10.1038/s43016-021-00424-4

Lincoln, Y. S. (1995). Emerging criteria for quality in qualitative and interpretive research. *Qualitative Inquiry*, 1(3), pp. 275-289. https://doi.org/10.1177/107780049500100301

Lincoln, Y. S., & Guba, E. (1985). *Naturalistic Inquiry.* Beverly Hills, CA: Sage.

Linneberg, M.S. & Korsgaard, S. (2019). Coding qualitative data: a synthesis guiding the novice. *Qualitative Research Journal*, vol. 19 (3), pp. 259–270. https://doi.org/10.1108/QRJ-12-2018-0012

Lioutas, E. D., Charatsari, C., & De Rosa, M. (2021). Digitalization of agriculture: A way to solve the food problem or a trolley dilemma? *Technology in Society*, 67, 101744. https://doi.org/10.1016/j.techsoc.2021.101744

McPhee, C., Bancerz, M., Mambrini-Doudet, M., Chrétien, F., Huyghe, C., & Gracia-Garza, J. (2021). The defining characteristics of agroecosystem living labs. *Sustainability*, 13(4), 1718. https://doi.org/10.3390/su13041718

Mourik, R. M., & Raven, R. (2006). A practioner's view on strategic niche management. (ECN-E; Vol. ECN-E-06-039 EN). ECN.

Nelson, R. R., & Winter, S. G. (1977). In search of useful theory of innovation. *Research Policy*, 6(1), 36-76. https://doi.org/10.1016/0048-7333(77)90029-4

Nordic Testbed Network (n.d.). *Gigacow*. Retrieved April 27, 2022, from https://nordictestbednetwork.se/gigacow-2/

Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice.* Sage publications.

Raven, R., Van den Bosch, S., & Weterings, R. (2010). Transitions and strategic niche management: towards a competence kit for practitioners. *International Journal of Technology Management*, 51 (1), 57–74. DOI:10.1504/IJTM.2010.033128

Regeringskansliet (2016, September 16). *845 miljoner kronor till en kraftsamling för innovation.* [Press release]. Retrieved April 27, 2022, from https://www.regeringen.se/pressmeddelanden/2016/09/845-miljoner-kronor-till-en-kraftsamling-for-innovation/

Rijswijk, K., Klerkx, L., Bacco, M., Bartolini, F., Bulten, E., Debruyne, L., Dessein, J., Scotti, I., & Brunori, G. (2021). Digital transformation of agriculture and rural areas: A socio-cyber-physical system framework to support responsibilisation. *Journal of Rural Studies*, 85, 79-90. https://doi.org/10.1016/j.jrurstud.2021.05.003

RISE, (n.d.) *Mer om Agrihub Sweden*. Retrieved March 20, 2022, from https://www.ri.se/sv/agrihub/mer-om

Rolandi,S., Brunori,G., Bacco, M., Scotti, I. (2021) The Digitalization of Agriculture and Rural Areas: Towards a Taxonomy of the Impacts. *Sustainability*, 2021, 13, 5172. https://doi.org/10.3390/su13095172

Rose D. C., & Chilvers, J. (2018) Agriculture 4.0: Broadening Responsible Innovation in an Era of Smart Farming. *Front. Sustain. Food Syst*. 2(87). doi: 10.3389/fsufs.2018.00087

Rose, D. C., Wheeler, R., Winter, M., Lobley, M., & Chivers, C. (2021). Agriculture 4.0: Making it work for people, production, and the planet. *Land use Policy*, 100, 104933. https://doi.org/10.1016/j.landusepol.2020.104933

Ruggiero, S., Martiskainen, M., & Onkila, T. (2018). Understanding the scaling-up of community energy niches through strategic niche management theory: Insights from Finland. *Journal of Cleaner Production*, 170, 581-590. https://doi.org/10.1016/j.jclepro.2017.09.144

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research Methods for Business Students* (5th ed.), Essex: Pearson Education Ltd.

Sengers, F., Wieczorek, A. J., & Raven, R. (2016). Experimenting for sustainability transitions: A systematic literature review. Technological Forecasting & Social Change, 145(aug 2019), 153-164. https://doi.org/10.1016/j.techfore.2016.08.031

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, 20(5), 537-554. https://doi.org/10.1080/09537320802292651

Slevitch, L. (2011). Qualitative and quantitative methodologies compared: Ontological and epistemological perspectives. *Journal of Quality Assurance in Hospitality & Tourism*, 12(1), pp.73-81. https://doi.org/10.1080/1528008X.2011.541810

SLU (2020). *Gigacow nyhetsbrev nr 2 2020* . Swedish University of Agriculture. Retrieved April 27, 2022, from https://www.slu.se/globalassets/ew/org/inst/hgen/gigacow/gigacow_nyhetsbrev_dec2020_final.pdf

SmartAgriHubs (n.d.). *From data collection to farmer notifications.* Retrieved April 27, 2022, from https://www.smartagrihubs.eu/portal/lesson/from-data-collection-to-farmer-notifications/23559

Smith, A., & Raven, R. (2012). What is protective space? reconsidering niches in transitions to sustainability. *Research Policy*, 41(6), 1025-1036. https://doi.org/10.1016/j.respol.2011.12.012

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Sushandoyo, D. & Magnusson, T. (2014). Strategic niche management from a business perspective: taking cleaner vehicle technologies from prototype to series production. *Journal of Cleaner Production,* 74, pp.17–26. https://doi.org/10.1016/j.jclepro.2014.02.059

Sweden food arena (2022) *Ett mordent innovationsystem* [Pilot study]. Sweden food arena. Retrieved April 27, 2022 from: https://swedenfoodarena.se/kunskapsrapporter/

Tillväxtanalys, (2017). *Vilka faktorer påverkar uppbyggnaden av en testbädd?* En analys av programmet Testbäddar inom miljöteknik, pm 2017/17

Toffolini, Q., Capitaine, M., Hannachi, M., & Cerf, M. (2021). Implementing agricultural living labs that renew actors' roles within existing innovation systems: A case study in france. *Journal of Rural Studies*, 88, 157-168. https://doi.org/10.1016/j.jrurstud.2021.10.015

Turnheim, B., & Geels, F. W. (2019). Incumbent actors, guided search paths, and landmark projects in infra-system transitions: Re-thinking strategic niche management with a case study of french tramway diffusion (1971–2016). *Research Policy*, 48(6), 1412-1428. https://doi.org/10.1016/j.respol.2019.02.002

Turnheim, B., Kivimaa, P., & Berkhout, F. (2018). Beyond Experiments: Innovation in Climate Governance. In B. Turnheim, P. Kivimaa, & F. Berkhout (Eds.), *Innovating Climate Governance: Moving Beyond Experiments* (pp. 1-26). Cambridge: Cambridge University Press. doi:10.1017/9781108277679.002

UN (2021). *Population, food security, nutrition and sustainable development*. UN. Retrieved February 27, 2022 from: https://undocs.org/en/E/CN.9/2021/2.

Verhees, B., Raven, R. P. J. M., Veraart, F. C. A., Smith, A. G., & Kern, F. (2012). Interrogating protective space: shielding, nurturing and empowering Dutch solar PV. (ECIS working paper series; Vol. 201204). *Technische Universiteit Eindhoven*. https://research.tue.nl/en/publications/interrogating-protective-space-shielding-nurturing-and-empowering-2/fingerprints/

Verhees, B., Raven, R., Kern, F., & Smith, A. (2015). The role of policy in shielding, nurturing and enabling offshore wind in the Netherlands (1973–2013). *Renewable & Sustainable Energy Reviews*, 47, 816-829. https://doi.org/10.1016/j.rser.2015.02.036

Vinnova (2021) *Testbed Sweden.* Vinnova. Retrieved April 27, 2022 from: https://www.vinnova.se/en/m/testbed-sweden/

Yin, R. K. (2003). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

Zhang, Y. & Wildemuth, B.M. (2009). Qualitative analysis of content. In: Wildemuth, B.M. (ed.) *Applications of Social Research Methods to Questions in Information and Library Science*. Westport: Libraries Unlimited, pp. 308–319.

Popular science summary

The agri-food system is facing several challenges. Firstly, the increasing global population creates a severe challenge of how to provide food to people in a food system that is already characterized by food inequality and lacking food security. Also, with a growing middle-class, the demand for animal products will increase. At the same time, there are growing concerns among consumers about the negative impacts of livestock farming on the environment, public health, and animal welfare. Secondly, the farming community suffers from other societal challenges, such as an aging population and depopulation in rural communities, failure to attract labor, difficulty in reaching markets, lack of public and health services, etcetera, which also negatively affects sustainable food production. Digitalization is improving nearly every industry imaginable, not at least agricultural. Thus, digital farming technologies are predicted to play an important part in the sustainable transformation of the agri-food system. Both academia, governments, and business agree that the so-called fourth agricultural revolution, where digital farming technologies, such as IoT, big data, AI, robotics, etcetera, offers ways to increase productivity with higher quality and fewer inputs, and provide solutions to the grand challenges the agri-food systems face today. Digital farming technologies cover a broad spectrum, from small mobile apps for decision support to sensor technologies for data collection to drones and robots for the automation of processes.

While digital farming technologies are already available, challenges still exist to their broad diffusion. Digital farming technologies differ radically from traditional agricultural technologies as well as the practices linked to them and are thus perceived as radical innovations. Thus, it is not only technological factors to consider but also many social dimensions that must mature simultaneously. Therefore, they need to be tested in experimental settings where they can be developed and fine-tuned and protected from the outside until they are mature enough to gain momentum by fitting in the existing world or changing the game rules in what is called a protective niche. This is at least what is argued for in transitions theories, especially Multilevel perspective (MLP) and Strategic Niche Management (SNM). One kind of experimental setting that is gaining attention in both academia, policy, and industries is testbed which is the topic of this study. While no established definition of testbed exists, the Swedish research authority, Vinnova, has a definition often used in the Swedish context. They state that a testbed is a “physical or virtual environment in which companies, academia, and other organizations can collaborate in the development, testing and introduction of new products, services, processes, or organizational solutions in selected areas”.

Studies on the role of testbeds in transitions are investigated in contexts such as urban planning, renewable energy, transport and health care. However, less has been done concerning the agricultural context. Moreover, the management of testbeds is seldom studied from a business management perspective, as studies often take an outsider perspective and focus on policy tools rather than the management practices within testbeds. Thus, the research aim of this paper is to contribute to the understanding of the management of testbeds in the context of the food and farming sector. The research questions that the thesis aimed to answer were:

- *What are the motives for developing digital farming technologies in testbeds?*
- *How are digital farming technologies developed in the testbeds in terms of management practices?*
- *What are the management implications for scaling up technology from testbeds?*

A qualitative research design was used to fulfill the research aim, as the thesis aim explore a subject and develop theory rather than test hypothesizes. Thus, a case study was conducted, more specifically a multiple case study, to find similarities and contrast between different testbeds acting within the same context. I used an inductive approach where the empirical data was analyzed to find patterns and themes which then can be put in relation to theory, rather than starting the other way around. Thus, the theoretical framework is used to understand the context rather than to underpin the aim and research questions.

For the data collection, two testbed managers were interviewed, one from FITPIG, a testbed for activity sensors for pigs, and Gigacow, a testbed that builds a platform for data collection that can be connected to existing dairy farm systems. Also, one researcher and one advisor related to Gigacow were interviewed, providing insights from users and stakeholders. Furthermore, secondary data was collected.

The results suggest that external funding provided to develop digital farming technologies in testbeds is fragmented, short term and project-based, resulting in a lack of resources to manage the testbeds optimally. Thus, it is suggested that the coordination of testbeds with similar directions should be a management priority to give the testbeds a more strategic role in testing emerging technologies that can resolve sustainability challenges in the agri-food industry. Moreover, the learning processes in testbeds are primarily focused on techno-economic performance and user preferences and learning processes about the social and institutional context are limited. Lastly, the plans to scale up technology beyond the testbed involve contradicting expectations between project stakeholders. Thus, managing stakeholders' multiple and sometimes diverse expectations is a critical management practice.

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Stockholm, 2022

Elin von Liewen Wistrand

Appendix 1

The mail that was sent to the respondents prior to the interviews

Bakgrunden till studien är att digital teknik förutspås bidra med lösningar till många av de hållbarhetsutmaningar som jordbruket står inför idag. Experimentering och testning vara en vital del för att initiera och accelerera spridningen av de nya teknologierna, men hur experimentella miljöer och testbäddar för digital jordbruksteknologi fungerar diskuteras sällan. Därav är jag intresserad av att undersöka vad det är för teknologier som utvecklas samt vilka motiv och utmaningar det finns med att utveckla digital jordbruksteknik i testbäddar/ demonstrationsmiljöer. Eftersom uppsatsen skrivs inom företagsekonomi är jag inte bara intresserad av tekniska utmaningar, utan främst organisatoriska och sociala utmaningar.

De frågor jag önskar att besvara är:

- Vad har din roll varit i testbädden/demonstrationsprojektet?

- Vilka är de största (organisatoriska och sociala) utmaningarna för att digitala teknologier/ hjälpmedel ska användas i praktiken av användarna/näringen utöver testbädden?

- Vad är avgörande för att övervinna hinder för användaradoption?

Appendix 2

The Interview guide

Bakgrunden till studien är att digital teknik förutspås bidra med lösningar till många av de hållbarhetsutmaningar som jordbruket står inför idag. Experimentering och testning vara en vital del för att initiera och accelerera spridningen av de nya teknologierna, men hur experimentella miljöer och testbäddar för digital jordbruksteknologi fungerar diskuteras sällan. Därav är jag intresserad av att undersöka vad det är för teknologier som utvecklas samt vilka motiv och utmaningar det finns med att utveckla digital jordbruksteknik i testbäddar/demonstrationsmiljöer. Studien kommer således fokusera på aktörer involverade i testbäddar där digitala jordbruksteknologier utvecklas. Och det är därför jag har tillfrågat dig om du vill delta i denna intervju.

Innan vi startar, är du bekväm med att jag spelar in? Jag kommer i sådant fall informera när jag startar inspelningen.
Jag vill också informera om att endast jag kommer lyssna på inspelningen, transkribera och hantera materialet. Du har rätt till att vara anonym om så önskas och kodar dig i så fall enligt din roll eller dylikt men utan sådant som kan koppla materialet till dig.
Du får dra dig ut när som helst och då raderar jag allt material på direkten.

Jag kommer även skicka min transkribering för dig att kika igenom så det känns okej för dig.

Några frågor innan vi startar?

Intervjufrågor

- Kan du berätta lite om din bakgrund?
- Hur kom du i kontakt med testbädden?
- Hur länge har du arbetat med testbädden?

- Vad är syftet eller ändamålet med testbädden?
    - Vilka problem är det ni försöker adressera? För vem?
    - Har syftet förändrats under arbetets tid?
    - Hur många är involverade i projektet?

    - Vad är det för typ av partners?

- Vilka användare är avsedda att använda teknologin?
- Hur engagerar ni användare i utvecklingsprocessen
    - Hur främjar ni användaradoption?

- Vilka är de största (organisatoriska och sociala) utmaningarna för att teknologin ska användas i praktiken av användarna (utöver testbädden)?
    - Hur arbetar ni för att övervinna dessa utmaningar?

- Vad anser du vara de viktigaste framgångsfaktorerna i testbädden/projektet?
- Hur ser det framtida arbetet i testbädden/projektet ut?

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