FACULTY OF
BIOSCIENCE ENGINEERING

Exploring agency, knowledge and power in the digital transformation of agriculture

Daniel van der Velden

Promotors: Prof. dr. ir. Joost Dessein, Prof. dr. ir. Laurens Klerkx, Dr. ir. Lies Debruyne

Thesis submitted to Ghent University in fulfilment of the requirements for the degree of Doctor of Bioscience Engineering: Socioeconomics

June 2024

Promotors:

Prof. dr. ir. Joost Dessein

Department of Agricultural Economics, Ghent University, Belgium

Prof. dr. ir. Laurens Klerkx

Department of Agricultural Economics at the University of Talca, Chile

Knowledge, Technology and Innovation Group, Wageningen University, The Netherlands

Dr. ir. Lies Debruyne

Social Sciences Unit, ILVO (Flanders Research Institute for Agriculture, Fisheries and Food), Belgium

Dean: Prof. dr. Els Van Damme

Rector: Prof. dr. ir. Rik Van de Walle

Dutch translation of the title: Onderzoek naar *agency,* kennis en macht in de digitale transformatie van de landbouw.

Cover ontwerp door Ann-Sophie De Steur

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Prof. dr. Gert Goeminne	Faculty of Political and Social Sciences, Ghent University
Prof. dr. Katharine Legun	Knowledge, Technology and Innovation Group, Wageningen University
Prof. dr. Hans De Steur	Faculty of Bioscience Engineering, Ghent University

Suggested way of citation: van der Velden, D. 2024 Exploring agency, knowledge and power in the digital transformation of agriculture. Doctoral Dissertation, Ghent University, Belgium.

ISBN: 978-94-6357-746-5

This work was supported by the European Commission's Horizon 2020 project DESIRA (Grant Agreement No. 818194). The content of this work does not reflect the official opinion of the European Commission. The views expressed in this work are solely those of the authors.

ACKNOWLEDGEMENTS

During the course of my PhD study, I have enjoyed the support of a number of people who I would like to acknowledge. To start, I would want to thank the interviewees and other people who generously provided their time to provide the data for this work.

I would like to express my thanks to the members of the jury for their insightful comments that helped me improve this manuscript. I appreciate the questions that you brought up during the internal defence and the critical comments that helped me rethink several topics brought up in this dissertation.

I also want to acknowledge my promotors. Laurens Klerkx, it has now been more than 6 years since I stepped into your office to discuss a vague notion of doing a master's thesis on precision agriculture. Throughout these years, I have appreciated your critical support, your in-depth advice and the creative ideas that helped provide new perspectives to the different chapters.

Joost Dessein, I would like to thank you for always being supportive of the introduction of new ideas and for encouraging me to stay critical in my work. I would also like to acknowledge the open and supportive space you provide to PhD students, developing the INSPIRA group into a space where a diversity of views and research directions co-exist and where PhD students have the space to develop themselves.

Lies Debruyne, I appreciate that I was always welcome to step into your office with a question, a frustration, or a lamentation about European research projects. I would also like to credit you for keeping me from becoming overly theoretical, and for providing a careful but necessary reflection whenever I was overly theoretical, critical, or cynical in my thinking.

I am equally thankful for my colleagues at ILVO, for providing a space where new ideas can develop and grow, and for providing a welcoming space. The same thanks extend to my fellow PhD students, both at the INSPIRA group and at the department of agricultural economics. I enjoyed the critical but supportive and open environment.

My original office buddies: Isabeau, Liselot, and Fanny, thank you for your welcoming me into the office four years ago and for your company over the past years. Also, thank you Siavash for the long conversations and discussions on politics, science and about working and living in Belgium, I appreciated these conversations immensely.

To my parents and siblings, thank you for being there, for taking an interest in my PhD and for everything else. Oma, bedankt voor alle opbeurende kaartjes en mails die u door de jaren heen heeft gestuurd.

Lastly, Cassandra, I want to thank you for everything. For your support in helping me take the step to move to Belgium and to start a PhD. But equally for listening to my rants, my new ideas and my frustrations in doing a PhD.

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LIST OF ABBREVIATIONS

AEA: *Ammonia-Emissie-Arm* (low ammonia-emission)

AMS: Area Monitoring System

CAP: Common Agricultural Policy

CBM: Checks-By-Monitoring

DST: Decision Support Technology

EU: European Union

MAA: Multi-Actor Approach

NDVI: Normalized Difference Vegetation Index

OTSC: On-The-Spot Checks

PA: Paying Agency

PAS: *Programmatische Aanpak Stikstof* (programmatic approach nitrogen)

PTB: Participatory Theory Building

RIA: Research In Action

RRI: Responsible Research and Innovation

SME: Small and Medium-sized Enterprises

STS: Science and Technology Studies

SUMMARY

The increasing use of digital technologies in agriculture is bringing about a digital transformation in agriculture. More and more data are collected, analysed, and used in agriculture and technologies used in agriculture are increasingly digitally connected. These changes do not come without impacts to agriculture, and there are concerns that the digital transformation has uneven impacts on agriculture and broader society. Over the past years, various authors have called for the inclusion of diverse actors in shaping the digital transformation to ensure a fair and just transformation. However, there remain knowledge gaps about both the impacts of the digital transformation and the response of diverse actors to this transformation.

This dissertation responds to these knowledge gaps by providing an understanding of how power, agency, and knowledge of actors in the agricultural system are changing. It does this through analysing the digital transformation of agriculture across Europe with a focus on The Netherlands and Flanders (Belgium). The main research question of this work that follows from this is: "w*hat is the current role and potential of diverse forms of agency and knowledge in the digital transformation of European agriculture, and what impact do participatory approaches have on including these diverse forms of agency and knowledges?".* Out of this main research question we develop five research questions that address the developments of power, knowledge, and agency in the digital transformation of agriculture. These research questions are answered in their respective empirical chapters (chapters 4-8).

The data that forms the basis for the 5 empirical chapters was collected between 2018 and 2023. Qualitative data formed the basis for this research and was collected through semi-structured interviews and focus groups. The five empirical research chapters provide the following answers to the main research question:

Chapter 4 describes knowledge conflict and claims of knowledge legitimacy in technology development and deployment. This chapter

shows how different forms of knowledge are mobilised to build technological legitimacy and the potential for more conflictual participation through agonistic pluralism in knowledge conflicts. Chapter 5 connects this to a case study on a participatory theory building process. This work shows how the fear of alienating stakeholders stops researchers from introducing theory into participatory activities. This also shows how participation is sometimes limited to deal with tensions in participatory research. Chapter 6 explicitly notes the agency of farmers in making digital agriculture work and the actions they take to shape digital agriculture on their farms. This is connected to the knowledge of farmers in digital agriculture in chapter 7, where we show how embodied knowledge plays a key role in how farmers make sense of precision agriculture. Chapter 8 extends the notion of agency to other actors in the agricultural system, describing how remote sensing technologies are negatively impacting the agency of bureaucrats in agri-environmental governance. Additionally, this chapter sets out potential approaches for digital technologies in agri-environmental governance that do enable agency.

Together, these chapters provide a more nuanced understanding of distributed agency than previously reported in studies on the digital transformation of agriculture, as well as the diffuse functioning of power. At the same time, this does not deny the uneven impacts of the digital transformation in agriculture, and we highlight the need for various approaches that can reduce power and knowledge hierarchies in agriculture. This includes both the resistance to repressive power, alternative technological platforms as well as regulation of existing structures.

SAMENVATTING

Het toenemende gebruik van digitale technologieën in de landbouw leidt tot een digitale transformatie in de landbouw. Er wordt steeds meer data verzameld, geanalyseerd en gebruikt in de landbouw. Technologie die in de landbouw wordt gebruikt is ook steeds meer digitaal verbonden. Deze veranderingen zijn niet zonder gevolgen voor de landbouw, en er zijn zorgen dat de digitale transformatie tot meer ongelijkheid leidt. De afgelopen jaren hebben een aantal auteurs opgeroepen om meer verschillende groepen mensen te betrekken bij de ontwikkeling van de digitale landbouw, om een eerlijke en rechtvaardige transformatie te garanderen. Er zijn echter nog hiaten in de kennis over zowel de gevolgen van de digitale transformatie in de landbouw en de reactie van diverse actoren op deze transformatie.

Dit proefschrift speelt in op deze kennishiaten door inzicht te bieden in hoe macht, agency en kennis van verschillende actoren in het landbouwsysteem verandert door de digitale transformatie. Daarbij wordt de Europese context als uitgangspunt genomen, met een focus op Nederland en Vlaanderen. Dit vormt de basis voor de hoofdonderzoeksvraag in dit werk*: "wat is de huidige rol en het potentieel van diverse vormen van agency en kennis in de digitale transformatie van de Europese landbouw, en welke impact hebben participatieve benaderingen op het de inclusie van deze diverse vormen van agency en kennis?"*. Op basis van deze vraag ontwikkelen we vijf onderzoeksvragen die samen ingaan op de ontwikkelingen van macht, kennis en agency in de digitale transformatie van de landbouw. Deze onderzoeksvragen worden beantwoord in de respectievelijke empirische hoofdstukken (hoofdstuk 4-8).

Deze empirische hoofdstukken zijn gebaseerd op kwalitatieve data die verzameld is tussen 2018 en 2023. Deze data zijn verzameld door middel van diepte-interviews en focusgroepen. De vijf empirische hoofdstukken geven de volgende antwoorden op de hoofdonderzoeksvraag:

Hoofdstuk 4 beschrijft kennisconflicten en claims over kennislegitimiteit in de ontwikkeling en toepassing van technologie. Dit hoofdstuk laat zien hoe verschillende vormen van kennis worden gemobiliseerd om technologische legitimiteit op te bouwen, waarbij er, door middel van agonistische pluraliteit, potentieel is voor meer conflict in participatieve methoden. Hoofdstuk 5 verbindt dit met een casestudy over een participatief theorievormingsproces en toont daarbij hoe de vrees om stakeholders te vervreemden onderzoekers ervan weerhoudt om theorie te introduceren in participatief onderzoek. Dit laat ook zien hoe participatie soms wordt beperkt om spanningen in participatief onderzoek op te lossen. Hoofdstuk 6 wijst expliciet op de betrokkenheid van boeren in de digitale landbouw en de acties die ze ondernemen om digitale landbouw op hun boerderij vorm te geven. Dit is verbonden met de kennis van boeren in de digitale landbouw in hoofdstuk 7, waar we laten zien hoe de belichaamde kennis van boeren een sleutelrol heeft in het betekenis geven aan data uit de precisielandbouw. Hoofdstuk 8 breidt het begrip 'agency' uit naar andere actoren in het landbouwsysteem, door te beschrijven hoe ‘remote sensing’ technologie de agency van ambtenaren over agro-milieubeheer beperkt. Daarnaast beschrijft dit hoofdstuk enkele toekomstpaden waarin digitale technologie juist wel de mogelijkheden voor agency doet toenemen.

Samen bieden deze hoofdstukken een genuanceerder begrip van agency dan eerder werd gerapporteerd in studies over de digitale transformatie van de landbouw. Tegelijkertijd ontkennen we hiermee niet de ongelijke effecten van de digitale transformatie in de landbouw en benadrukken we de noodzaak om via verschillende benaderingen de machts- en kennishiërarchieën in de landbouw te verminderen. Dit omvat zowel het verzet tegen repressieve macht, alternatieve technologische platformen en regulering van bestaande structuren.

CHAPTER 1. INTRODUCTION

1.1 The digital transformation of agriculture

Over the last years, if not decades already, there has been the notion that agriculture is undergoing a digital transformation, as part of a broader technological revolution in agriculture, coined 'Agriculture 4.0' (Klerkx et al., 2019). This digital transformation is based on the combination of technologies that collect data (e.g. soil sensors, satellite images, temperature and light sensors, yield monitors and imaging technologies) with data analysis tools. Large amounts of data are analysed to provide information and recommendations to farmers and other actors in the agri-food chain (Bhakta et al., 2019). Digital technologies also provide auto-navigation through GPS, variable rate applications of inputs, robotics and autonomous machinery leading to an increasing automation of farm tasks (Bhakta et al., 2019; Daum, 2021; Wolfert et al., 2017). The use of more and more data provided through sensor technologies, analysed through increasingly advanced algorithms, and presented to farmers through decision support systems, is promised to revolutionise decision-making in agriculture (Wolfert et al., 2017). This decision-making can also be used for variable rate technologies that allow the specific application of inputs, in effect reducing inputs while preserving yields (Bhakta et al., 2019; Lindblom et al., 2017). Together, these technological changes hold the promise of providing food security by increasing yields while reducing harmful environmental impacts of agriculture (Lajoie-O'Malley et al., 2020).

Both agri-business and policymakers see the digital transformation of agriculture as a priority (Bronson & Sengers, 2022; Fairbairn et al., 2022; Rijswijk et al., 2021). Agri-business leaders anticipate a new market for their products and a new data market where they can be important players (Bronson & Knezevic, 2016; Fairbairn et al., 2022). In European Union policy, both the Green New Deal and the Farm to Fork strategy contain a call to expand the use of digital technology as an enabler for attaining sustainability goals (Rijswijk et al., 2021).

Other articles and reports have described the great potential for digital technologies in transforming policy itself (Ehlers et al., 2022; Ehlers & Huber, 2021; OECD, 2019). In Europe, science and innovation programmes focus on digital agriculture and its social and environmental aspects, where a number of Horizon2020 projects have begun to address these topics (Klerkx et al., 2019; Rijswijk et al., 2021). One of these projects was the Horizon2020 DESIRA project, which this research was embedded in, which aimed to assess the socio-economic impact of digitalization on agriculture, forestry, and rural areas.

1.2 Critiques and the impacts of the digital transformation - Power, knowledge, and agency

Despite this promise of transformative, game-changing, and radical technological change, the technological developments of the digital transformation are critiqued for not actually transforming the current agricultural system. The digital transformation is more of a step than a leap in the move towards sustainable agricultural systems, and might not even lead to more sustainability (Klerkx & Rose, 2020; Miles, 2019). Other authors have pointed out that current technological developments do not necessarily address the drivers of harmful impacts of agriculture but rather seek to alleviate the worst impacts (Barnes, 2016; Wojtynia et al., 2021). Miles (2019) specifically describes this for precision agriculture, where pesticides are applied through variable rate technologies, but where there is no space to question the use of these pesticides. There is always a risk that these technologies form techno-fixes rather than being radical and transformative, with the techno-fix being the incremental improvement to the current system rather than a re-think of this system (Firbank, 2020; Montenegro de Wit & Iles, 2016; Wojtynia et al., 2021).

Several more critical authors have described how the digital transformation is affecting farmers and farm workers. Farm workers can become the targets of surveillance, de-skilling and are at risk of losing their jobs due to automation (Carolan, 2016a; Prause, 2021;

Rotz, Gravely, et al., 2019). The negative impacts of these technologies are not divided equally, and especially more marginalised people are experiencing adverse impacts (Prause, 2021; Rotz, Gravely, et al., 2019). The existing power imbalance in the agri-food chain drives this uneven distribution of impacts and benefits, where large corporations benefit most from the digital transformation (Bronson & Knezevic, 2019). This imbalance also affects the development of digital technologies in agriculture, where a number of authors have pointed out how these technologies are largely developed for large-scale monocropping farms (Carolan, 2020a; Miles, 2019; Rotz, Duncan, et al., 2019).

Concerns also exist about the impact that digital technologies have on the knowledge of farmers and farm workers. A number of authors have noted that local and embodied forms of knowledge are at risk of being replaced by digital and data-driven knowledges (Brooks, 2021; Gardezi & Stock, 2021; Stone, 2022). Farmers use forms of tacit knowledge such as embodied and experiential knowledge, and several recent articles note the experiential knowledge involved in the manual labour performed by farm workers (Klocker et al., 2020; Pitt, 2021). That data-driven knowledges pose a risk to these tacit forms of knowledge is broadly recognized, but with competing views on the extent of this risk. Several authors describe this not as a replacement of knowledge but as a knowledge conflict, or as tensions between forms of knowledge (Legun et al., 2022; Tsouvalis et al., 2000).

These risks and impacts of digital agriculture speak to the limited involvement of diverse knowledges and diverse actors in the development of digital agriculture. There are existing power imbalances, existing inequalities, that are worsened through the introduction of digital technologies (Carolan, 2020a; Prause, 2021). These previous authors set out that digital agriculture remains tied to productivist imaginaries for large and specialised farms. Impacts on more marginalised communities, forms of farming, and diverse forms of knowledges are largely negative, requiring a reorienting of the current direction of digital agriculture (Daum, 2021; Ditzler & Driessen, 2022; Metta et al., 2022).

Essential to this reorientation are farmers, technology developers, policymakers and other actors (Bronson, 2018; Rose & Chilvers, 2018). They play a role in this transformation, both in responding to it and in addressing its impacts. Their actions and reactions to the digital transformation show agency, a notion that people can impact and change the agri-food system while also acknowledging that agency is distributed and partially restricted by other actors and structures (Darnhofer, 2020; Higgins, 2006; Higgins et al., 2017; Legun & Burch, 2021). Agency is often understood as intentional and explicit actions that directly respond to the digital transformation of agriculture. However, this agency can also be recognised in everyday activities, where it might not be an explicit choice to respond to the digital transformation in a certain way (Higgins, 2006; Higgins et al., 2017). Power differences between actors impact the potential agency that different actors have, where there are disadvantaged and marginalised groups with limited agency over the direction of the agri-food system (Burch & Legun, 2021; Carolan, 2018a; Coulson & Milbourne, 2021). Knowledge is not always evenly recognised in the digital transformation of agriculture, with tensions between forms of knowledge (Legun & Burch, 2021; Tsouvalis et al., 2000).

1.3 Potential to address impacts of digital agriculture through participation

Considering the uneven and negative impacts of the digital transformation of agriculture, there is a need to consider how these impacts can be avoided (Bronson, 2018; Rose & Chilvers, 2018). The most common solution is the call for participatory, responsible, and inclusive innovation (Bronson, 2018; Burch & Legun, 2021; Rose & Chilvers, 2018; Steinke et al., 2022). Most authors have described this as a need for responsible research and innovation (RRI) or responsible innovation (RI) approaches, although several researchers call for inclusive innovation, co-innovation, or other approaches that effectively overlap with RRI and RI in their focus on inclusion and reflection in innovation processes (Bronson, 2019; Ditzler & Driessen, 2022; Fraser, 2021; Ingram et al., 2020; Townsend & Noble, 2022). In this work we broadly categorize these approaches as participatory and inclusive innovation approaches.

What these approaches have in common is the inclusion and participation of a broader variety of stakeholders early in the innovation process (Stilgoe et al., 2013). A broader group of actors are involved in steering technology development, allowing the process of technology development to respond to the needs and interests of these actors (Bronson, 2018; Klerkx & Rose, 2020). Through reflecting on socio-ethical issues, power relations, and the potential impacts of digital technologies, action can be taken to deal with these issues and impacts (Gardezi et al., 2022; Steinke et al., 2022). This also assigns a responsibility and duty to care for the innovation to the actors involved in the innovation process (Prutzer et al., 2023).

While uneven power relations are acknowledged in the call for inclusive innovation approaches, how these power relations actually influence the process of including stakeholders is often not acknowledged in precision agriculture studies, with some notable exceptions (Bronson, 2019). This is intriguing, as other authors have made explicit mention of the tensions in including stakeholders and in re-directing innovation processes (Blok & Lemmens, 2015; van Oudheusden, 2014). Generally, authors in digital agriculture describe the need to acknowledge these uneven power relations, but provide few concrete suggestions to deal with these relations after they have become acknowledged (Gardezi et al., 2022; Jakku et al., 2023; Townsend & Noble, 2022). Equally, while it could be said that including stakeholders enables their agency over innovation processes, relatively few authors explicitly link to farmer agency in participatory and inclusive innovation processes (a notable exception being Legun & Burch, (2021))

1.4 Research questions

We have set out the challenges and uneven impacts in the digital transformation of agriculture and the current enactment and potential for everyday agency and participatory approaches in the development of digital agriculture. Based on this we see a need for an analysis that links power, agency, and knowledge to the potential of influencing technology development through participatory and inclusive approaches. This requires a deeper understanding of the functioning of power, agency, and knowledge in the digital transformation, building on the existing literature in critical agricultural studies. Equally, by providing this understanding, it will be possible to help build on existing participatory approaches and to strengthen the potential of these approaches in a building a fair and just digital transformation of agriculture. The main question that comes up is:

What is the current role and potential of diverse forms of agency and knowledge in the digital transformation of European agriculture, and what impact do participatory approaches have on including these diverse forms of agency and knowledges?

This forms a broad research question that we will return to throughout this work and that we will answer in the discussion and conclusion. This main research question is split into five separate empirical research questions to answer one or more elements of this question.

The first question relates to the diverse forms of knowledge used in agriculture. Diverse forms of knowledge are broadly recognised in studies on agriculture, where farmers, technology developers, and other diverse stakeholders are all said to possess a variety of knowledge (Lowe et al., 2019; Šūmane et al., 2018). We focus on the development and use of this knowledge by a variety of actors as well as the attempts at creating legitimacy for diverse forms of knowledge. In this, the claim for legitimacy of diverse knowledges is heard in a broad range of studies, and different actors seek to stake a claim to the legitimacy of their knowledge in speaking for a certain issue (Jain & Ahlstrom, 2021; Leino & Peltomaa, 2012; Montenegro de Wit & Iles, 2016). This forms the context for our first empirical research question, which is:

How is the legitimacy of technologies, developed in response to agri-environmental regulation, perceived and constructed in the Flemish livestock farming sector, and how are knowledge claims involved in the construction of this legitimacy?

We provide an answer to this research question in chapter 4. This claim to knowledge legitimacy returns implicitly in later research questions and chapters, but we do not use this as an explicit concept for the broader study. Tensions between different forms of knowledge, with actors seeking to gain the legitimacy to speak over a certain issue brings us to the next empirical research question. In this question we turn to participatory knowledge production and co-theorising. This partially answers to the recurring call for participation in response to knowledge conflicts (Doudaki & Carpentier, 2021; Edelenbos, 2004). Participatory approaches are often said to be a solution to these knowledge conflicts, where we ask to what extent different tensions in these processes are resolved by participatory approaches:

How are tensions between project needs, stakeholder needs, and co-theorising resolved by researchers in a European research project, and what is the relevance and potential of theoretical concepts as boundary objects in participatory research?

This question will be answered in chapter 5, in which we analyse the DESIRA project, which focused on the socio-economic impact of digitalization on agriculture, forestry and rural areas. Together, these two questions bring up the conflicts and tensions between knowledges and in participatory processes. Through this, we also partially describe the potential agency that different actors have, as the use of knowledge claims and the claims for legitimacy imply a form of agency for diverse actors in staking these claims. Earlier authors have noted how farmers *tinker,* using their knowledge to assemble digital agriculture in a specific way, highlighting how knowledge and agency are used to make digital agriculture work (Higgins et al., 2017). To build on this relation between knowledge and agency, and to further focus on the everyday dynamics in the digital transformation of agriculture, we also seek to specifically address what agency farmers have in the digital transformation, for which we formed the following research question:

Which forms of tinkering do French, Australian and Dutch farmers employ in assembling precision agriculture to make it workable and what do these forms of tinkering engender for farmer agency?

We answer this question in chapter 6. While the literature has looked at potential risks of the digital transformation to farmers' knowledge (Brooks, 2021; Gardezi & Stock, 2021; Miles, 2019; Stone, 2022), the development of this knowledge in everyday use of digital technologies has remained unexplored, with the exception of a few authors (Legun et al., 2022; Lundström & Lindblom, 2018). Brooks (2021) and Stone (2022) are among the authors who warn of a potential de-skilling and a threat to diverse knowledges, whereas other authors describe the potential for farmers to use digital technologies in developing their knowledge (Lundström & Lindblom, 2018). To respond to this debate on farmer knowledge in the digital agriculture, and to explore whether this leads to a 'cyborg farmer', integrating both analogue and digital knowledge, we turn to the research question that we answer in chapter 7:

How does the embodied use of precision agriculture by Dutch crop farmers take shape and what does this mean for the formation of cyborg farmers?

As we described previously, the understanding of power in digital agriculture and its resulting consequences for the development of digital agriculture has often been focused on large corporations (Bronson & Sengers, 2022; Rotz, Duncan, et al., 2019). However, digital technologies are increasingly used by governments, especially for the monitoring and governance of the environmental impact of agriculture (Aistara, 2009; Ehlers & Huber, 2021). This will have specific consequences for the functioning of power, agency, and knowledge in the digital transformation of agriculture. In order to study this we have formulated the following specific research question that will be answered in chapter 8.

What is the impact of digital monitoring technologies, especially the use of remote sensing technologies, on the governance of the CAP across European member states?

We return to these questions in the empirical section of this dissertation. Before doing so we will provide background information and a broad theoretical framework (chapter 2). In the second chapter we review the existing literature and critically reflect on power, agency and the use of knowledge in the digital transformation of agriculture. We describe how these three concepts are currently understood in the literature and how this can be used to analyse the digital transformation of agriculture. We also consider the potential for participation to meaningfully address the imbalances of power, agency, and knowledge and the resulting impacts on the digital transformation of agriculture.

The theoretical framework is followed by a methodology chapter (chapter 3) that sets out the broad epistemological and methodological choices that were made in this work. Afterwards, we answer the specific research questions in the 5 empirical research chapters (chapter 4-8), followed by an overarching discussion and conclusion (chapter 9) which is used to answer the main research question.

CHAPTER 2. EMPIRICAL AND THEORETICAL BACKGROUND

This chapter starts with a broad context of this work, followed by the theories and concepts used throughout this work. Concepts and theories we explore in this chapter will be used to provide a broad discussion of the empirical findings in chapter 9. To guide the reader through this background and theory chapter, we begin by providing the context of this study, which will mainly be useful to readers unfamiliar with European, Dutch, and Flemish agriculture. Readers more familiar with this context might want to turn directly to the sections following this, which provide a background on theories of knowledge, power, agency, and participatory approaches in the digital transformation of agriculture.

2.1 The context of European agriculture

This work is situated in the context of European agricultural. There is no way to fully capture the diversity of European agricultural systems in the few paragraphs that we dedicate to it here. At the same time, there are common elements that are, broadly speaking, true across Europe. One element has been the ongoing intensification and scale enlargement across Europe (Van Zanten et al., 2014). Scale enlargement is not a uniform development across Europe, where family farms still dominate in most of Western Europe, while historical developments in Eastern Europe have generally marginalised family farming, although major contrasts between individual countries exists (Swain, 2013). However, agricultural intensification is happening across Europe, with an increased use of agricultural inputs, increases to field sizes and a homogenisation of the landscape, and the abandonment of marginal agricultural areas (Van Zanten et al., 2014).

Policy choices have had a significant impact on these developments. Food security, as one of the key historic drivers of the common agricultural policy (CAP), has largely been solved across the European

Union (Matthews, 2015). At the same time, this focus on food security has been achieved through a productivist paradigm that also resulted in the intensification of agriculture across Europe (Pe’er et al., 2020; Van Zanten et al., 2014). This focus on food production in order to achieve food security has never fully gone away, but has over time made space to a broader variety of concerns, including social and environmental concerns (Kuhmonen, 2018). This has been a reason for some to describe the current status of agriculture in Europe as post-productivist, indicating a move to agriculture that also incorporates other aspects than yields alone (Ward et al., 2008).

The CAP is not the only factor impacting European agriculture, as a range of other policies (especially those targeting environmental outcomes) have also recently had significant impact on agricultural change (Melse et al., 2009). Recently protests have once again impacted these policy choices, driving politicians away from environmental regulation (Wax & Brzezínski, 2024). These are but some of the indicators of a changing agricultural system, where there is a desire for change to the current system but uncertainty about the desired direction for the agricultural system. Digital technologies are often seen as an easy solution to this problem, where the digital transition becomes encouraged by policymakers in the ‘twin transition’ to a sustainable and digital economy (Lenz, 2022).

2.2 Dutch and Flemish agriculture in context

Several chapters in this work (chapter 4, 6 and 7) are focused on Dutch and Flemish agriculture. Because of this, we provide a short general description of agriculture in this region, providing an overview for the Netherlands and Flanders at the same time. As a region of Belgium, Flanders shows similar developments in agriculture to the Netherlands, and is also dealing with similar environmental and regulatory problems brought about by intensive agriculture (Boezeman et al., 2023). Both areas show a similar intensification in the agricultural sector, with resulting environmental and social impacts in regions with high population densities. Historical developments, especially the trade of grains and protein crops combined with large harbours in a delta region, have produced forms of (livestock) agriculture that are producing high yields but that also require large amounts of external inputs (Levers et al., 2016).

Both the Flemish and the Dutch government are searching for ways to deal with the environmental impacts of agriculture. The Netherlands has for example seen concepts such as circular agriculture (promising a closing of nutrient loops and a reduction of external inputs) (Ministerie van Algemene Zaken, 2021). Equally there have been calls for an extensification of livestock farms, reducing external inputs and yields to reduce nutrient losses to the environment (Schrijver et al., 2022). Agroecological approaches have seen increasing attention, although as a diverse collective of (sometimes conflicting) approaches (Ewert et al., 2023). Digital technologies are also seen as one of the key solutions to the current environmental impacts of agriculture, as these technologies are promised to help reduce inputs while increasing food security (van der Wal et al., 2020; Wolfert et al., 2017). The European Commission (EC) has supported this development by classifying the use of digital agriculture technologies as one of the eco-schemes that countries can use in the CAP, funding the adoption of these technologies (DG AGRI, 2021). Both the Netherlands and Flanders have made use of this opportunity, supporting digital technologies as a solution to environmental impacts.

Data on the adoption of digital technologies by Dutch and Flemish farmers are only available for 2017 and 2018 respectively and this data is generally limited. For the Netherlands, the 2017 survey indicates an increasing adoption rate for GPS autosteering technology, which is used by over half of small farms (<25ha) and by nearly all farms over 50ha in size (Van der Wal et al., 2017). The same study indicates the use of soil scans, crop scans, soil mapping, soil moisture monitoring and decision support systems (apps and other tools) by crop farmers as well as the use of variable rate technologies for fertilizer and pesticide applications (Van der Wal et al., 2017). For Flanders, significantly more information is available. For Flanders, a majority of farmers (57%) is currently using, or expects to start using, precision agriculture in the years 2018-2023 (Departement Landbouw & Visserij, 2018).

Considering these statistics, the digital transformation of agriculture is still in an early phase, with certain technologies showing relatively low adoption rates. Despite this, the rate of adoption is increasing over time, and there is an increasing impact of these digital technologies on agriculture (Bhakta et al., 2019; Klerkx et al., 2019; Wolfert et al., 2017). We consider both the impacts of the digital transformation in agriculture and the role that diverse forms of agency, knowledge and power have on this transformation. This begins with an exploration of the agency of different actors in the development and use of digital agriculture.

2.3 Precision agriculture and agency in the digital transformation

The concepts used in this work require some explanation. This work deals with the digital transformation of agriculture, a broad transformation that is driven by a range of digital technologies. We use the concept digital agriculture as a more generic term for all digital technologies in agriculture. The concept precision agriculture is used to describe a specific set of digital technologies, including the use of autosteering through GPS, the use of variable rate technologies for input applications, the use of sensor data and remote sensing data and the use of decision support systems. We use the broad term precision agriculture to discuss the changes brought about by this collection of technology but do focus on separate elements of precision agriculture in empirically analysing this (e.g. discussing the use of data, the specifics of remote sensing, or the use of software programs).

There is a concrete, material side to these technologies that will be explored in this research, describing how precision agriculture technologies are changing agriculture and how farmers change precision agriculture. However, this does not mean we should ignore the discourse around precision agriculture and what the term precision agriculture implies. The concept of precision agriculture is questionable, as the term alludes to the fact that precision in agriculture becomes possible precisely through this set of digital technologies (and conversely that farmers not using these technologies are imprecise) (Duncan et al., 2021; Visser et al., 2021). A number of authors point at the technical solutionism packaged in this term, where high-tech solutions are provided as the future of agriculture (Duncan et al., 2021; Miles, 2019; Visser et al., 2021).

Precision agriculture has been challenged based on its perceived precision, with precision being promised that does not materialise in practice (Visser et al., 2021). Other authors have also called to attention the performative nature of precision agriculture, highlighting how precision agriculture makes real certain visions of agriculture (Carolan, 2020b; Fairbairn et al., 2022). Technologies are marketed as a solution to grand societal problems, creating an image of the future of agriculture as a high-tech, clean, and productive industry that has solved the larger environmental and societal problems of current forms of agriculture (Carolan, 2020b; Fairbairn et al., 2022). This is a broader discourse, or even a socio-technical imaginary that does not move away from current productivist and extractivist forms of agriculture (Fraser, 2019; Stone, 2022).

This does create a space to question what happens when discourse of precision agriculture meets the farm, or more precisely, what happens when farmers start using the technologies that make up precision agriculture, which is what this work will provide. A main question that comes up in the literature is the question of how much agency farmers have in using these technologies. This literature is built on a (largely) political economy body of work that describes limited agency, where the digital transformation is driven by venture capital and by large corporations (Brooks, 2021; Duncan et al., 2022; Fairbairn et al., 2022; Stock & Gardezi, 2021). The claim is not that farmers, or people in general, have no agency but that this agency does not have much of a meaningful impact, as the transformation of agriculture is driven by larger interests. The structural forces of capitalism and the power of large corporations and venture capitalists are the main drivers of this transformation in these accounts (Duncan et al., 2022; Rotz, Duncan, et al., 2019).

However, other authors have shown that precision agriculture does not have to be this way. A second stream of literature, closer to this thesis' focus and premise, does not deny that the development of these technologies is largely driven by these same interests. However, where this literature diverges is that it understands farmers as having agency over how they implement digital agriculture in their local context (Carolan, 2020b; Ditzler & Driessen, 2022; Higgins et al., 2017; Legun & Burch, 2021). Our work adds to this in chapters 6, 7 and 8 by exploring how agency over digital agriculture shapes digital technologies and the impact of these technologies. To conceptualise this, we need to further explore the notion of agency. In analysing and describing agency in this thesis, there are different understandings of agency that we can use. Some ascribe agency only to human actors, focusing on the deliberate actions that human actors take and defining this as agency (Giddens, 2004). This form of agency concerns *"events of which an individual is the perpetrator, in the sense that the individual could, at any phase in a given sequence of conduct, have acted differently"* (Giddens, 2004, p. 9). Our approach is however closer to new materialist and relational approaches to agency, which take an understanding of agency as formed through relations in networks and assemblages, where agency is distributed and not solely possessed by human actors, but where humans form part of a relational network of distributed agency (Bowden, 2020).

This links to a relational turn in (agricultural) sociology, understanding agency as distributed, linked to non-human agency and focused on relations over entities, emphasising interdependence (Darnhofer, 2020). However, we do not follow the radical relationism that Darnhofer (2020) proposes, where agency is fully extended to the non-human (Darnhofer, 2020; Müller, 2015). This is for two main reasons that will be relevant to this work. First, as stated by several other authors, this understanding limits the potential to account for power, creating difficulties in thinking of power differentials related to class, gender, and race (Fine, 2005; Knudsen, 2023; Müller, 2015). Second, in this understanding of agency as (fully) distributed, there is a risk that intentionality is ignored in ascribing agency (Knudsen, 2023). These approaches carry the risk of not being able to distinguish between the intentional agency of humans and the agency of animals or things, where intentional agency cannot be afforded to these non-human actors (Elder-Vass, 2008; Flatscher & Seitz, 2020).

2.4 Intentional agency in the digital transformation of agriculture

The choice for intentional agency means that we limit agency, where we do not understand agency as fully distributed. Certainly, we do not deny some form of agency to non-humans, but we see a difference between human and non-human agency. The capacities and intentionality of humans come with a responsibility that cannot be assigned to non-human actors (Elder-Vass, 2008; Knudsen, 2023). It follows that agency is asymmetrical, with a notion of human agency as intentional actions where people draw on imaginative goals and try to attain them (Giddens, 2004; Knudsen, 2023). At the same time, animals do have agency and can in some instances act purposefully, as well as inanimate objects being able to exert influence over agency, constraining human and animal agency (Knudsen, 2023).

To expand on this last point, in studying technologies we assign these technologies with a form of agency, but an agency that is inscribed to the technology by human actors (Hornborg, 2021). This is not exclusive to the designers of the technology but also includes users who bestow meaning on these technologies, or other actors who provide this agency by how they relate to the technology. These meanings and functions do however draw on human actions, on interpretations, design and manufacture (Hornborg, 2021). Agency can be recognised in diverse actions, where previous authors have highlighted agency when farmers adapt technology or when they adapt their farm to changing circumstances, due to the introduction of digital technologies (Higgins et al., 2017; Legun & Burch, 2021). There is a need to further explore how different forms of engaging with technology enable agency and how agency is expressed through these actions, as this work will do in the empirical chapters.

In this thesis we focus on this agency through a focus on human actors, analysing how their agency is expressed in the digital transformation of agriculture. As Bowden (2015) shows, this central role for human agency does not have to exclude a relational understanding to agency, but rather provides an understanding of networks and assemblages that are assembled by humans (made explicit in chapter 6), where human actors deliberately construct certain assemblages. This also assigns an ethical duty to humans for their role in assemblages, to reflect on and to potentially remove themselves from assemblages that cause harm (Bowden, 2015).

Despite diverging from the radical relational approach as described by Darnhofer (2020), the approach we described in the previous section does tie in with broader understandings of agency in digital agriculture studies. For example, despite claiming that agency is distributed and that non-human actors have agency, Comi (2020) still describes that only human actors have intentionality. In general, authors working with a relational perspective in digital agriculture studies hold a notion that non-humans have agency, but where human agency are afforded a specific intentionality (Brooks, 2021; Carolan, 2020b). This is especially prevalent in accounts that study how farmers and other actors interact with digital technologies, which show how farmers resist, modify and work around digital technologies (Carolan, 2020a; Higgins, 2006; Higgins et al., 2017). In this sense, our approach largely ties into this broader body of work.

This approach also partially counters the view that digital agriculture is a process of domination by large agri-tech firms and input suppliers in agriculture (Brooks, 2021; Gardezi & Stock, 2021; Stone, 2022). In these works, power relations are reduced to asymmetrical, pre-existing power relations where digital agriculture allows for a domination of farmer subjectivities through the knowledges produced by these technologies (Brooks, 2021; Gardezi & Stock, 2021; Stone, 2022). For example, Gardezi and Stock (2021) tie a Foucauldian understanding of the functioning of power to the domination of farmer subjectivities through digital agriculture. This view sees digital agriculture as a top-down development which dominates farmers and further enrols them into capitalist markets, with little space to farmer (or anyone's) agency. In opposition to this, we follow Comi (2020) in understanding the functioning of power as the functioning of distributive agency, where all actors do have agency and hold power, a notion that we further develop in the next section.

2.5 Power and resistance in digital agriculture

When agency and power in digital agriculture is described, authors often ascribe power to large corporations that dominate the food supply chain, focused on input suppliers and tech firms that sell to farmers (Bronson & Sengers, 2022; Duncan et al., 2022; Jakku et al., 2019; Rotz, Gravely, et al., 2019). This limits the functioning of power to top-down relations where one party holds power and where power is used to control and dominate farmers and other more marginalized groups in the agri-food supply chain (Brooks, 2021; Rotz, Gravely, et al., 2019). This largely hold true in certain situations, but we want to expand on this by understanding power in a more diffuse way, where diverse actors are enrolled in the functioning of power. In providing this understanding of power, we mainly draw on a Foucauldian understanding of the functioning of power as a diffuse but uneven distribution of power through society (Agrawal, 2005; Ettlinger, 2018; Foucault, 2007). This diffuse but uneven distribution of power leads to the question of power structures. In this work we take a relational approach to power, where the relations between actors create power structures (e.g. capitalism, the broader agricultural system), but where these power structures are also temporary configurations of relations that shift over time (Dépelteau, 2018).

Digital technologies and tools are political and they have a performative effect, they shape how we understand and make the world (Kitchin, 2017). However, in the use of digital technologies there are unanticipated effects that change the way that technology is used. Users of technology never follow the rules inscribed in the technology, and through a combination of unanticipated use, biases and bugs, and users changing how technology is used in practice, the functioning of technologies change (Finstad et al., 2021; Kitchin, 2017). These are the forms of agency and power that interest us, where the users of technology shape the digital transformation (Higgins et al., 2017; Holloway et al., 2014; Søraa & Vik, 2021). The designer of a technology never gets to control or determine how a technology is used in practice, complicating any notion of power that sees a direct and linear relation between digital agriculture design and the functioning of power. This is clear when Higgins et al. (2017) describe how farmers work with digital agriculture technologies, where they adapt and retrofit technologies, showing both the agency of farmers and how this diverts top-down control.

These diffuse and diverse ways of working with digital agriculture can be seen as forms of resistance. This broadly follows the notion that resistance comes first in the functioning of power (Checchi, 2014). As a creative, active, and unpredictable force, the resistance of diverse actors determines how the transformation of digital agriculture takes shape, which turns around the typical notion of the functioning of power in digital agriculture studies (Checchi, 2014; Ettlinger, 2018). Digital technologies afford many opportunities for users to subvert, resist and change the technology itself and how this technology becomes used and adopted across society (Ettlinger, 2018). There is potential for diverse actors to express their agency and to change the direction of agricultural transformations, but this does require these actors to employ this potential. There are opportunities for this, whether it is designing digital tools that support the agroecological transition (Ditzler & Driessen, 2022), or the development of alternative tools and the hacking of technologies produced by large agri-tech firms (Carolan, 2018b; Rotz, Duncan, et al., 2019).

These notions of resistance can in part be recognised as an everyday form of resistance, which might not always be fully intentional or shaped by conscious actions, as will be made visible in chapters 4, 6, and 7, with an exploration of these forms of resistance in the discussion in chapter 9. The re-shaping of a technology by users can happen through everyday activities, where the technology becomes adapted to fit into daily routines and practices (Ettlinger, 2018; Pinch & Bijker, 1984). The shaping of technology is often a mix between acts of intentional change and everyday activities that together shape the technology (Bear & Holloway, 2019; Driessen & Heutinck, 2014; Finstad et al., 2021). In more pro-active and intentional forms of agency, several authors describe how farmers actively shape their farm and digital agriculture to be able to work with digital agriculture (Higgins et al., 2017; Legun & Burch, 2021). The opportunities for alternative approaches to digital agriculture, to subvert the digital transformation of agriculture, are dependent on these more intentional and proactive forms of agency according to the existing literature (Carolan, 2018b; Ettlinger, 2018).

2.6 Knowledge forms in digital agriculture

Fundamental to both the potential of resistance and for the functioning of power is knowledge. Knowledge makes the functioning of power possible, legitimizes political choices and knows its own hierarchy, where scientific forms of knowledge are often privileged (Foucault, 1990; Van Assche et al., 2011; Wynne, 1998). In this work we take a view of knowledge as situated, meaning that knowledge is influenced by the person who produces this knowledge and the environment in which it is produced (Haraway, 1988). This has an impact on the knowledge produced within this body of work (as we discuss in chapter 3) and also means that there are different forms of knowledge that can be valid in specific contexts. This relates to knowledge produced on farms, in laboratories, or through digital technologies (Leino & Peltomaa, 2012; Lundström & Lindblom, 2018). Knowledge is also never separate from other forms of knowledge. Rather, forms of knowledge are mutually influencing each other, as Burton & Riley (2018) for example highlight this in how traditional ecological knowledge and scientific knowledge have mutually influenced each other, where already in the 1700s there were efforts to transfer ‘scientific’ information to the wider farming community.

Despite this, we still need to make a distinction between farmers' and practitioners' tacit, experiential, and embodied knowledge and the more formal knowledge structures of scientific and data-driven knowledge. These latter forms of knowledge are often seen as objective, but are as equally situated as the diverse forms of knowledge we described before (Haraway, 1988). There is a common critique on the objectivity of these forms of knowledge in agricultural studies, also because on-going (agri-)environmental crises have made visible the uncertainty and the fallibility of scientific knowledge, (Bruce, 2013; Thorsøe et al., 2017; Turnhout et al., 2007; Wynne, 1998). We add to this literature by showing how technology developers use this uncertainty over knowledge to claim legitimacy for their own knowledge and for the technologies they develop in chapter 4, contributing to the literature by showing how different forms of knowledge are used and are in conflict.

Data-driven knowledges are promised to once again provide objectivity, through large amounts of data, only accessible through machines and advanced algorithms, providing knowledge beyond the capacities of humanity (Frické, 2015). However, both data-driven and scientific knowledge suffer from the fact that they are starting from a universalist and objectivist account that seeks to break down the objects of their study in discrete and discernible units for analysis (Kitchin, 2014; Turnhout et al., 2014; Weber & Prietl, 2021). While providing an approximation and a situated understanding of the objects of their study, these attempts fail at producing the objectivist and universal accounts that they set out to provide.

Despite this, there are forms of truth produced through these knowledges (Beer, 2017). Data-driven knowledges output, cement, and maintain certain truths, as exemplified by algorithms reproducing notions of productivist agriculture and providing knowledge for large-scale mono-cropped forms of agriculture (Carolan, 2020a; Miles, 2019). While this is not essential to data-driven knowledge, as this knowledge can support different forms of agriculture, the notion that data is neutral and objective reinforces the status quo (Beer, 2017). This tension between data-driven knowledge and the diverse knowledges in use by farmers and farm workers have led to the claim that diverse knowledges are under threat from information and knowledge derived through digital technologies (Stone, 2022). Data-driven knowledge, produced through sensor technologies and advanced algorithms, are seen as a danger to the embodied knowledge of farmers. Other authors fear that this will lead to a de-skilling of farmers, where vital skills are lost through an overload of information (Brooks, 2021; Stone, 2022). In digital agriculture studies this has been understood as a top-down process of subjectification, where people come to understand themselves through knowledge transferred to them (Gardezi & Stock, 2021; Miles, 2019; Sletto, 2005).

A small number of authors have explored how farmers are using data-driven knowledge in practice, where they find that this knowledge is not replacing or subjugating the knowledge of farmers. Early literature on precision agriculture already noted the limited use of data-driven knowledge and the conflict between different forms of knowledge (Tsouvalis et al., 2000). Recently, several authors have explored how farmers are linking their own situated and embodied knowledges to data-driven knowledges, and how embodied forms of knowledge are preserved (Legun et al., 2022; Lundström & Lindblom, 2018). This literature does not deny that there are tensions between forms of knowledge, but also describes that data-driven knowledge might not replace the diverse knowledges of farmers. Concerns about the accuracy and reliability, as well as the black-boxing of decision-making in decision support tools, provides farmers with a reason to doubt the quality of this data-driven knowledge (Rotz, Gravely, et al., 2019; Visser et al., 2021). This makes the claim that digital knowledge is replacing tacit, embodied, and local forms of knowledge less likely. Chapter 7 (and to a lesser extent chapter 8) contribute to this by showing how different forms of knowledge are intertwined and are used to come to new forms of knowledge.

2.7 Participation in response to undesired impacts in digital agriculture

While we nuance the descriptions of highly negative impacts of digital agriculture on power, knowledge, and agency, there is no question that there are negative impacts. As described in the introduction, a large number of authors have set out the need for participatory and inclusive innovation to deal with the negative impacts and uneven power structures of digital agriculture (Bronson, 2018, 2019; Ditzler & Driessen, 2022; Eastwood, Klerkx, et al., 2019; Fleming et al., 2021; Gardezi et al., 2022; Jakku et al., 2022, 2023; Klerkx & Rose, 2020; Metta et al., 2022; Prutzer et al., 2023; Rijswijk et al., 2021; Rose & Chilvers, 2018; Steinke et al., 2022; Townsend & Noble, 2022). Common to the call for participation in innovation is the need to include more diverse actors, marginalised voices and diverse knowledges of people in the digital transformation (Bronson, 2019; Klerkx & Rose, 2020; Rose & Chilvers, 2018). In talking about participatory approaches we include a diversity of participatory programs that are common to researchers. This includes both participatory and inclusive innovation such as RRI, participatory knowledge production and participatory research, which all have the aim of including diverse people in these processes (Ingram et al., 2020; Prutzer et al., 2023; Steinke et al., 2022). These participatory approaches emphasize the importance for each actor to exercise their knowledge, agency and skills in the innovation process (Berthet et al., 2018).

Our work adds to this by exploring to what extent this exercise of knowledge and agency is possible in participation (throughout the chapters but especially in chapter 5). A general point of critique in the literature is that participatory approaches do not deal well with power relations and even run the risk of reinforcing existing power structures (Blok & Lemmens, 2015; Boogaard, 2021; van Oudheusden, 2014). It is complicated to ensure the participation of marginalised groups, as is recognised in studies on digital agriculture (Burch & Legun, 2021). However, Blok & Lemmens (2015) note that even if this participation is ensured, existing configurations of power often make transformative change impossible, leading to disappointment among the stakeholders involved. While there is a notion that understandings of power are vital in innovation processes, relatively few authors in digital agriculture seem ready to move from being aware of power structures to actively resisting these (Fraser, 2021). When authors do address power in participatory digital agriculture development, this often involves a move beyond participation, where a combination of regulation, a break-up of monopolistic corporations, and a move to alternative platforms are highlighted as potential solutions (Bronson, 2019; Carolan, 2018c; Fraser, 2021).

Equally, in the literature beyond digital agriculture there are concerns that participatory and inclusive approaches do not function to include diverse forms of knowledge, but still reproduce knowledge hierarchies and the status quo (Boogaard, 2021; van Oudheusden, 2014). When different knowledges meet in a participatory project, it is often the objectivist (scientific and data-driven) knowledges that seek to integrate the knowledge of farmers and other actors (Boogaard, 2021; Boon & Van Baalen, 2019; Latulippe & Klenk, 2020). Sometimes this is also encouraged by authors who describe the potential for participation, where the uptake of these forms of knowledge in digital systems becomes the aim (Gardezi et al., 2022). This is a variation on the replacement of diverse knowledges in digital agriculture, as it does not involve a replacement of knowledges per se, but rather indicates the desire to absorb this knowledge in data-driven knowledges (Duncan et al., 2022).

Whether this participation happens in a just and fair way depends on how different actors perceive their agency in participatory processes (Legun & Burch, 2021). The potential for actors to influence the direction of development, or the agency they can express in using digital technologies, is essential to an effective participatory process (Higgins et al., 2017; Legun & Burch, 2021). In some accounts, agency seems to be taken as a given, where the agency of diverse actors is automatically taken up as long as the participatory process is sufficiently inclusive and participatory (Berthet et al., 2018). This is challenged by the notion that actors might not realize the agency they have, where they conform to existing structures and patterns of development (Legun & Burch, 2021) Equally, the inclusion of marginalised groups might not be possible due to other, more powerful actors that are involved in the participatory process (Blok & Lemmens, 2015; Burch & Legun, 2021). Whose voice counts, and who actually gains agency in participatory approaches is strongly tied to the power structures described before.

Considering these limitations, there is a need to consider how participatory innovation approaches might change to involve these concerns. One potential solution is to become more focused on conflicts and power structures in participation through an agonistic pluralism lens. Agonistic pluralism sets out that there is a need to both be aware of these uneven power structures and to actively seek to go against them in participatory processes (Mouffe, 2007; D. Scott, 2021). This builds on the notion that there will be incompatible visions in participatory technology development, which cannot all be included (D. Scott, 2021). To steer technology development to forms that allow smallholder farmers to use digital agriculture will be a choice not to develop this technology for large-scale mono-cropped farms (Ditzler & Driessen, 2022). There is a choice for a type of farming system in the development of a technology, and this choice involves the technology developer in the conflicts and tensions over the future of farming. Agonistic pluralism allows for this conflict to be mediated and considered, rather than seeking consensus for a decision (Mouffe, 2007; D. Scott, 2021). Our work adds to this by exploring different potential roles for agonistic pluralism, especially in chapter 4 and returning in the discussion.

This also ties in to the choice to resist the dominant model of farming, to resist the mono-cropped large-scale technology development common to agriculture (Carolan, 2020a; Miles, 2019). Several authors have noted that participatory approaches are valuable, but that the focus should be on alternative platforms that subvert existing power (Ettlinger, 2018; Fraser, 2021). This is a normative aim that is not necessarily common to participatory innovation, as it directs innovation to subvert dominant power structures rather than assuming that deliberation and consensus-building through participation alone will disrupt these structures (Ettlinger, 2018).

We return to these notions of power, agency, and knowledge throughout our empirical chapters (4-8) and in the discussion and conclusion. We also build on the potential for participation in the discussion and conclusion. Before we turn to the empirical chapters, we provide a short methodological chapter that sets out a broad overview of the methodologies chosen in this work.

CHAPTER 3. METHODOLOGY

Each of the empirical chapters has a separate section outlining the specific methods used in that chapter. For this reason, we use this methodology chapter to outline the broader epistemological, ontological, and methodological choices that were made in writing this manuscript. For this methodology chapter I (author Daniel van der Velden) use the I statement to describe how and why specific methods were chosen and to describe the more fundamental reasoning behind certain methodological choices.

3.1 Broader epistemological and ontological framing

To an extent, this section forms an ex-post analysis of the broader underlying methodological choices and the underlying epistemology and ontology that formed the basis for my research. While these choices have informed my research, this ex-post analysis is where I explicitly describe the underlying thinking that has structured this research. Part of this writing is uncertain, as it is based on assumptions that have shifted while writing the different chapters. I do finally end up at a position that is close to being a critical realist but in the early phases of this research I was closer to seeing the world as socially constructed (mainly while writing the chapters 4, 6 and 7) while remaining tied to a relational ontology. Chapter 5 and 8 are also written from a perspective that is based on a relational ontology, highlighting the role of material objects in the social world, but is already closer to a more critical realist position. This relational ontology also provides the linkage between rural (or agricultural) sociology and science and technology studies (STS), as it is common to both (Carolan, 2016b; Darnhofer, 2020; Müller, 2015).

This means I largely take from a relational approach, where subjects and objects are defined by the relations they hold to other subjects and objects (Burkitt, 2016). The implication of this is that agency (in how we act), the power agents accrue and constraints on agents do not depend on the relations of agents to overarching structures but depend on interdependence (the relations) between the agent and others (Burkitt, 2016). The main aim of taking a relational approach is to perceive and study social phenomena as fluid processes that can and do change, in this sense even taking a process-relational approach at times (as can be read in chapter 6 and 7 especially). This includes a foregoing of solid social structures, cultures and societies and accepting that things are in a constant state of *becoming* (Dépelteau, 2018). Entities are defined by the relations they undertake with other entities, not defined by some pre-relational essence but formed through their relations with others.

In my understanding this largely aligns with a Foucauldian understanding of power that regularly returns in this work, where power is diffuse and built through the relations between agents. I do still at times talk about power structures, but with power structures do not mean solid unchanging power structures, but rather see these structures as ultimately temporary configurations of relations that can shift over time (Dépelteau, 2018). At the same time, I do view the social structures that form out of these relations as having some form of causal powers over the entities that form these structures. In other words, a social structure can be understood as something that emerges out of (historic) social relations and also has a causal effect on people and their behaviour (Dépelteau, 2018).

This view on relations and power has developed over the fieldwork of this dissertation. The basis for this viewpoint has been there since the beginning. However, in accepting that society has to be understood in a relational way, I have personally shifted between where agency is situated, how power can be defined and the role that social structures play in this. While writing chapter 4, 6, and 7 I was more ready to afford agency to non-human actors, where I have now specified agency in sections 2.3 and 2.4 to intentional agency held by human actors, a position that influenced the work in chapters 5 and 8. This is mainly written in opposition to agency afforded to non-human objects in parts of STS, where Latour and Latourian scholars move towards an equal affordance of causal capacities to humans and non-human objects (Elder-Vass, 2017). In a similar way, the understanding that social structures do exist also goes against the flat ontology of Latourian scholars in STS, where my understanding is based on an acceptance of causal contributions of social structures and entities (Elder-Vass, 2017).

In writing this section and in providing the analysis of chapter 2 and 9, I have aligned myself with a critical realist understanding that does stress the importance of the material world in understanding the social world. While I highlight the importance of social structures and human agency, this does not ignore the very real effects of the material world, which is the main focus of this research. At the basis of this is that there is some theory of truth, not necessarily a truth we can access but that there is some form of observable reality. However, observations are not neutral, so that this observable reality is always understood through interpretations (Porpora, 2018). Truth determination in this sense is fallible, things will be wrong, and there is no pre-determined way to achieve the truth, but there is also no equal truth that can be accorded to all perspectives (Porpora, 2018).

This is of particular importance to my understanding of knowledge in this work. My position is that there are ways of producing knowledge that come closer to observable reality, that produce a higher quality knowledge than others. I follow Haraway (Haraway, 1988) in viewing that there is objectivity in situated knowledge, that some better form of knowledge in the form of faithful accounts of the real world must exist. Ultimately, I take a critical realist position in the belief that through situated knowledge a more objective account of the world can be formed.

3.2 Reflections on positionality

In the spirit of situated knowledge, which will return with some regularity in this work, I would like to add a section on my own positionality, which might aid in understanding the interpretations I make throughout this work. To start, I am an educated cis white male, born in The Netherlands. My academic background consists of a bachelor’s degree in plant biotechnology followed by a master’s degree in the social sciences oriented towards rural sociology with linkages to STS. Relevant to my positioning in the study of agriculture is me not being from a farming background, which farmers respond to, and which does mean that in interviewing farmers I am seen as an outsider. In a similar way, the research in Flanders is coloured by me being from the Netherlands, where I remained an outsider peering in, influencing the field work and the perspectives gained from these studies.

Regarding my positioning towards agriculture, my position has shifted throughout writing the chapters that make up this manuscript. I start out (and fundamentally believe) that the current agricultural system requires fundamental changes, especially considering the harmful impacts of the current agricultural system on people, the environment, and animals. With some variation this has been true throughout writing this manuscript. However, this position is balanced by a contrasting view that fundamental change is both difficult to achieve and that some of the main alternatives do not promise a radical improvement on the current system. This can be read throughout my work, where different chapters hold different positions towards change of the current system, but where a belief in change is a recurring theme throughout the chapters.

3.3 Case selection and case studies

As this research is part of the broad field of science and technology studies (STS), case studies were a logical choice to approach the research questions (Law, 2008). Case studies have a long history in this field and are of particular use in tracing the development and use of (new) technologies. The use of case studies allows for an exploration of the situated nature of technologies and science, a central aspect of STS (Beaulieu et al., 2007). Central to the cases in this research is the exploration of how digital technologies take shape in a specific context, how universal claims over these universal technologies might be deconstructed within local, situated cases. For four of the five chapters that form the empirical part of this work focus is on a specific technology. A fifth article (chapter 5) is not focused on a technology but is instead used to describe a participatory research method used by a researchers, once again fitting well within the STS framework, being somewhat akin to a Latourian approach (Latour, 1987).

The case study is at its simplest the study of a particular group, topic, or issue in a relatively short amount of time, producing in-depth descriptions and interpretations. The case study in qualitative research does not seek to produce generalisable results, but rather to describe and interpret the uniqueness of the case, producing results that might be transferable to other cases (Hays, 2003). This transferability is particularly visible in chapter 6, where a multi-case study is used to show how similar trends do occur across various cases. The case studies in this research are instrumental (following Njie & Asimiran, 2014) in that they are used to provide insight into a broader topic. The case is an element of a broader phenomenon and speaking for this larger phenomenon. The case studies in my research are bound by the topic of the case, generally a technology and a group of people connected to this technology (whether developers or users) (Njie & Asimiran, 2014). Case study research is an evolving process, where the research starts with a broad research question and a number of specific questions, but where these questions develop throughout the research process as the case in question becomes clearer and better understood (Hays, 2003)

Cases for this research were selected in relation to the main question driving this research (related to the digital transformation of European agriculture and the role of participation in this). Partially, case selection was limited by funder requirements, where chapter 4 and 5 formed out of the H2020 DESIRA project that funded part of this research. The cases in these two chapters were part of existing research activities within the project, with additional data being gathered to answer the specific research questions. Chapter 6, 7, and 8 provided specific answers to elements of the digital transformation. The cases of chapter 6 and 7 were selected to provide an answer to how precision agriculture (as part of the digital transformation) takes shape on farms. The case of chapter 8 came out of an interest to explore the digital transformation in relation to agri-environmental governance and the role of the government in the digital transformation. Together, these cases provide a broad base of data that answer both the empirical and general research question.

3.4 Methods used in the case studies

In the case studies for this research, the most common method used was the semi-structured, in-depth interview. The specifics for the interviews are described in the method sections of each of the empirical chapters. For two of the chapters I also used workshops and focus group discussions (chapter 4 and 5). The use of focus groups in this research was limited and was focused on further elucidating specific aspects that came up during interviews or as an additional data source. Focus groups were never the primary data source used for any of the chapters, but rather served as a form of data triangulation in the case studies where they were used (Creswell, 2007). An overview of all the chapters and the methods used is provided in table 1 on the next page.

Participants in this research were selected by purposeful sampling methods, often combined with snowball sampling. This choice was made because each of the cases is dealing with specific topics, where the number of potential respondents was small. This is generally described as sufficient reason to opt for a purposeful sampling method (Palinkas et al., 2015; Patton, 2002). Expanding on this, I followed intensity sampling in chapters 6, 7 and 8, where I specifically sought out participants who were advanced in using the specific technology (Patton, 2002). These participants were more than average involved in the use of the specific technologies I studied. For chapter 4 and 5 I did not opt for a specific sampling strategy. For chapter 4 the number of potential participants was small enough to involve all of them in the research, as few technology developers were working on ammonia emission reducing technologies. For chapter 5, the case was most akin to a homogeneity sample, specifically involving researchers who were willing to attempt participatory theory building (Palinkas et al., 2015)

Table 1: Overview of methods used in the case studies

Chapter	Methods	Sampling technique	Data/Sample size	Respondents	Study location
8	Semi-structured interviews	Purposive (intensity) sampling	12 interviews	People working at paying agencies or for companies and	European member states
7	Semi-structured interviews	Purposive (intensity) sampling	26 Interviews	Farmers (Crop, arable) farmer-contractors,	The Netherlands
6	Semi-structured interviews in a comparative case	Purposive (intensity) sampling	118 interviews (59 AUS, 33	Farmers (Crop, arable, rice) farmer-contractors,	The Netherlands, Australia, France
5	Semi-structured interviews & Focus groups	Purposive (homogeneity) sampling	17 interviews	Researchers working with living labs in the H2020 DESIRA project	European member states (NL, LV, IT, ES, FR, SCT, BE)
4	Semi-structured interviews & Focus groups	Purposive sampling	15 interviews, 2 focus groups with 21	Technology developers, agricultural unions, researchers. advisors	Flanders

In the selection of participants, interviews were carried out until data saturation was reached. Once I experienced data saturation (in that concepts and topics started being repeated), several more interviews were held until any new topics and themes were sufficiently discussed with a number of participants, reaching full data saturation (Guest et al., 2020).

3.5 Data analysis

For the data analysis I did not focus on achieving objective accounts through this research. Instead, I emphasize positionality, reflexivity and transparency that highlights how I interpreted the data (Madill et al., 2000; Ryan, 2009). Results are not meant to be generalisable across agriculture, but rather highlight transferability (Merriam, 2009). I have not set out, nor have I produced, universal and generalizable knowledge that holds true across agriculture, but have rather produced empirical accounts that indicate certain developments. These accounts can help provide an understanding of similar developments in different contexts and cases (Merriam, 2009).

This position has also informed my analysis. Data was analysed by making transcripts of focus groups and interviews. These transcripts were coded with a lean coding method to provide a categorisation of the data (Creswell, 2007). The analysis of the data happened through a constant reflection on the data, aided through coding, which helps organise the data and presents it (Ryan, 2006). The analysis itself is an interplay between reflecting on the data, linking this data to existing research and broader theories, and re-coding of the data to reflect my changing understanding of what the data means until this forms a coherent narrative that links data, theory and previous research (Ryan, 2006). Theory was never the starting point of an analysis, but theory and data came together through a process of interpretation (Madill et al., 2000). In this, I accept that the different empirical case studies are interpretations of the truth, a realization that links up with the understanding that there is no objective truth that can be reached through research.

CHAPTER 4. CONSTRUCTING LEGITIMACY FOR TECHNOLOGIES DEVELOPED IN RESPONSE TO ENVIRONMENTAL REGULATION - THE CASE OF AMMONIA EMISSION-REDUCING TECHNOLOGY FOR THE FLEMISH INTENSIVE LIVESTOCK INDUSTRY

This chapter is based on:

Van Der Velden, D., Dessein, J., Klerkx, L., & Debruyne, L. (2023). Constructing legitimacy for technologies developed in response to environmental regulation: The case of ammonia emission-reducing technology for the Flemish intensive livestock industry. Agriculture and Human Values, 40(2), 649–665. https://doi.org/10.1007/s10460-022-10377-4

Author contribution statement: Daniel van der Velden: conceptualisation; methodology; investigation; writing—original draft preparation; writing—review and editing. Joost Dessein: writing—review and editing. Laurens Klerkx: writing—review and editing. Lies Debruyne: conceptualisation; writing—review and editing.

Link with the broader work and the following chapters

We begin our empirical chapters with an account of how technologies become (de-)legitimised. We understand this process of legitimation through knowledge claims made by technology developers, linking the knowledge that technology developers have to agency over the legitimation processes. Two elements are particularly relevant here. First, there is the finding that legitimacy of ammonia emission-reducing technologies is strongly connected to the amount of emissions that these technologies are said to reduce, which in turn depends on scientific knowledge on reduction percentages. This connects to the inherently uncertain scientific knowledge on emissions, which provides openings for technology developers to question the legitimacy of this knowledge. Technology developers are however so far unable to claim legitimacy for their own knowledge, and consequently for the technologies they develop. We conclude this with a call for agonistic pluralism, to open the debate on knowledge on emissions.

4.1 Introduction

It is commonly known that agriculture, and especially intensive livestock farming, causes a number of environmental harms. These harms include emissions to the air (of ammonia, odour, greenhouse gasses, and particulate matter), as well as the contamination of watersheds with nitrogen, phosphorus, organic matter, and faecal microbes (Melse et al., 2009; Tullo et al., 2019). Agri-environmental policies have been drafted in response to these environmental harms. In Europe, international protocols, and directives alongside national (and regional) regulation are employed in order to meet environmental targets (Cullen et al., 2021; Melse et al., 2009). These policies range from voluntary agri-environmental schemes to mandatory practices that farmers need to comply with. Similar variety exists in how policies address environmental impact, whether through environmental permits, by seeking to change farmer behaviour and farm practices, or by ensuring compliance to minimal environmental standards (Burton & Schwarz, 2013; Cullen et al., 2021).

Novel technologies that address and reduce agri-environmental impacts often play a key role in agri-environmental policies. As other authors have pointed out, these technologies generally address agri-environmental impacts without fundamentally altering the agricultural system (Barnes, 2016; Firbank, 2020). For this reason, several authors have taken to calling these technologies techno-fixes (Mooney, 2018; Wojtynia et al., 2021). Governments have a key role in directing the development of these technologies, by setting out the problem-solution space in agri-environmental regulation (Borrás & Edler, 2020; Conti et al., 2021; Wojtynia et al., 2021). Other authors have shown that existing socio-technical configurations lend legitimacy to such technological solutions (or techno-fixes) for environmental problems (Montenegro de Wit & Iles, 2016; Vanloqueren & Baret, 2009).

A major element in legitimising these technological solutions is what (and whose) knowledge is considered legitimate (Montenegro de Wit & Iles, 2016). The direction of knowledge production, and the knowledge claims that become accepted, lend legitimacy to certain technologies over others (Vanloqueren & Baret, 2009; Wesselink et al., 2013). As a concept, legitimacy can be understood as the fit of entities (in this case technologies) with existing institutional environments, with existing technologies, regulations, cultures, and knowledges (Binz et al., 2016; Bork et al., 2015; Dehler-Holland et al., 2022; Geels & Verhees, 2011; Markard et al., 2016). In technology studies, legitimacy has generally been used to explore how novel technologies become part of existing institutional environments. However, as other have pointed out, it is equally important to understand how existing socio-technical regimes remain legitimate (Frank & Schanz, 2022; Geels, 2014). As de Boon et al. (2022) highlight, legitimacy is key in transitioning to sustainable agri-food systems. Unsustainable agri-food systems legitimate technologies that solve agri-environmental impacts, where the connection of these technologies to the socio-technical regime makes it easier to construct technology legitimacy (Mooney, 2018). At the same time, these technologies lend legitimacy to unsustainable agri-food systems (Mooney, 2018; Wolf & Wood, 1997).

In our research, we use these two concepts (legitimacy and knowledge) to understand how technologies become seen as the main solution to agri-environmental issues. In order to study this, we focus on technologies that are developed to reduce ammonia emissions from livestock farms in Flanders (Belgium). These technologies are part of current agri-environmental regulation and are used in order to reduce the emissions of ammonia to the environment. We study the legitimation process of emission-reducing technologies through semi-structured interviews and workshops with technology developers and other stakeholders in the intensive livestock farming industry.

The focus of this research is how regime actors in the intensive livestock industry seek to construct legitimacy for technologies that reduce agri-environmental impacts. This provides a deeper understanding on the stability of existing regimes and opens up opportunities for disruption of the existing regime. In this, we do however not focus on macro-political forces that keep the regime intact, but on the interactions between actors within the socio-technical regime, and how they employ knowledge claims, construct legitimacy and through this seek to make their technologies the legitimate solution to agri-environmental impacts.

This leads us to a two-fold research question: *How is the legitimacy of technologies, developed in response to agri-environmental regulation, perceived and constructed in the Flemish livestock farming sector, and how are knowledge claims involved in the construction of this legitimacy?*

This research question allows us to explore both how the legitimacy of these technologies is perceived by other actors and how technology developers construct this legitimacy. We explore this research question throughout our paper, where we first set out the theory behind technology legitimacy and connect this to debates around knowledge and knowledge claims. Following this we set out the case and the methods used to study this topic, which is focused on technology developers who develop ammonia emission-reducing technologies. We use the findings to describe and analyse the case, followed by a discussion and conclusion.

4.2 Theoretical framework

To develop the theoretical framework we use legitimacy studies and connect this to the literature on knowledge conflicts and knowledge claims. To recall, we aim to improve the understanding of how technology developers use knowledge claims to construct legitimacy for their technologies. We first engage with the concept of legitimacy, which describes how entities become considered legitimate, something that is essential to the success of an innovation (Bork et al., 2015; Geels & Verhees, 2011). In the latter part of this framework we set out the literature on knowledge claims and how this is tied to constructions of technology legitimacy.

4.2.1 Technology legitimacy

Legitimacy as a concept fits within an institutional lens on innovations and technologies. Innovations start out lacking legitimacy, where technology developers have to make these innovations seem legitimate to other actors. In the introduction we already made mention of the socio-technical regime, and connected legitimacy to this concept. In exploring legitimacy, we do tie legitimacy to this broader institutional lens and concept, where legitimacy is understood in relation to existing (power) structures that can lend technology legitimacy. In this, we lend the concept of the socio-technical regime from Geels (2014) to indicate the socio-material nature of these power structures, but do not further engage with the broader theories around regime transitions of Geels.

The socio-technical regime in this case should then be understood as the network of actors that make up existing socio-technical configurations (Geels, 2014). This can for example be the existing energy network, dominated by fossil fuel companies and existing configurations of actors, but can also be the agricultural system where certain (productivist) types of farming fit better in the existing network of actors. Legitimacy can be conceptualised as the fit of an entity within these larger institutional frames and systems, or as Suchman

(1995, p. 574) defines it: “a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions.”

This means that technologies need an integration with existing institutions and a broader societal embedding for them to become considered legitimate (Geels & Verhees, 2011). This can be made concrete by separating legitimacy into different pillars of technology legitimacy (Binz et al., 2016; Suchman, 1995). Which pillars are identified, or used to define legitimacy, differs per author. Generally, these tend to coalesce around pragmatic, regulative, normative (or moral), and cultural-cognitive legitimacy, based on the definitions of legitimacy by W. Scott (1995) and Suchman (1995). We define the pillars in table 2, displaying the aspects of legitimacy within these pillars. Important to note is that few authors apply all pillars of legitimacy and that understandings of the different pillars of legitimacy diverge between different authors. Following this, in our article we will focus on regulative, normative, and cognitive legitimacy.

Table 2: Aspects of legitimacy (based on *W. Scott (1995) and Suchman (1995))*

	Cultural-Cognitive legitimacy	**Normative legitimacy**	**Regulatory legitimacy**
Specific to our study	It is clear which technologies reduce emissions and what reductions these technologies can achieve	Emission-reducing technologies fit with existing norms and values, both in society and among farmers	The technology fits (or is made to fit) with existing agri-environmental regulation and policies
Essential element	The technology operates according to expectations people have of the technology	The technology fits with existing norms and values in society	The technology functions in accordance with government standards and regulations
Motivation	Taken-for-granted understanding of technology	Moral obligations in a given place and culture	Existing rules and laws

Previous studies on legitimacy have focused on processes of legitimation and de-legitimation, especially considering the sustainable transformation of the energy sector, although several recent articles have also addressed legitimacy in agricultural transitions (de Boon et al., 2022). This provides ties to a more politicised view on legitimacy, where incumbent actors seek to preserve the legitimacy of the existing socio-technical regime while new entrants and new industries are seeking to disrupt the regime and build legitimacy for themselves (Geels, 2014; Haas, 2020; Novalia et al., 2021). This is an antagonistic view on legitimacy, where legitimacy is gained at the expense of other actors. Through this lens, the struggle for legitimacy is often also a struggle between incumbent actors and new entrants (e.g. developers of new technologies). This fits with a process-relational view of legitimacy, where we understand legitimacy as constructed by a network of actors. This sees legitimacy as being in flux, in a constant process of legitimation and de-legitimation (Binz et al., 2016; Geels & Verhees, 2011; Suddaby et al., 2017). Legitimacy is not a static property but is rather formed as an element of an active and continuous process, where actors can take from a number of strategies in order to increase or reduce the legitimacy of certain technologies (Geels & Verhees, 2011; Jansma et al., 2020; Suchman, 1995).

Multiple authors have identified various strategies that actors can take in gaining legitimacy. For our analysis, we classify these strategies into three overarching categories, which are 1) conforming to institutions, 2) selecting among environments for the most favourable one, and 3) manipulating or lobbying institutions. This understanding follows common categorisations of legitimation strategies (Van Oers et al., 2018). All three strategies connect to a systemic view of technology acceptance, where legitimacy is constructed within larger socio-technical configurations (Binz et al., 2016; Markard et al., 2016). Practically, technology developers can conform to institutions by making their technology fit with the three aspects of legitimacy that we described in table 2. They also have the option to find a specific environment where their innovation is considered legitimate, or otherwise try to change existing institutions. In changing institutions, technology developers can lobby for changes to regulation, reframe their technologies or seek to change the perception of their innovations. We summarize these strategies in table 3, where we also provide some examples of agricultural technologies in terms of the three strategies of legitimation.

Table 3: Strategies of legitimation

Strategies for legitimation	**Examples in agriculture**
Conform to institutions	Early-stage biogas plants that fit with farm infrastructures, farming procedures and environmental regulation (Markard et al., 2016)
Select among institutions	Selecting favourable markets or geographic locations (i.e. close to cities for farms that sell directly to consumers) (Van Oers et al., 2018)
Manipulate or lobby institutions	Lobbying governments to change regulation on insect feed (Marberg et al., 2017) or GMO crops (Jansma et al., 2020). Change the public perception of GMO crops (normative & cognitive legitimacy) (Jansma et al., 2020)

This informs the first set of specific empirical questions in our research, focused on perceptions and constructions of legitimacy. These questions are:

How are normative, cognitive and regulative legitimacy of technologies developed to reduce ammonia emissions perceived by stakeholders in the intensive livestock industry in Flanders?

What strategies do technology developers employ to construct normative, cognitive and regulative legitimacy for technologies developed to reduce ammonia emissions?

In manipulating and lobbying institutions, knowledge is key, as knowledge can be mobilised to strengthen claims about a specific technology or be used in a broader discourse that legitimises the technology. This can be read throughout many of the articles on legitimacy, although relatively few authors make this explicit. Particularly relevant are accounts of how knowledge production and the direction of research can lend legitimacy to some technologies over others (Cashore, 2002; Jain & Ahlstrom, 2021; Montenegro de Wit & Iles, 2016). In understanding this central role of knowledge in legitimacy processes, we move to the literature on knowledge and knowledge claims.

4.2.2 Knowledge claims for legitimacy

Knowledge conflict and the use of knowledge claims are a vital aspect in the construction of legitimacy (Jain & Ahlstrom, 2021). Knowledge claims refer to the use of reports and studies in order to prove a new technology to the public and to institutional actors, where different actors set claims over the right kind of epistemology and make claims over what data should be valid in proving the technology (Bergek et al., 2008; Binz et al., 2016; Jain & Ahlstrom, 2021). This connects to the literature on how knowledge is used in governance (Buuren, 2009; Lee, 2012; Leino & Peltomaa, 2012). This is particularly relevant for agri-environmental governance, where uncertainties exist around agri-environmental impacts and where scientific knowledge cannot provide all the answers (Bruce, 2013; Thorsøe et al., 2017).

Knowledge claims can be used to both construct and to weaken the legitimacy of technologies (Bergek et al., 2008; Geels & Verhees, 2011). This can be recognised when reports are constructed that discuss the potential performance of new technologies, based on expert and scientific knowledge, as Bergek et al. (2008) show. Scientific forms of knowledge, used to develop these reports, already have a certain legitimacy that can be employed in the legitimation of technologies (Bergek et al., 2008; Kraft & Wolf, 2018). Equally, competing knowledge claims can be developed because different actors, including the private industry, societal groups and various experts, can produce and legitimise knowledge claims in order to influence other actors and policy processes (Bergek et al., 2008;

Edelenbos, 2004). This is a political process, where different actors use knowledge claims to further their interests. These competing claims can be at the level of debating the performance of a new technology, but can also be at a larger scale, as is shown by the use of knowledge on climate change in order to disrupt the fossil-fuel based industry (Ruebottom, 2013).

In response to these developments and conflicts over knowledge, authors have generally called for co-production of knowledge, where actors develop knowledge together (Edelenbos et al., 2011; Schut et al., 2014). Equally, in response to conflicts over what knowledge should be used, authors have called for joint fact-finding and collaborative policy processes (Edelenbos, 2004). These inclusive and multi-actor processes seek to solve conflicts over knowledge by involving local actors, private industries and societal organisations alongside scientists and policymakers in order to build consensus on how knowledge should be used (Schut et al., 2014).

In turn, these co-productive approaches have been critiqued for not being able to deal with existing power imbalances (Aarts & Leeuwis, 2010; Purcell, 2009; D. Scott, 2021). The main critique is that these approaches provide a way for powerful actors to provide a veneer of legitimacy for their decisions. The co-productive approach is employed to provide legitimacy by having different actors involved, but the status quo is maintained as powerful actors dominate the co-productive process (Purcell, 2009; D. Scott, 2021). Approaches that contest power relations and hegemonies have been proposed in response (Mouffe, 2007; D. Scott, 2021). These approaches might also offer a way to disrupt the socio-technical regime by disrupting current institutional structures and by contesting the ideas that help maintain these institutions (Frank & Schanz, 2022; Geels & Verhees, 2011).

This informs our second set of empirical research questions, focused on knowledge conflict and knowledge claims:

What knowledge claims are used in constructing legitimacy for ammonia-emission reducing technologies?

How are knowledge claims used to construct legitimacy for ammonia-emission reducing technologies?

What is the link between knowledge claims used to construct legitimacy and the current socio-technical regime of intensive livestock farming?

We will study this social construction of legitimacy using a qualitative case study, involving stakeholders connected to the intensive livestock farming industry and technology developers who develop ammonia-emission reducing technologies. We set out how we developed and analysed this case study in the methods section below.

4.3 Methods

To address the research question, we study technologies that are developed for the intensive livestock farming industry in Flanders, specifically for pig and dairy farms. The focus of this case study are the technologies that are developed to reduce ammonia emissions, one of the environmental harms produced by intensive livestock farming. In this section, we illustrate the case and then describe the methods used to analyse the case.

4.3.1 Case study background

Similar to other places, livestock farms in Flanders (the northern part of Belgium) are increasing in scale while decreasing in number (Departement Landbouw & Visserij, 2019a, 2019b). In general, livestock farming in Flanders follows an intensive model, where livestock populations are disconnected from available land, creating a dependency on imported feed and the export of manure. The typical livestock farm in Flanders is specialised, raising a single type of livestock. The average number of livestock per farm remains relatively low (at around 1500 pigs or 59 dairy cows respectively) (Departement Landbouw & Visserij, 2019a, 2019b). A second characteristic that typifies the Flemish livestock industry is the proximity of farms to natural areas and nature reserves, as well as to (sub-) urban populations. This is particularly striking in Flanders because of high spatial fragmentation combined with high population densities (497 inh./km^2) (*Bevolkingsdichtheid | Statbel*, 2023). This brings intensive livestock farming in conflict with other societal actors and necessitates interventions to reduce environmental impacts (of odour, particulate matter, and ammonia).

Flanders, as a region in Belgium, has legislative powers over agriculture and sets its agricultural policies following European regulation. Ammonia emissions are one of the driving elements in regulation for livestock farming in Flanders and are addressed through successive EU protocols and directives (Melse et al., 2009; Tullo et al., 2019).

Technologies are seen as the main solution in order to reduce emissions in both international and Flemish policies. This can be recognised in lists that set out government-approved technologies for reducing emissions (Jacobsen et al., 2019; Kros et al., 2013; Van der Heyden et al., 2015). Two lists in Flanders set out the technologies that are approved for reducing ammonia emissions. The first list, the AEA-list (freely translated to: list of ammonia-emission-poor barn systems) was developed in 2004 and slowly expanded over the years with several additional technologies. This list sets out a range of technologies that apply to pig and poultry farming. Later, a second list, the PAS-list (programmatic-approach-nitrogen) was developed that applies to all livestock animals and contains a wider range of interventions that farmers can use to reduce ammonia emissions. These lists set out which technologies farmers can use to reduce emissions, the level of emission reduction that these technologies can achieve, and lastly, how these technologies should be used by farmers.

The lists are tied to the environmental permits of intensive livestock farms. When permits are renewed, farmers are generally obliged to install a technology from the government-approved lists. The government develops the lists in consultation with a committee of selected scientists. The role of scientists is to determine whether a technology reduces emissions and the reduction percentage that can be achieved. Technologies that have a place on either of the two lists are developed by a range of companies and have diverse mechanisms for reducing emissions of ammonia on livestock farms. This starts with feed technologies that improve nutrient uptake and that reduce the amount of ammonia that can be formed in manure (Bruce, 2013; Melse et al., 2009). A second set of technologies are focused on preventing the formation of ammonia in manure. A third option is to prevent the emission of ammonia to the outside air, either by trapping manure gasses or by using air scrubbers to filter the outgoing air in the livestock shed (Van der Heyden et al., 2015).

Technology developers who develop these technologies are often specialized in the agricultural sector and work for small to medium-sized enterprises (SMEs). Feed technologies are an exception, where technology developers mainly work for larger multinational companies. Both groups of companies were included in this research, alongside other stakeholders (researchers, agricultural unions, permit-bureaus, and government advisors). To develop the case and to study the research question we (author DV) opted for a qualitative case study following the methods described below.

4.3.2 Data collection and analysis

The fieldwork for this study took place during 2021. As an entry point to the case, we primarily focused on technology developers, as the process of technology development was of particular interest to us. To study our case, we used a purposive sampling strategy combined with snowball sampling to select respondents for this research. We (author DV) opted for this approach because there are a limited number of technology developers active in the field of ammonia emissions in Flanders and several key respondents were already known to the researcher. Technology developers (or more precisely the companies they worked for) were selected by going through the lists of technologies present on the AEA-list and the PAS-list mentioned in 4.3.1 and contacting the companies that developed these technologies. Additionally, searches on the internet and existing contacts were used to find companies that also developed technologies with the potential to reduce ammonia emissions.

As a group, technology developers were male, ages between 30 and 60, working for both SMEs and multinational companies. The respondents were selected by the companies developing these technologies, leading to interviews with engineers developing these technologies, owners of SMEs, and managers of innovation processes at feed companies. Companies involved in the research were 1) barn construction companies (SMEs) that develop floor systems to reduce emissions, 2) companies that develop air scrubbers (SMEs) and 3) feed companies (multinationals) developing low-protein feeds and feed additives.

Additionally, a diverse group of stakeholders were interviewed on how they perceived the legitimacy of emission-reducing technologies. This group of stakeholders was balanced in gender, roughly varying in age from 25 to 50 and consisted of researchers, agricultural unions, permit bureaus, and advisors. All participants of this research have ties to the intensive livestock sector in Flanders. Technology developers and stakeholders generally know of each other through existing organisations and collaborations. These relations vary, and are generally one-on-one, where some technology developers work together on the development of a new technology or where a technology developer has contacts with researchers or advisors.

Participants of our research were interviewed using semi-structured interview guides (provided in appendix 1). We used specific interview guides for the technology developers (asking about the development of the technology) and for the other stakeholders (asking about their views on emissions, the technologies and technology development). Interviews lasted 30 to 90 minutes. Additionally, we held two workshops with a broader, diverse group of stakeholders. These workshops were part of a larger research project about the future of agriculture and ammonia emissions. The structure of these workshops is presented in appendix 2. The workshops were focused on the role of technology in ammonia emission reduction and allowed the participants to interact and discuss both the role of technology, the development of these technologies and how they saw the future of technologies in ammonia emission reduction.

In total 15 people were interviewed, and 21 stakeholders were involved in the workshops (for 36 total participants). After 6 interviews the first workshop was held, followed by 9 more interviews before the final workshop that concluded the fieldwork in October 2021. Most of the respondents that were interviewed also took part in the workshops. An overview of the respondents is provided in table 4 that we provide below. Audio recordings from the workshops and the interviews were transcribed using a clean verbatim style in NVIVO 12. Transcription and data analysis was done in the native language (Dutch). Quotes used in the article are translated from Dutch by the first author.

Table 4: Overview of participants

Type of data gathering	Semi-structured interviews	Workshops
Number of participants	15 interviews 8 technology developers (5 SMEs, 3 Multinational) 2 respondents from agricultural unions 2 researchers 1 respondent from a research farm 1 innovation advisor 1 policy advisor	21 stakeholders 8 researchers, studying ammonia emissions 5 advisors on agri-environmental permits 5 respondents from research farms 1 respondent from an agricultural union 1 technology developer 1 farmer

In data analysis our goal was to strive for consistency between the data and the results, rather than working towards a single objectivist account (Creswell, 2007). Our position is that knowledge is socially constructed, that multiple interpretations are possible and that interpretations are always temporal, located and open to re-interpretation (Creswell, 2007; Merriam, 2009). The goal of our analysis is to provide an account that is consistent between data and the results, where different methods can be used in order to show the validity of these results. In our research we sought to provide this validity both through a thick description of the data and by data triangulation (by involving both a diversity of stakeholders alongside the technology developers and by using workshops so respondents could interact and react to each other's statements) (Creswell, 2007)

The interpretation of the data followed principles outlined by Creswell (2007) and Merriam (2009), starting with a broad categorisation of the data, and working towards a more fine-grained analysis. We started analysis during data collection by broadly categorising the incoming data using inductive coding (Skjott Linneberg & Korsgaard, 2019). Following Creswell (2007, p. 152) we linked these codes to text segments, focused on 'lean coding' to end up with a limited first set of codes (25 codes in this case) which were aggregated in 4 broader categories, as shown in appendix 3. After discussing key themes that emerged through this categorisation, the decision was made to approach the data with a technology legitimacy lens, linked to issues around knowledge and knowledge claims, as presented in the theoretical framework. Based on this framework, a new set of codes was developed for deductive coding. This set of codes is also provided in appendix 3, including references to where codes originated in the literature. We used this categorisation in order to describe and interpret the case. Combining the inductive and deductive steps of coding allowed us to remain open to the reality of our respondents while still connecting this to existing theory and academic debates.

4.4 Findings

We structure our findings in three parts. In the first section we discuss how emission-reducing technologies are perceived (both by the stakeholders involved in this research and in wider society). In the second part of the results we discuss how regulative legitimacy is the main focus for technology developers and how this affects technology development. Lastly, we discuss how technology developers seek to construct regulative legitimacy through knowledge claims.

4.4.1 Perceptions of legitimacy

As we showed in the theoretical framework, there are several types of legitimacy: normative, cognitive and regulative legitimacy. We show how stakeholders perceive the emission-reducing technologies through these three types of legitimacy, starting with normative legitimacy and then discussing cognitive and regulative legitimacy in turn. At the end of the section, we use table 5 to summarise our findings.

One finding on perceived legitimacy is that the group of stakeholders were themselves generally supportive of the intensive livestock industry. Stakeholders emphasised in both the workshops and the interviews that technologies were essential to ammonia emission reduction. Technical innovations were seen as the main answer to ammonia emissions, as the quote below also shows. Two advisors discuss (AD1 & AD2):

"AD1: Well, we need better policy, but we also should have research that helps us towards new innovations and insights [in emissions].

AD2: Hm, for new technologies

AD1: Yes, that is what we do hope for."

This is linked to the view that if technology is not sufficient, the only other option is to reduce the number of animals in intensive livestock farming, completely changing the current system of livestock farming.

During the second workshop, several of the respondents (two advisors (AD1, AD2), a researcher (R1) and a farmer F1) discussed this. This was after they were asked to sketch out a negative scenario for ammonia emission reduction:

"AD1: The most negative scenario is that a reduction of livestock is the only way to reduce emissions. […] That technology is insufficient.

R1: Or if it is unaffordable

AD2: Or not suitable to farmers

F1: If it is not economical, if your energy bill increases

AD1: Yes, that it's cheaper to reduce animals rather than to invest in technologies [to reduce emissions]"

These two discussions show the view on emission-reducing technologies by stakeholders. They see it as the only real solution to ammonia emissions. Within this group, of stakeholders connected to intensive livestock farming, these technologies are seen as the legitimate (and only) solution to ammonia emission reductions. There concerns live among stakeholders and technology developers. They feel threatened by recent developments, both in broader society and in government, where they feel that the view on intensive livestock farming and emission-reducing technologies has shifted. The legitimacy is under threat from outside, as an advisor explains during the second workshop:

"Well, you can have a technological innovation for farms that makes them even more industrial. But that might still not make those farms justified. Well, maybe that's not the right word, but if they are not accepted [in society], then you also have a problem, right?"

Related to this topic, at the first workshop a discussion took place between a technology developer (TD) and an advisor (AD) where they highlight the difficulties in addressing societal concerns on livestock farming:

"TD: I also want to return to animal welfare. And I ask you how that impacts ammonia emissions? […]

AD: Well, there is no clear answer to that, is there?

TD: Well for sure it will get worse [i.e. more emissions]. We have measurements showing it.

AD: Well, that is the difficulty, right? Similar to organic farming and emissions. The more space and animal welfare you give, the worse your [ammonia] emissions become. But you have to find the middle ground somehow."

These developments are seen as a threat to the legitimacy of emission-reducing technologies. It is a broader process of delegitimation of intensive livestock farming and emission-reducing technologies. Normative legitimacy is under threat, as these technologies are tied to intensive livestock farming industries that have come under scrutiny. Equally, the trade-offs between forms of sustainability are a risk and make it difficult to keep the technologies seen as legitimate. This is recognized by the technology developers, as one of them describes below in relation to air scrubbers (a technology he himself did not develop):

"Well, I note that those things use a lot of water, a lot of energy, and electricity. And well, with water, we have had three years of dry summers. Water should be used for drinking and not for an air scrubber. That is not a sustainable solution. You don't improve animal welfare, don't improve the conditions in the shed, it's only good for some forest and the neighbours but other than that nobody has a use for it. [for the emission reduction, and the air scrubbers]"

The quote above touches on normative legitimacy, but with ties to cognitive legitimacy. Normative, as the respondents seek to articulate what should be a good and sustainable technology. Cognitive, as this is an argument over what emission-reducing technologies are, and what they do, especially when it concerns the impact on forests and neighbours (who would stand to benefit from reduced emissions). These contestations show doubt over what the technology is and does, linking perceptions of cognitive and normative legitimacy.

Summarising the perceptions on legitimacy, respondents in this research are worried that emission-reducing technologies are becoming delegitimised. There are threats to legitimacy, even though they themselves see these technologies as the main solution. Despite these threats, technology developers did not see these developments as a key issue but were more concerned with regulative legitimacy. The reason for this concern was given by a respondent working at a research farm, who described the reality of how these technologies are adopted on farms:

"A farmer wants to farm, and the whole thing about emissions is a necessary evil, so to speak. So they do it because they have to, and because they need it for a permit. But well, I would not say that they care whether it works or not, as long as the government accepts it."

The response from technology developers is relatively straightforward. As long as ammonia emissions are an issue, and as long as intensive livestock farming exists, their technologies are the solution for governments seeking to reduce emissions. Adoption of the technology is a pragmatic choice of farmers, as they adopt these technologies not because they are seen as normatively or cognitively legitimate, but rather because it is the only way to gain an environmental permit from the government. Such 'forced technology use' is intimately linked to regulative legitimacy, as environmental permits and government regulation necessitate the use of these technologies. Regulatory frameworks become the main driver for technology developers in constructing legitimacy for their technologies, something we further explore in the next section. An overview of the findings on how legitimacy is perceived is also provided in table 5.

Table 5: Discussions on the legitimacy of emission-reducing technologies

Form of legitimacy	As shown in the results
Cognitive	Centres on the uncertainty around emissions. Due to the variability of emissions it is difficult to provide an exact number for the emission reduction that a technology can achieve.
Normative	Perceived risks in normative legitimacy because of societal perceptions of intensive agriculture, sustainable farming, and animal welfare. Technologies fit intensive farming practices and can increase resource use.
Regulative	A key issue because government approval and environmental permits are essential to technology adoption. Technology developers seek to claim government approval and focus on constructing this form of legitimacy.

4.4.2 Constructing regulative legitimacy

We start our discussion of regulative legitimacy with a short quote from an advisor, who describes what is needed in order to sell an innovation for emission reduction:

“Here in Flanders, if you want to implement something or sell something [to reduce ammonia emissions], well you will need to get it on the PAS-list. And then you have to show reports of measurements and a whole number of things to prove it”

Government approval (and the connected regulative legitimacy) is essential. Our data shows that technology developers can take from two approaches in the construction of regulative legitimacy, which we have illustrated in figure 1 below. A first, seemingly simple option, which we will describe here, is to conform to regulation and to get a technology on the list of approved technologies. This has happened in the past but is no longer possible for reasons we outline below. A second option, which we will discuss in the last part of the results, is a manipulating, or lobbying strategy where the role of knowledge claims becomes important. We first discuss the conforming strategy.

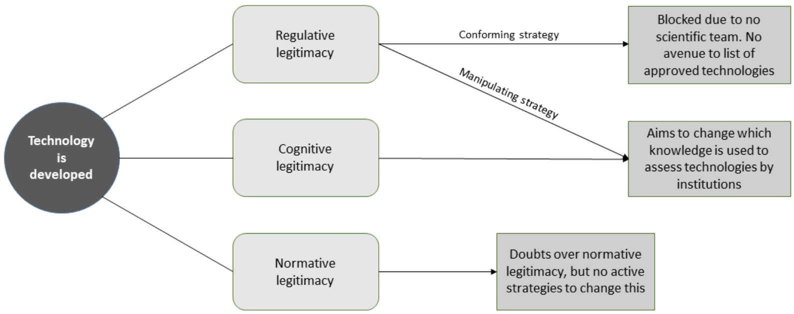

Figure 1: Strategies used by developers to construct legitimacy for their technologies

Most technology developers interviewed for this research had technologies on the government-approved list and had thus at some point used a conforming strategy in order to construct regulative legitimacy. One technology developer describes how this process worked:

"Yes, we were worried that we had to do a full report where we measured emissions for a full year, and we were worried because of the cost of it all. And what if you get a disappointing result [i.e. a low reduction of emissions]? But luckily, we could also get it approved with a model, based on literature and studies, with documentation from other partners that were involved in this project"

This quote highlights one of the paths (using a simulation model) for approval to the list. This approval process, as highlighted in figure 2, depends on a government team and a scientific team who determine how effective a new technology is in reducing emissions, and whether a technology is effective at all. The scientific team uses expert judgements based on existing knowledge and literature, as well as simulation models. If this is insufficient, they can also request additional measurements on the performance of a new technology.

Following this, the scientific team advises the administrative team on whether to approve the technologies, who in turn advise the minister of the environment to approve the technology to the list. However, as one technology developer will describe below, this approval process is no longer functional:

"Very recently I contacted them because I wanted to discuss the possibility of adding some new technologies to the list. But apparently, that is no longer possible because there is no scientific team anymore. […] So they [the government] ask us to develop new technologies, but at the same time it's not actually possible [to have them approved]."

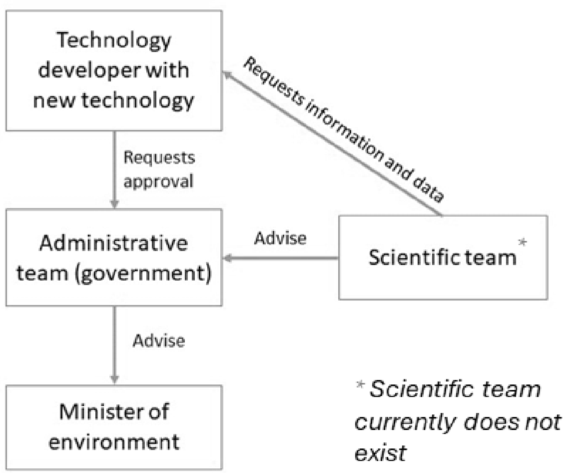

Figure 2: Schematic overview of the approval process of emission-reducing technologies (Vlaamse Landmaatschappij, 2021)

As technology developers indicate, the scientific team has been disbanded. This makes it impossible to follow a conforming strategy. A lack of information on the underlying reasons for disbanding the scientific team caused frustration among the technology developers as it makes the conforming strategy impossible. One developer indicates below:

"But nowadays that doesn't work. There is no scientific team, there is no… Well, as if you enter the court and there is no judge, that is the current situation. And that's been for two years, right? So… yeah. As long as there is no stability, as long as there is no workable framework? […] We first need that, and only then can we go back to innovating. But for now, you can't do anything."

As the quote above indicates, this has impacted the development of new technologies. Most technology developers were holding back on developing new technologies. They also changed their approach to constructing regulative legitimacy, where they changed from a conforming approach to a more combative manipulative (or lobbying) approach, as indicated by one technology developer when discussing what action he was taking now that the conforming strategy was no longer feasible:

"Well, I have nothing against them [against the scientists who used to be involved in approving technologies], but I will start to take action. […] I am also in contact with politicians"

The manipulating strategy for constructing regulative legitimacy contrasts with the conforming strategy. In the conforming strategy, there was an avenue for the knowledge of technology developers to be used in constructing regulative legitimacy, by developing a dossier and handing this over to the government. In a manipulating strategy, knowledge is used in a more confrontational way, and claims over knowledge structure the strategy. It is this strategy that forms the next part of this article: the knowledge claims of technology developers and how they mobilise these in constructing regulative legitimacy.

4.4.3 Knowledge claims in constructing legitimacy

We now turn to how technology developers seek to manipulate institutions to construct regulative legitimacy. We do this by analysing how knowledge claims are used in the construction of cognitive and regulative legitimacy. As we showed at the start of the results, there is tension about the cognitive legitimacy of emission-reducing technologies. This tension is connected to the construction of regulative legitimacy, where lists of technologies show the performance of each technology. As the quote below shows, technology developers dispute this listed performance and doubt the knowledge behind the formation of the government-approved list.

"And every technology is classified at 25% reduction. You must have noticed that in the list, for all those systems, all floor systems have the same classification of 25% reduction. And I have my doubts about that".

An essential element of the manipulating strategy is that scientific knowledge on ammonia emissions is somewhat uncertain. At the same time, the administrative and scientific team (see figure 2) use average and predetermined values for approving technologies for ammonia emission reduction. This creates a tension between understandings of the scientific knowledge. Researchers themselves do not always fully agree with how government departments use their knowledge in order to approve the technologies. This tension is best shown by a conversation between a policy advisor (A) and a researcher (R) at one of the workshops.

"A: Yes, that is the issue of scientific research, which has partially caused that for regulation we are now calculating it [ammonia emissions] to the letter.

R: No, that is an interpretation of scientific research, an interpretation of the data. We provide data with the caveat: "well, it's not accurate to the dot". But they do use it like that. That is frustrating."

This comment highlights broader issues around environmental knowledge and the use of this knowledge. Important to consider is the complexity of accurately measuring the performance of technologies that reduce livestock emissions, something that the researcher alludes to in the quote above. Emissions can show high variability between different farms, between different livestock sheds, and also between different breeds of livestock. Equally, emissions vary with the weather, with wind and temperature changes impacting emissions. This has been balanced with average values in the past, upon which government regulation is based. However, due to the variable nature of emissions, the accuracy of these average values and their use in approving technologies can be called into question by technology developers. This is especially relevant because the emission reduction that a technology can reach is essential to the construction of regulative legitimacy for new technologies. As one of the respondents from a feed company describes:

"Because of regulation you have to take measures that reduce emissions with 50%, and that is very difficult to reach with feed. And the effect is that as far I know, no pig farmers are seeking to reduce emissions through feed management. There are known techniques to do so, but nobody uses them. […] And to a large extent it all depends on regulation. If they tighten the regulation further, well then you have no choice but to reduce emissions through air scrubbers."

This shows the value of emission-reduction percentages that are assigned to technologies. A higher reduction percentage (as listed on the government-approved list) will mean that more farmers will use the technology. As a consequence of this, feed technologies were not being used to reduce emissions, as they provided a small reduction in emissions that provided no benefit to farmers (in receiving an environmental permit). Technology developers make knowledge claims about the performance of their emission-reducing technologies in order to construct this regulative legitimacy.

The arguments of technology developers are informed by their own knowledge. The knowledge production of technology developers generally involves experimental set-ups on farms, experiments at research farms and universities, as well as literature studies and the modelling of emissions. Elements of this knowledge production were also essential in the conforming strategy as described above, when technology developers had to collect this information to prove their technology to the scientific team (figure 2). One of the developers describes their knowledge by discussing an experiment they did together with a university:

"We also noticed when we worked together with [a university]. So we had three set-ups, two with our test and one as a control. […] And we

saw that we had 30 kilos of emissions from the control and the two tests had emissions of 6 and 11 [kilos]. Identical departments. So I asked the researchers, "how is that possible, they should be identical right?" And they said it was probably some other effects. So I told them, "Well that's fun for your research, right?" If you have an outside effect of factor two."

While describing how technology developers produce knowledge, this quote also shows some of the disillusionment of technology developers in scientific forms of knowledge production. This forms a basis for contesting the emission values as they are accepted by the government, as another innovator does in the following quote:

"And in emissions, so emissions in agriculture, especially in intensive livestock farming, there are no secrets for us. It is clear as day. We know perfectly well what leaves the barn and we know perfectly well how much a chick, a sow, or a cow, how much ammonia they produce. We know what it is like in practice. And based on those values […], we have had to deviate from the values as they are assumed by the government."

Disagreeing with the knowledge as it is accepted by the government, technology developers seek to contest the government's use of knowledge and wish to have their knowledge considered as well. What knowledge is used is essential both to understand the performance of their technology (cognitive legitimacy) but also for governments to approve technologies (regulative legitimacy). Technology developers are however so far unsuccessful in having their knowledge recognised by the government. In turn, technology developers seek to manipulate institutions, to change the procedures that are in place to approve technologies. Technology developers were focused on getting procedures in place that can take into account the variability of emissions, something that they have experienced in developing their technologies. This is illustrated by one of the technology developers who describes how he is seeking to change this:

"Because what I do not understand, and what I would like to ask those people, also the politicians, because I also concern myself with politicians: how can you say, 'we do not approve the current measuring

protocol' if you have no alternative? […] I find that much less scientific than approving a technology based on measurements, even if you can debate the findings, but it's the best we have".

This formed the main push of this lobby, where technology developers had approached politicians and scientists to convince them of changing the procedures for approving technologies. This lobby has not been successful so far. It remains to be seen whether technology developers will be successful in convincing the government to include their knowledge alongside the scientific knowledge in making decisions and in approving technologies. Recent news articles also indicate that several technology developers are now seeking publicity for their need to have new government procedures in place (Vilt VZW, 2022a, 2022b).

Discussions about what knowledge is legitimate, and which forms of knowledge production should be considered by the government remain important. In constructing technology legitimacy, there is a claim for knowledge legitimacy. The knowledge of technology developers is currently not seen as legitimate and as it turns out this creates difficulties in constructing regulative legitimacy. In response, they seek avenues for constructing regulative legitimacy by contesting the legitimacy of the 'official' knowledge and comparing it to their forms of knowledge. This leads to technology developers lobbying for procedures that consider their knowledge.

4.5 Discussion

We return to the twofold research question posed at the end of the introduction: *How is the legitimacy of technologies, developed in response to agri-environmental regulation, perceived and constructed in the Flemish livestock farming sector, and how are knowledge claims involved in the construction of this legitimacy?*

We studied this by taking the position of the technology developers themselves, but further studies could aim to bring in government actors and scientists as well.

Throughout this discussion, we will highlight the struggle for technology legitimacy, and how this links to a broader struggle on the legitimacy of intensive livestock farming. We also highlight the struggle for technology legitimacy as a potential space to disrupt path dependencies and to work towards novel co-productive approaches in technology development.

4.5.1 Perceptions of legitimacy

An interesting aspect of the legitimacy of emission-reducing technologies stems from the fact that technology developers and stakeholders were both connected (in some way) to intensive livestock farming. Respondents viewed technologies as the main solution to ammonia emission reduction. This can be linked to broader understandings of legitimacy, where the legitimacy of a technology ensures that it becomes seen as the only solution (Genus et al., 2021).

This is however only an element in a broader process. Respondents acknowledged a relative lack of normative and cognitive forms of legitimacy in broader society. Emission-reducing technologies are tied to the intensification of livestock farming at a time when livestock farming itself is suffering from a legitimacy crisis (Caffyn, 2021; van Wessel, 2018). Respondents recognise a delegitimation of the technology in connection to this, as society and governments are putting pressure on the status quo of livestock farming. This further highlights how technology and the broader socio-technical regime are intertwined, where a delegitimation of the regime is putting pressure on the legitimacy of the technology (Markard et al., 2016). It also adds some nuance to how technologies tied to the dominant socio-technical regime become legitimate, as the processes in our research shows the continuous struggle to construct and preserve this legitimacy.

While this delegitimation is a concern to technology developers, they did not describe strategies to improve normative legitimacy, and they focused on cognitive legitimacy only to gain regulative legitimacy. As we described, the Flemish government, through regulation, sets limits to the expansion of livestock farms but does allow farmers to expand their farms when they adopt these emission-reducing technologies. This creates an environment where technology developers seek to construct technology legitimacy towards regulators rather than to broader society and to farmers, as farmers only adopt these technologies because they ‘have to’ (Klerkx et al., 2006; Leeuwis, 2003). As we described, adoption is driven by the achieved reduction of emissions rather than by other parameters. The government and scientific teams determine this reduction.

Technology developers thus seek to claim this legitimacy from the government, where they employ two main strategies. These are a conforming strategy, where technology developers conform to existing institutions, and a manipulating strategy, recognised through the knowledge claims made by technology developers. These strategies can be recognised in other legitimacy studies, where authors describe that strategies generally either fall into conforming, selecting, or manipulating strategies towards existing institutions (Binz et al., 2016; Markard et al., 2016; Van Oers et al., 2018). We did not find a selecting strategy in this research but will discuss the conforming and manipulating strategy in the next sections. We follow this with a discussion of other potential strategies in (de-)legitimation of emission-reducing technologies.

4.5.2 Conforming to institutions for legitimacy

To choose a conforming strategy is to construct legitimacy by aligning with the broader intensive livestock farming sector. As other authors have described, these technologies are legitimated by the current farming system and also legitimate this type of farming (Wolf & Wood, 1997). This links to an analysis of how legitimacy is part of hegemonic structures, where legitimacy and power are co-constitutive (Mouffe, 2007). Existing institutional structures, at the government level and through the intensive livestock industry benefitted technology developers, whose technologies in turn provided legitimacy to the Intensive livestock industry (Markard et al., 2016).

The role of the government is interesting in this respect, as the legitimacy of emission-reducing technologies has been supported by government policies and regulation. The importance of government regulation for technologies addressing agri-environmental impacts can be recognised in the broader literature (Borrás & Edler, 2020; Klerkx & Begemann, 2020; Wojtynia et al., 2021). The government forms an element in the broader power structure that supports the need for emission-reducing technologies. In a conforming strategy, technology developers seek to align, and conform to these institutions in order to construct legitimacy for new technologies.

However, the government processes for approving emission-reducing technologies have stalled, as is illustrated by the lack of a scientific team and the disruption of the conforming strategy. The effect of this development is striking and shows vulnerability of the current socio-technical regime, where technology development has halted after the conforming strategy was disrupted. This creates perspective to strategies that seek to disrupt path dependencies, as it shows the sometimes limited effort needed to disrupt existing technological developments (Conti et al., 2021). The lack of new technology development is however also due to a lack of broader forms of legitimacy. Normative and cognitive legitimacy were not a major concern to technology developers, but this also means that there is no adoption of their technologies in the absence of regulative legitimacy. This has implications for the promotion and induction of technological change by governments, and for technologies that promise to reduce environmental impacts. Techno-fixes that are developed purely to comply with regulation are only adopted when regulation also ensures this adoption.

The solution for technology developers in this situation is to (re-)construct legitimacy for their technologies. As we saw in the results, they are using a lobbying strategy in order to construct legitimacy. In the next part of the discussion, we will discuss this strategy and highlight several other strategies that can be employed by various actors in the (de-)legitimation of emission-reducing technologies.

4.5.3 (De-)constructing technology legitimacy

In our research, we see that in absence of regulative legitimacy, technology developers are mainly focused on constructing technology legitimacy through a conflict over knowledge and through knowledge claims. The main goal of these strategies is focused on re-instating government procedures for approving technologies, which can be read as a manipulative strategy that has the aim of changing the regulatory environment to come to a status quo where legitimacy can again be gained through conformance. A second goal of this strategy is to have their technologies classified with a higher performance than they currently have. This highlights the strategies that actors utilise in legitimation processes and links these processes to the broader literature on knowledge conflicts (Leino & Peltomaa, 2012; Markard et al., 2016). These strategies are so far unsuccessful in this case, leading us to propose several other solutions to the construction of legitimacy for emission-reducing technologies. This ranges from methods to construct legitimacy to more transformative approaches that can de-legitimise these technologies and help disrupt the current socio-technical regime.

Other authors have proposed knowledge co-production in dealing with knowledge claims (Edelenbos et al., 2011; Wesselink et al., 2013). Knowledge co-production is helpful in dealing with the uncertain nature of knowledge, as in environmental governance, as it allows for the various parties who make knowledge claims to come together and build consensus (Edelenbos et al., 2011; Lee, 2012; Thorsøe et al., 2017). A range of authors have described how these approaches may be used to make both governance decisions and innovations legitimate to broader society (Eshuis & Stuiver, 2005; Leino & Peltomaa, 2012; Runhaar, 2017; Singh et al., 2021; Thorsøe et al., 2017).

Generally, the goal of these approaches is to seek consensus between different knowledge claims and to work towards a shared truth. This process would help construct legitimacy for the claims of technology developers, as it acknowledges the legitimacy of their knowledge claims and allows them to seek consensus with researchers and government agencies over how to deal with these knowledge claims. The downside of this approach is however that it does not critically interrogate issues of power in the legitimation process and in knowledge conflicts. This is especially true for those actors seeking to disrupt existing regimes and work towards the sustainable transformation of agriculture. Following Mouffe (2007) and D. Scott (2021) we propose to use agonistic pluralism in order to (re-)politicise discussions on technology and innovation processes.

Agonistic pluralism tackles several weaknesses in typical co-productive approaches, taking an approach that highlights dissent over consensus and that stresses the role of power in dealing with knowledge claims. This perspective is especially relevant to our case, where a large group of actors are connected to intensive livestock farming. These actors see technologies as the solution to deal with the legitimacy crisis of intensive livestock farming, while there is a broader societal and political move away from intensive livestock farming. If co-productive approaches are too limited (not involving a plurality of voices), there is a strong risk that these approaches end up legitimising the status quo.

Agonistic pluralism seeks to highlight conflict between groups of actors, where conflicting power relations (and desired power relations) are essential. This conflict already exists in broader society, where there are different viewpoints on the future of the agri-food system. However, these conflicts are kept out of technology development and out of the choice for certain technologies by the government. In relation to our case, this would mean highlighting the different knowledge claims but also involving a broader diversity of knowledges. Rather than seeking consensus between the parties involved (technology developers, scientists, and governments) it would keep these conflicts alive and involve additional actors who have a stake in the game. This broadening of actors can include both human actors who are impacted by emissions and the intensive livestock industry (e.g. rural people, farmers, nature conservationists) but on a more radical and disruptive path can also pay attention to the relatively recent notion of multi-species justice in technology development (Tschersich & Kok, 2022). This would tie conflicts over knowledge to broader political visions for the future, where knowledge claims are part of these politicised debates. This creates the struggle necessary to envision different agri-food systems and to break the legitimacy of current farming systems.

4.5.4 Limitations and further research

In our research, we were limited to the perspectives of technology developers and other stakeholders in the livestock farming sector. Despite several attempts, government agencies involved in approving the technologies did not wish to be involved in this research. Future studies on this topic could seek a broader perspective, including government actors and possibly other societal actors. Especially the formation of government-approved lists of technologies might form an interesting avenue for future research.

More research is needed to understand how these findings translate to other domains. Ammonia emissions are a core focus in Flemish agri-environmental policy, influencing the legitimation processes, as more actors are involved, and the stakes are higher than for other agri-environmental domains. Whether similar dynamics play out in other, less contested domains remains to be seen. Further research might test whether this also plays out in issues such as eutrophication or water usage of agriculture, where technologies are promised to solve these issues so that we would not have to radically transform our food system (Kaspersen et al., 2016; Pérez-Blanco et al., 2020). It might also be interesting to reflect upon this in relation to pesticides and pesticide approval, where similar knowledge conflicts in the face of regime destabilisation take place (Frank & Schanz, 2022). Especially the ongoing battle over neonicotinoids is interesting in this aspect, where knowledge conflicts play a central role in whether these pesticides can be approved for use in the EU (Bozzini & Stokes, 2018).

Further research is also needed on approaches that can deal with the legitimacy issue of ammonia-emission reducing technologies. We have described two possible approaches, but further research could identify additional pathways for (de-)legitimation. Pathways for legitimacy that are less dependent on the government could be beneficial to technology developers. This could be a transfer of responsibility over approval to the industry, reducing the difficulties of gaining approval at the risk of regulatory capture (Saltelli et al., 2022).

4.6 Conclusion

We started this article by asking how technologies that reduce agri-environmental impacts become seen as legitimate solutions to agri-environmental harms. We asked the question of how technology developers construct legitimacy for technologies that are developed to reduce agri-environmental impacts and sought to understand the role of knowledge claims in this process.

Our account adds some nuance to the belief that technologies developed to reduce agri-environmental impacts gain legitimacy just because they fit within the dominant socio-technical regime. It shows the struggles in constructing and preserving this legitimacy, especially when the dominant regime of intensive livestock farming is itself in a process of delegitimation. Technologies that address the environmental impact of intensive livestock farming are intimately tied to this type of farming and depend on regulation and regulative legitimacy in order to be adopted and used. Normative and cognitive legitimacy for these technologies is lacking. What our account adds to previous work is to highlight the strategies that technology developers utilise to preserve and construct legitimacy in the face of this broader delegitimation.

In response to these threats to legitimacy, technology developers seek to find ways to retain and reconstruct regulative legitimacy. Conforming pathways to construct this regulative legitimacy are currently non-functional, and technology developers use knowledge claims to lobby other actors, especially government agencies and scientists, to construct legitimacy for their technologies. This highlights the importance of knowledge claims in the construction of legitimacy, and ties knowledge conflicts to the process of legitimation. While this has been shown in other fields than agriculture, our account shows some of the specific elements around agri-environmental issues that impact the link between knowledge conflicts and legitimacy processes. The uncertainty inherent to agri-environmental impacts enables developers in their knowledge claims.

There are several ways forward for policy makers and other actors involved in this process. It might be possible to legitimise technologies through a co-productive approach that would acknowledge the knowledge claims of technology developers. This can however be problematic as the focus on technology as a solution to reducing environmental harms may remain uncontested, leading to continuation of strong path dependencies and system lock-ins.

We see a more contested view on knowledge conflicts as fruitful. An agonistic pluralism lens on knowledge and legitimacy conflicts, which acknowledges the power relations and lock-ins in this field, would enable other actors to be involved and to contest the ideas and narratives underlying the need for ammonia-emission reducing technologies. This approach might conclude that other solutions to environmental harms are needed, such as reduction of livestock and a move to plant based protein, potentially impacting the intensive livestock farming sector as a whole (see e.g. Broad, 2019). In turn, this will most likely lead to resistance from technology developers and other actors in the intensive livestock farming industry, making this approach more challenging than a co-productive one.

Either choice is a political one, to be made by societal actors, policymakers and politicians. The intensive livestock farming sector is in transition and the technologies studied here are part of the transition. Whether they will have been a temporary fix during a transition away from intensive livestock farming, or a permanent feature in continued intensive livestock farming, depends on the choices that will be made.

CHAPTER 5. CO-PRODUCTION IN THEORY BUT NOT IN PRACTICE? CHALLENGES OF CO-PRODUCING THEORIES WITH STAKEHOLDERS IN A RURAL PAN-EUROPEAN RESEARCH PROJECT

Authors: van der Velden, D., Debruyne, L., Dessein, J., Klerkx, L.

Author contribution statement: Daniel van der Velden: conceptualisation; methodology; investigation; writing—original draft preparation; writing—review and editing. Lies Debruyne: conceptualisation; investigation; writing—review and editing. Joost Dessein: conceptualisation writing—review and editing. Laurens Klerkx: writing—review and editing.

Link with the other chapters and with the main research question.

Our second empirical chapter provides a case study on the potential of participatory theory building. This chapter is used to examine a ‘participatory theory building process’ that we held in the DESIRA research project which focused on digitalisation in rural areas. This builds on the idea that participation can be a tool in knowledge conflicts, as described in the previous chapter, and also partially answers our question on the use of diverse knowledges in the digital transformation of agriculture. This builds on a broader participatory project, where stakeholders were involved in discussions on the digital transformation of agriculture, rural areas, and forestry. Based on a conceptual framework developed early in the broader research project, we attempted to link the concepts in this framework to stakeholders in the project. This allows us to question to what extent stakeholders in a participatory process can be involved in co-theorising. What we find is that there are boundaries drawn by researchers in the participatory process, which determine where participation is possible and where participation ends. This drawing of boundaries formed a way for researchers to resolve perceived tensions between project needs, stakeholder needs, and co-theorising, where they assume that stakeholders neither benefit nor are interested in the theories used to describe the digital transformation. We conclude this by questioning the relevance of a project theoretical framework and by accepting that participation does not need to be complete participation, but that there remains potential for a more complete participation in the theories we use as researchers.

5.1 Introduction

The participation of citizens, laypeople, or stakeholders in research processes has become established as an approach for developing scientific knowledge. The co-creation of knowledge and innovations is often described as a key aspect of solving complex, or ‘wicked’ problems (Hakkarainen et al., 2022). This approach has also become commonplace in projects financed by the European Commission. For example, the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) supports this approach, indicating that from now on: “Knowledge is co-created between practice, scientists, advisers, enterprises, NGOs, etc.” (EIP-AGRI, 2017, p. 3).

Such knowledge co-creation is part of a multifaceted yet cohesive effort to integrate diverse knowledges and integrated approaches in knowledge development, aimed at addressing the 'grand challenges' of our time (Caniglia et al., 2020). It has commonly been described as a move away from disciplinary, linear and hierarchical modes of knowledge production to a socially distributed, transdisciplinary and application-oriented mode of knowledge production (Jahn et al., 2012; Nowotny et al., 2003). This resonates with a broader call for democratizing science, where innovation becomes a shared practice between multiple actors and stakeholders, involving their concerns, knowledge, experiences and practices (Ingram et al., 2020). This development has seen increased popularity in agricultural science since at least the late 80s with Chambers (1989) frequently cited as the starting point of a broader involvement of diverse knowledges in agricultural research. However, there are competing views on the desired level of participation, the forms participation should take, and on the desired outcomes of participation.

The levels or intensity of citizen and stakeholder participation desired, or required, have been recognized in the participation ladder (Arnstein, 1969). This highlights the different forms that participation can take, from non-participation and manipulation, through consultation, to full citizen control and partnership (Arnstein, 1969; Galende-Sánchez & Sorman, 2021). These different levels of participation are also visible in the multi-actor projects that make up Horizon2020 research projects in rural areas (Feo et al., 2022). Multi-actor approaches fit within a broader European research funding context, where research projects are encouraged, if not required, to include a diverse actors in the process of co-creating demand-focused knowledge (Slavova et al., 2023). Effectively, this means that different actors are involved and at different levels of participation, but as Feo et al. (2022) describe, this is mainly limited to events, rather than stakeholders becoming integrated in the research process. Concerns about the level of participation are also linked to the need for inclusivity, as there are concerns about which actors can participate and about the power relations between actors (Adamsone-Fiskovica & Grivins, 2022; Burch & Legun, 2021; Fieldsend et al., 2021).

On a more fundamental level, there are running debates about the forms and outcomes of participation. While authors discuss the value of involving a diversity of knowledges, there are different views on what this diversity means for the participatory process (Doudaki & Carpentier, 2021; Dunlap et al., 2021; Koskinen, 2014). The common approach in multi-actor research projects is that a diversity of knowledges is valuable in that it can strengthen scientific knowledge and legitimise the outputs of the research process (Adamsone-Fiskovica & Grivins, 2022), and increase its applicability in practice. This has however been critiqued as limiting participation to involvement in research methods and analytical tools, as it does not fundamentally question concepts and theories underpinning the projects (Felt et al., 2012; Hakkarainen et al., 2022). Equally, there are concerns that the integration of different forms of knowledge into scientific knowledge does not accurately reflect this knowledge and that participation can reconfirm hierarchical relations between forms of knowing and knowledge (Latulippe & Klenk, 2020; Nadasdy, 1999; Repo & Matschoss, 2019; Rosa et al., 2018).

These tensions between what participation is desired, the potential contributions of participants and how researchers deal with tensions between desired participation and other needs of the research project are the principal interest to this research (Schikowitz, 2020). Linking the focus of European funded research to the discussions on co-production, we discuss in this article an account of participatory theory building (PTB) which deals specifically with the potential for stakeholders in participatory projects to co-produce theoretical concepts. This process does start from the principles and beliefs of opening theorising to a broader group of actors. The focus of this research are the practices of researchers, how researchers work with the requirements of participatory research and how they deal with the tensions that they encounter.

This leads us to the research question of: *How are tensions between project needs, stakeholder needs, and co-theorising resolved by researchers in a European research project, and what is the relevance and potential of theoretical concepts as boundary objects in participatory research?*

Specifically this takes places in a H2020 research in action (RIA) project utilising a multi-actor-approach (MAA) in the form of living labs. While there are a good number of case studies focused on how participatory research is done, and how it can be improved, there are relatively few studies that analyse how researchers deal with the tensions that participatory research brings, especially concerning the development of theoretical concepts and broader theories through integrating diverse knowledges (Felt et al., 2016; Schikowitz, 2020; Slavova et al., 2023). Our paper is structured in the following way. We first provide a theoretical background for our analysis. Following this, we introduce our case and the methods we used, which also includes a description of the PTB process. The last chapters include the findings and an integrated discussion and conclusion.

5.2 Theoretical framework

We start our theoretical background with an exploration of the tensions in participatory processes and how these tensions relate to diverse forms of knowledges. The main aim is to clarify the various outputs of participation, the forms of knowledge involved, as well as the epistemological underpinnings of these processes.

5.2.1 Levels of participation

Participation in research projects does take different forms and has different aims depending on the researcher leading the participatory process. These aims and views on participation are not always made explicit by researchers engaged in participatory methods. This both frustrates a more thorough understanding of the outcomes and effects of participatory processes and can allow participation to remain shallow and rhetorical (Brandt et al., 2013; Ingram et al., 2020; Jahn et al., 2012). To clarify participatory methods in this case study, the participation we speak of in our research was participation as a research method, where participants are engaged in the research process to provide and produce knowledge, but where they are not involved in all phases of the research process. To some authors this is already an imperfect participatory process (Jahn et al., 2012; Renn, 2021).

This calls back to the participation ladder from the introduction. Participation can take different forms, moving towards full citizen control (Arnstein, 1969). Often, increased participation is seen as a good thing, a normative aim that researchers should work towards. This is a linear approach to participation, indicating that it is possible and desirable to move towards the most intense form of participation, a view that is in turn critiqued by others who describe that meaningful participation can occur even in processes that at first sight seem to be low on the participation ladder (Neef & Neubert, 2011). For research this means that participation is somewhere on a spectrum, between linear, science-driven knowledge production and more inter- and trans-disciplinary research, which is oriented towards application (Ingram et al., 2018). Research projects often contain elements of both models, where it is more accurate to speak of a blend between these archetypes (Ingram et al., 2018; Neef & Neubert, 2011).

This also has implications for the production of knowledge in participatory projects. This can be recognised when scientific knowledge production is separated from the co-production of knowledge. This allows for participation in some aspects, while retaining agency at the researcher in 'doing' the participation (Heyman, 2007). The structures of knowledge production are unequal, where researchers often still determine what questions are discussed and the type of collaboration that is possible (Felt et al., 2016). While participation is sought in collecting the data, the researcher is the one who uses their skills, writings, and access to author the reports, to produce the 'co-created' knowledge and to present this to funders and policymakers alike. It is an act on behalf of the participant, where the researcher is the one who decides who and what is relevant in knowledge production and what knowledge is valuable enough to make it into scientific theory (Heyman, 2007; Repo & Matschoss, 2019).

5.2.2 Tensions in participation and co-production

There is an inherent tension between the production of concepts and theories and the participatory (socially relevant) knowledge that is expected to be built in the process of participatory research (Brandt et al., 2013; Felt et al., 2016; Schikowitz, 2020). In a specific scenario for participatory research, there might be an open epistemic arena where different knowledges are valued and questions and answers are coproduced, but for scientific research these answers need to be refined. Experiences, knowledge and reflections are translated into a scientific form that is valued following to scientific standards (Felt et al., 2016; Schikowitz, 2020). Brandt et al., (2013) take the view that in participatory research, publishing scientific outputs might become a secondary aim to retain the tight link between practitioners and researchers in solving shared problems. This allows the aim to shift away from producing peer-reviewed publications. For others, scientific outputs remain important but are separated from the participatory process (Jahn et al., 2012). A question that remains is to what extent scientific outputs should drive the process, as other authors describe the tension between these outputs and other achievements in participatory research (Felt et al., 2016; Schikowitz, 2020). Felt et al. (2016) for example describes several tensions: the promise of radical change to science while retaining legitimacy within science, tensions between generalisation and local relevance, and between developing broad knowledge and expertise while retaining distinctions between science and society.

These tensions to participatory research are dealt with in different ways, depending on the participatory project. Part of this is the occasional ambivalence to scientific theories and knowledge in certain areas of participatory research. Scientific theories are sometimes described as having no real use to participants in the process, lacking utility and only finding meaning within specific networks of shared understandings (Gergen & Gergen, 2008). This is similar to other authors who share the view that stakeholders might not find meaning in the scientific process of developing theories (Djenontin & Meadow, 2018). The risk of theories is that overly broad and structured theories do not fit the complex realities on the ground, but foregoing theories completely risks losing out on a consolidation of knowledge that emerges from the involvement of broader actors in research processes (Schlüter et al., 2022).

In response there is the view that we need to craft different scientific theories, that do find relevance with stakeholders. Friedman & Rogers (2009) set out that *'good theory'* provides accessible and useful tools for practitioners, academics, and other actors/participants alike. In this, they respond to earlier-mentioned ambivalence to theory by stating that good theory helps to co-create shared knowledge on the causal conditions of the social world, knowledge that is in essence theoretical. Discussing theory can then provide a way for research participants and researchers alike to come to a shared understanding and to understand their own social reality better (Genat, 2009). To these authors, the aims of scientific theory in participation are to enable research participants to interpret the world in new ways, to understand their social reality and to have local knowledge participate in theory-building (Friedman & Rogers, 2009; Málovics et al., 2021). This connects to the idea of socially robust knowledge as we set it out, socially relevant scientific knowledge, made relevant through participation of stakeholders (Nowotny, 2003). In an ideal scenario of participatory research, it might then be assumed that tensions between practical relevance and scientific relevance are limited, as the knowledge that is produced is relevant to both.

5.2.3 Theoretical concepts and boundary objects in participation

The aim of participation in research is often to produce increasingly socially relevant scientific knowledge (Neef & Neubert, 2011; Nowotny, 2003; Polk, 2014). This links up to a conceptualisation of knowledge as situated, where knowledge is not generally true across contexts but has to be considered within the specific context where it is applied (Leino & Peltomaa, 2012). By continually testing the knowledge that is produced and by involving non-scientific actors, researchers can ensure that the knowledge produced is relevant to both these actors and to broader society (Nowotny, 2003; Schikowitz, 2020). There are however varying views on how this knowledge is or should be produced and how it relates to scientific knowledge in the form of concepts and theories.

In this research we discuss this in terms of theoretical concepts, a broad term we use to describe concepts developed by researchers for the project and that function to some extent as boundary objects. These concepts have a theoretical underpinning but are still broad terms, used by researchers to indicate certain aspects present in the theories. With boundary objects, we understand anything that functions as a bridge between different social worlds. Boundary objects can be both physical and concrete objects (e.g. maps, physical spaces) or abstract (e.g. theoretical concepts, ideas) (Star & Griesemer, 1989). These objects make working together across boundaries with different actors possible, whether boundaries between researchers, between stakeholders or between researchers and stakeholders (Turnhout, 2009).

Boundary objects require a level of interpretive flexibility, where different social groups can provide their own meaning to the boundary object, using it in their own context and for their own needs (Star & Griesemer, 1989). Objects need to retain ambiguity and flexibility so that they can travel across different social worlds and obtain different meanings for different social worlds (Lundgren, 2021; Turnhout, 2009). In other words, interpretive flexibility allows the boundary object to be vague and malleable, not tied to a specific discipline. This conception of boundary objects also brings to light an issue in the use of boundary objects, in that the actual meaning of the concept can be unclear (Brand & Jax, 2007). We highlight this issue as it brings to light the balance between interpretive flexibility versus interpretive rigidity. Rigidity locks down the concept to a specific meaning, as happens when a boundary object is used, claimed, or owned by a specific group that holds a dominant interpretation over the concept (Huvila, 2011; Klerkx et al., 2012). This becomes particularly pressing when it relates to theoretical concepts, developed by researchers where they hold ‘ownership’ over these concepts.

5.3 Methods

We provide a short overview of the case study and the methods used in analysing the case study. We also clarify steps taken in this research process, where our case study involved researchers who were project partners in the research project. Our work focused on how researchers themselves brough participatory methods into practice. These researchers themselves were doing research with stakeholders in a participatory context. To avoid confusion, the definitions we use in the methods, results and discussion are the following: *respondent and researcher* refers to the researchers in the project, who led the living labs*. Living labs* are the framework for the participatory activities in the project and *stakeholders* are the participants in the living labs that researchers refer to when describing the living labs.

5.3.1 Case Study Approach

The case we study in this article is based on a PTB process, which formed part of a broader Horizon2020 project (H2020DESIRA). The main aim of this project was to study the social and economic impacts of digitalization on agriculture, forestry, and rural areas. The H2020DESIRA project was a research-in-action (RIA) project, utilising a multi-actor approach (MAA) by involving 20 living labs in different European countries. Living labs provide a new term to classify the MAA process, with a focus on user-centred, open innovation processes with significant co-innovation or co-creation (Gamache et al., 2020). Particular of living labs is the place-based and 'real-life focus' of these co-creation processes, focusing on a particular community or group of users, although this does not need to be exclusive to living labs (Toffolini et al., 2021).

Our case study was focused on researchers who were leading living labs, only involving the researchers who in turn kept contact with their living labs. The living labs themselves took shape through several workshops and focus groups with groups of stakeholders (which depending on the specific living lab varied in consistency). The key activities of the living labs consist of a workshop to determine needs and current impacts of digitalisation, two workshops to build future scenarios for potential impacts of digitalisation and one policy workshop. This made for around 4-5 meetings between researchers and the stakeholders making up the living lab. Research in the living labs was focused on different digital technologies, with living labs involved in this research focusing on themes such as access to digital broadband for rural communities, remote sensing in forestry, sensors for agricultural emissions and digital marketplaces for short food supply chains. The PTB exercise we study in this paper formed a minor part of the project, with seven of the 20 living labs taking part. A short description of the theme of each of these seven living labs is provided in table 6. The contexts and research topics were different between the living labs, with the unifying theme being digital technologies. Participation of stakeholders varied between the living labs, but within the confines of the project, participation was generally limited to focus groups and workshops.

The PTB exercise had as an aim to use the empirical findings of the participatory activities in the project to further develop the conceptual framework. In the original project proposal this process was listed as: "a transdisciplinary and reflexive effort that will ground the conceptual framework (developed at the start of the project by a selection of researchers) with the empirical findings of the project, leading to a refined conceptual framework." We held this PTB exercise with project partners, where researchers involved in the living labs were invited to interviews and workshops. This unilateral focus on researchers, with limited involvement of stakeholders active in the living labs is a limitation of our case study. We will expand on this in the results and the discussion.

Table 6: The themes of the living labs active in the PTB exercise

Country	Focus of the living lab
Netherlands	To help organise short food supply initiatives through digital platforms
Latvia	Developing innovative support systems for traceability and marketability of beef cattle meat
Italy	Improve communication for land management between citizens, stakeholders, and public administration through digital tools
Spain	Using digitalisation to help reduce the risk of forest fires and for effective fire fighting
France (two living labs)	1) To improve the digitalisation of the wine sector, and 2) to use digital technology to contribute to innovations for the agroecological transition
Scotland	To find appropriate pathways for equitable and beneficial digitalisation for crofting communities
Belgium	To understand the impact of digital farm-based monitoring of emissions in the intensive livestock farming sector

5.3.2 Research Methods

The proposal of the research project contained a minimal and open description of PTB (see appendix 4 for an overview of how PTB was described in the proposal). We approached this process as a form of action research, aiming to develop a process that would build on the theoretical concepts developed in the project while also studying the process of PTB itself. This follows the view of action research as collaborative problem-solving while also aiming to generate new knowledge (Coghlan, 2011). As methods, we (as author LD and DV) opted to start this process with workshops and interviews. These workshops and interviews ran throughout the participatory phases of the research project to gain insight in how theoretical concepts of the conceptual framework were used by partners in the project.

After a first online workshop with all 20 living labs we started a collaboration with six project partners who volunteered for the PTB process. Our initial aim was to have project partners explicitly discuss theoretical concepts from the conceptual framework together with stakeholders during the activities of the living labs. After a first round of interviews and a workshop with the researchers involved, we realized that this did not produce the results we were looking for, as researchers hesitated to add theoretical concepts to the activities in the living labs. Throughout the research, the use of a theoretical concept within the living lab was understood as either an explicit or implicit reference to this concept (i.e. they did not have to specifically mention the socio-cyber-physical concept, as discussions in the living lab that were inspired by this theoretical concept also counted as a discussion of the theoretical concepts). However, we found little evidence of the use of theoretical concepts in the living labs, which meant that stakeholders did not get in touch with the theory and could thus not co-produce the project theory. In response we shifted our focus in the second and third round of interviews, where we focused on how researchers used the conceptual framework in the participatory activities and how they saw the use of the theoretical concepts. We will return to this change of focus in the results, as it forms part of the analysis of how PTB functioned in this project.

Fieldwork began with an exploratory workshop with all living labs, where the theoretical concepts were explored. Following this workshop, the main living labs that taking part in the PTB exercise were selected, with the first round of interviews (see table 7 on the next page) taking place after the first activities with the living labs. In this sense, the researchers were made familiar with the main concepts of the project before the research began. Researchers also all had access to the conceptual and analytical framework of the research project, which provided a detailed description of these concepts.

Interviews were semi-structured, following the question guidelines that are provided in appendix 5. Three sets of interview questions (one for each round of the interviews) were developed. These interview questions were provided to the interviewees before the interviews. The development of the interview questions shows the shifting focus of the research, starting with a focus on the use of the concepts between stakeholders and researchers and shifting to a focus on how researchers view these theoretical concepts. 17 interviews were held with project partners, distributed over 3 rounds of interviews. Participation by respondents varied through the project, where project partners were not always able or willing to join interviews. We provide an overview of which living labs joined which round of interviews in table 7 below. The interview R3Italy was held twice, with two different researchers. Interviews for the Belgian living lab were also a reflexive exercise, as this living lab was included in the PTB exercise but was also led by the first two authors. The same interview questions used for the other interviews were used for these reflective interviews, following the view that this improves the reflexivity of us as researchers (Olmos-Vega et al., 2023).

Table 7: Interviews per round of interviews per country

Round of interviews	1	2	3
Belgium	X	X	X
Latvia	X	X	X
Spain	X		
Scotland		X	X
Italy		X	X (twice)
Netherlands	X	X	X
France	X		X

Throughout the research and fieldwork, interviews were transcribed and analysed using Nvivo12. Inductive coding was used to form a broad categorisation of the incoming data and for a first broad analysis. Following this analysis and with the framework we set out in the theoretical framework we developed the list of codes provided in appendix 6 to code and analyse the data a second time. Both lists of codes are presented in appendix 6. In the findings, respondents are indicated with the round of interviewing (1-3) and their respective country. This means that R1Spain indicates that the quote is from round 1 and is an interview with the Spanish project partner.

5.4 Findings

5.4.1 Overview of the project

We start our findings with a short overview of how PTB functioned in practice. The participatory elements of the research project were limited to the focus groups and workshops. Stakeholders were not involved in the early stages of the research project, also due to structural limitations of project proposal writing. Nuance needs to be made in that several of the living labs were part of longer-running initiatives and communities. Other research has pointed out that this can shift the power balance, where the community has increased say over the process of participation (Felt et al., 2016). However, these communities were also not necessarily involved in other phases of the project, such as developing the research proposal or evaluating the resulting knowledge (Jahn et al., 2012).

As with similar projects, a shared conceptual framework was developed that consisted of several theoretical concepts by several partners in the project. This conceptual framework was used to provide an understanding of how digital technologies are affecting agriculture, rural areas, and the forestry sector and was based on RRI and systems thinking. The conceptual framework emphasized the effects of technology on society, the values that are inscribed into technology and the possibility to influence the values that are inscribed in technology. Specifically, three broad theoretical concepts of the conceptual framework stand out and have been the focus of our work in PTB and can be recognized in two articles published on these concepts (Bacco et al., 2020; Rijswijk et al., 2021). These three are:

1) A systems view on digitalization conceptualized through a socio-cyber-physical system, with a basis in science and technology studies (STS), specifically linked to the RRI concept. In a broader sense, this concept is adapted from the cyber-physical system in engineering and technical studies, integrating it with an understanding from STS that

highlights the values that are inscribed in technologies and the co-determination of technology and the social.

2) Several concepts (drivers of change, digital game changers, digital transformation) that highlight the transformative element of digitalization, which understand technologies as having agency, and that focus on the impact of technology on society. This is linked to innovation studies, linking to a view of novel technologies as disruptive, revolutionary, and transformative.

3) Concepts focused on the socio-economic impacts of technologies and the potential to influence this. The concepts of access, design and system complexity are used to highlight impacts of digitalisation and the need to influence technology design, again linked to RRI. Access is linked to uneven socio-economic development and the digital divide (Rotz et al., 2019). Design is linked to the view that (digital) technologies can have both positive and negative influences on society, and that through improved design, negative impacts can be reduced while positive impacts can be enhanced. The concept of complexity is again more technical, focusing on the interconnectivity and technical complexity of highly digital systems and the skills needed to work in these environments.

5.4.2 Fear of alienating stakeholders

The first round of interviews for this research were held after the first workshop in the living labs. We asked how researchers used the concepts of the conceptual framework in their workshops, how stakeholders responded to these topics, and whether they took up these concepts during the workshop. This line of thinking was cut short when we realised that the concepts had not reached the stakeholders at all during the workshops. A quote from R1Spain highlights the role of the conceptual framework in the project:

"Because the conceptual framework is in English, and the terms and concepts are difficult to translate, we did not discuss them with stakeholders, and I think that is not what we expected from them.

I do not know if that was different for other living labs. But we tend to be very respectful with the time of stakeholders because normally they do not win anything by coming to our workshops, or very little. Right? But we did not go on that, I think theory building was not the objective of our workshop, so…"

As the respondent indicates, the concepts of the conceptual framework do not reach stakeholders. The engagement with concepts was not the main objective of the living lab and stakeholders would not gain from this exercise in the eyes of our respondent. This is a first indication of the role of theoretical concepts developed for the project, which are seen as irrelevant to the stakeholder. This also disrupted the potential of the PTB process we had in mind, where our original idea of connecting scientific concepts and theorising with the stakeholders did not come true. Our own reflections, in an interview between author DV and author LD following a workshop with stakeholders to discuss digitalization in agriculture:

"Yes, I know we tried to ask something about that [the theory of the conceptual framework]. But yeah, if you do not name the concepts then you also can't really expect a response. […] You would have to completely restructure the workshop, but then I wonder why you would do that. You do the workshops to provide maximal value to your participants, of course with your research in mind. But you may already be happy that they take part, so you do not want to burden them, to make them think about these concepts and to ask for their opinion. […] And I think to myself, how much useful feedback would you get? With people who don't know anything about these theories."

These findings show the reality of our attempt at PTB. Interesting is the feeling that the project activities can easily alienate stakeholders, where they stop showing up to activities. This was a broader fear around participation, where different activities risk alienation, but doing PTB seemed to researchers a surefire way of alienating stakeholders. This clashes with the ideals of co-producing knowledge, as stakeholders are not involved in the discussions of how their knowledge relates to theories and concepts that are used to study their context and that inform the scientific outputs of this process.

5.4.3 What is co-produced?

This allows us to question what is actually co-produced in the co-productive process. The findings show a separation between stakeholders and project researchers. Concepts developed for the project rarely reach the stakeholder level, with a small exception for the SCP concept which was used in the workshops to stimulate a systematic view of the impacts of digitalisation in the living labs, but which was not discussed with stakeholders at a fundamental level. This failure of co-producing theory can be tied to the fact that the theoretical concepts already have a function in the project, which turns out to be relatively rigid. The function of the concepts is to provide generalizable results back to funders and in publications. As R3Lat describes:

"*And it is very much on how researchers perceive the role of conceptual framework. So when you... not meaning to be critical but rather recognizing the diversity, in the projects where a research component is really strong, and we need to maintain a comparative dimension, well there the conceptual framework plays a crucial role in ensuring that this comparative dimension and the interlinkages between the observed factors are presented. But if you do not have this really, well then, the conceptual framework is much more symbolic.*"

The conceptual framework provides either an instrumental role to allow for comparison or becomes symbolic. As a method of comparison, the conceptual framework structures the analysis of data in the project and provides a framework that allows comparison between disparate cases in different countries. Project researchers have made use of aspects of the project theory, as seen in several publications that utilise concepts explored in the conceptual framework (Bacco et al., 2020; Brunori, 2022; Ciliberti et al., 2021; Ferrari et al., 2022; Metta et al., 2022). This shows the use of these concepts between researchers, where different researchers from different disciplines use the same concept with different interpretations and understandings of the same concept. But the concepts are useful only as far as research goes.

At the same time, the scientific relevancy of these concepts is in tension with the practical needs, or the needs for practical knowledge in the living labs. As R2Scot and R2NL describe, concepts that were used, such as those of 'digital game changers' and 'digital transformation' are of little use to stakeholders who want to discuss how they should use digitalization that does not transform. They have no need for a game changer and the concept itself implies a reality that does not exist in the living labs. The concepts are disconnected from the needs of local people, indicating that starting PTB with concepts developed by researchers is part of the problem. Rather than basing ourselves on the interaction between stakeholder knowledges and scientific knowledge, the PTB process was an attempt to bring scientific theories and concepts to the stakeholder to see how well they fit the local context. R2Scot and R2NL describe:

R2Scot *"It is probably good to point out that they* [our stakeholders*] are not the most digitally savvy, I mean in some ways yeah, they are using smartphones and laptops and whatever. And some of them have good examples of useful apps and whatever. But […] they are not advanced digital users by any stretch. […] Add to that that it is an ageing community and the participants in our workshop were mostly of retirement age, so that should give you an idea that they are not really talking about state-of-the-art technologies. But instead they are interested in the influence of digital platforms and social media, and you know... that type of thing."*

R2NL: "*See, the point is […] the game changers here are on the social, on community building. […] and the discussion is not about the game changers, but it's about how to create a community that is motivated, where producers and consumers are part of a shared system."*

We found similar remarks about other concepts in the conceptual framework. What this indicates is that we based ourselves on explanatory concepts and theories that could be developed based on the assumptions built into the project. However, when confronted with the diverse contexts and knowledges of stakeholders these concepts turn out to be rigid, as they are based on assumptions that turn out to not be relevant for the stakeholders. The need for comparison between cases excludes participation, as participation is only possible if it conforms to the need to have generalising theories (as opposed to locally specific knowledge). To seek an overarching theory that can be used by all living labs requires theoretical concepts that can be used in a variety of contexts and across different socio-technical circumstances. The concepts are not adapted to the local context and local needs, their fit needs to be universal, rather than specific for each of the cases. The use of these theoretical concepts and frames is questioned, where R2NL describes the following:

"And I wonder how much use this is to you? Because of course we take the concepts into account when we prepare the workshops, but you don't want to bring those up during the workshop because you just want a good conversation. So you are constantly balancing between getting results that are useful to the project and on the other hand providing something meaningful to the people who give their time to you."

The tensions persist, between getting useful project results, doing something practical for stakeholders and scientific relevance. These three aims are in tension, they are not just achieved through the participatory work, but one comes at the cost of the other. We use section 4.4 of the results to show how researchers deal with this tension and highlight approaches that are used to balance these tensions while ensuring that stakeholders keep participating.

5.4.4 Parallel tracts of participation

Two seemingly contrasting approaches that researchers take to deal with tensions are to 1) focus more on the practical needs and requests of stakeholders and/or 2) to take a more extractivist approach to the knowledge that is needed (either for project needs or for scientific outputs). We analyse each in turn, before discussing how these approaches are linked. Researchers (R3NL) indicate in response to a question on whether theoretical concepts could have been added to the living lab:

"Well, we could have done so with this living lab, but this is a living lab where we have done a lot already, with this group of people. And usually you just take if you're doing research, you request a lot from those people. So what we decided to do now […] was that this was a chance to give something back. To connect to the questions that are there and couple those to the project needs. So yeah, we could have chosen to go more theory-heavy, but we actually went the opposite way."

Several things stand out: one, in the participatory research project a lot is taken, asked from the stakeholder. We will elaborate on this after the next quote below. A second element is that despite the limitations of the project, it is possible to meet local needs of stakeholders, but this requires an effort and a move away from activities like PTB. The decision to meet local needs is made by limiting the connection of stakeholders to the project, and in effect by moving away from project and scientific activities to activities that work for the stakeholder, as mentioned later in the interview with R3NL:

"If you would focus on a scientific contribution you would need to be much stricter with how to do the workshops. To keep it methodologically sound. […] But if you […] want it to be useful, well we finally said, we do what we need to do for DESIRA, but we add other elements. So we do what needs to be done and then we move to […] the practical questions that are not scientifically interesting. It's just interesting for the people in the living lab. […] Because we have often come to interview people, to make them fill in a survey. […] Whereas if you want to give them something, you have to allow people to nag and whine about things. But you get it, it's not of interest to science."

This quote links the three concerns of the research project and separates them at the same time. Scientific activities are of interest to the researcher, but with the caveat that these limit the participatory potential of the workshop. The researcher decides to forego scientific interests to focus on the needs of the stakeholders. Equally, project activities are necessary, but are not actually what meets the stakeholder interests. The project forms the reason to hold the workshop, but does not meet the needs of the stakeholder, so additional activities are required to meet these needs. Participation is achieved but is separate from other aims of the project. The practical requests of stakeholders might be too simple or too off-topic to be useful for the project. At the same time, topics that hold scientific relevance might be of no interest to the stakeholder, as R3Scot also indicates:

"So […] you can explain it to a certain extent and maybe talk about, "okay, so digitalisation is a sort of process, of making something digital. But digital is also more societal and all that." Then you can sort of see their eyes glazing over. We're going too far in this academic direction now and we have to remember not to do that too much."

Intriguingly, one approach to deal with this tension is to combine more extractivist approaches with the participation of stakeholders. This could be recognised in the quote from R3NL above, who describes how they do the project activities before moving on to the 'real' participatory activities. R3italy and R3Bel describe this extractive approach in relation to the project activities and to what is required from the stakeholder:

R3Ital-2: "Res: No I mean, the knowledge that […] participants bring to the living lab is huge. It is up to the facilitator and the researchers to, let's say to be able to mine, to do this mining of knowledge. So you really have to pose the right questions, because also these people, in most of the cases take things for granted."

R3BEL: "We just don't have a lot of time, you don't want to overburden people with things that they, strictly speaking, do not need. So we do work from a perspective of what we need to take from them, from the group, how can we do that as efficient as possible.

Interviewer: How can we efficiently extract information?

R3Bel: Yes, I do think that we take that as our starting point, and not from any ill intentions. […] But from a perspective of; we will bother those people as little as possible and not demand any more of their time than necessary.

This is a compromise between seeking participation that produces tangible outputs to stakeholders, while still producing knowledge that is useful to the project and that helps build scientific theories and concepts. It is a realisation that the knowledge of stakeholders is impressive, and that knowledge can be co-produced, but this does not translate to the potential for PTB. It indicates that what is best for the stakeholder is not to be bothered with the co-production of scientific knowledge. Theorising remains the domain of the researcher and the stakeholder does not need to think about theories and theoretical concepts. At the same time, participation is achieved when discussing the practical needs of stakeholders, but these practical needs do not necessarily fit with the project and scientific aims of researchers.

The tensions between project needs, stakeholder needs, and scientific relevance are reduced by allowing the participatory activities to focus on stakeholder needs, while researchers take the results from these activities to refine into project and scientific outputs. The reality then is, in our project, that tension is resolved by separation. Participation happens but is separated from theoretical concepts and from project activities. Knowledge production happens, but the refinement of the knowledge into concrete outputs is the domain of the researcher. These outputs are seen to offer relatively little value to the stakeholder in question. This is of course the view of the researcher, but as the conductor of the participatory activities, they are in charge of this process.

At the same time, several researchers do critique these developments and point out how scientific theories need to change to accommodate stakeholder knowledge and to become useful to stakeholders. R3Scot indicates their hope for new forms of knowledge production that can include stakeholder knowledge and where stakeholders are able to critique scientific knowledge and theories:

So yeah, there are certain theories that are very questionable, aren't they? And if you actually had input from your research participants, they might just pull it apart. How would that go in the academic community? It might call into question just how academic knowledge is produced. But I think we are moving towards a more responsible way *of how that knowledge is produced anyway, which is exactly what you are doing here. I don't know what the answer is to that, it could pull a few things apart, but make those theories a bit more authentic and useful in the real world as well. Hopefully.*

5.5 Discussion & Conclusion

Even though this article deals with PTB that never truly got to the point of co-producing theoretical concepts, we find much to learn from the attempt. In the results we have indicated why researchers were reluctant to engage stakeholders, providing insight into the researcher-stakeholder relationship, and analysed the functioning of multi-actor projects which seek to engage a variety of actors in knowledge production. The clear limitation of this research is that we did not directly engage with stakeholders in this reflection, which provides a one-sided view of the potential of PTB. Both the PTB activities and our own reflections on PTB were focused on the researchers leading the living labs, rather than on the stakeholders active in them. It is possible that stakeholders would defy the expectations of researchers, and that they would not be as easily alienated. However, as they did not get this chance, this account is focused on the researchers who were active in the PTB process.

5.5.1 Fear of alienating stakeholders

The recurring concern that stakeholders become alienated from the research project is linked to the tensions in participation that we described. There is a tension between the practical needs of stakeholders, the need for project results, and the potential for co-theorising. These tensions needs to be balanced (Schikowitz, 2020). The risk of alienation (which exists in this article mainly as a fear of researchers) indicates that a focus on including the stakeholders in theorising comes at a cost of practical relevance to the stakeholder. To safeguard the practical relevance of participation, researchers choose to exclude discussion on theory and theoretical concepts from the living lab, keeping these concepts away from stakeholders.

This leads us to question why the theoretical concepts were seen as irrelevant to stakeholders. As seen in several of the living labs, concepts did not always fit the context of the stakeholders, as happens when concepts like system complexity, digital game changers or transformation are brought to a local context where these topics are not relevant. At the same time, these concepts form the shared comparative element that unites the various participatory exercises in different contexts and in different nations. The project needs universal, cross-European results, and these needs come first despite the realisation that these results might not be universally true across living labs, situated in different countries and contexts (Klerkx et al., 2017). This is in agreement with the tensions described by Felt et al. (2016), where generalisable results are demanded despite the realisation that locally specific knowledge is needed (Berthet et al., 2016). The concepts in the project framework provide this universal element to the researchers, where they function as a boundary object between researchers from different disciplines, who use the project concepts to write their own papers, following their own interpretations of these concepts (Bacco et al., 2020; Brunori, 2022; Ciliberti et al., 2021; Ferrari et al., 2022; Metta et al., 2022).

When we view the theoretical concepts as boundary objects, several things become clear. As boundary objects, they function between researchers to come to shared understandings of digitalisation across different contexts and spaces. They function as boundary objects to link across the different living labs taking part in the research project. However, researchers refuse these same concepts as potential boundary objects between researchers and stakeholders. It seems that the use of the concepts as boundary objects between researchers excludes these concepts from being used in the living labs themselves. There is a level of interpretive rigidity to these concepts that keeps them in the sphere of researchers and precludes the use of them between researchers and stakeholders.

This leads us to wonder why it is that these concepts are flexible enough to be shared between researchers, even though they find that they do not fully cover the contexts of the living lab, while they are too rigid to cross the boundary with stakeholders (Turnhout, 2009). Two reasons come to mind; first, that it takes effort to translate these concepts to a non-academic space, to introduce flexibility that allow concepts based on overarching theories to travel to non-academic space (Lundgren, 2021). Turnhout (2009) relates to this in exploring why certain boundary objects are rejected while others are accepted and indicates the importance of modifiability of the boundary object. A second reason we believe is the fact that these concepts come from research, developed by researchers, using the language common to researchers, which hints at the fact that researchers 'own' these concepts. The theoretical concepts function on the boundary, not as boundary objects but as the boundary itself, creating the border between research world and participant.

Of course, Star & Griesemer, (1989) already indicated that boundary objects cannot be imposed, which would be what happens when theoretical concepts are tried to be used as boundary objects. Here the further conceptualisation of the boundary by Huvila (2011) is helpful in exploring the ownership of the boundary object. Linking the concept of boundary objects to hegemonic forms of power, they describe how the articulation of the boundary object is a hegemonic intervention, in a search to be the social group to define what the boundary object means. The boundary object is not a neutral term, but structures the conversation in the living lab, or in the participatory research project.

To use theoretical concepts as boundary objects for stakeholders might thus require a different approach to these concepts in multi-actor projects. These projects have already been described as excluding various groups of actors in setting up the project (Cronin et al., 2022; Fieldsend et al., 2021). Additionally, participatory projects do run into the issue that the participation leads to new realisations that shift the focus of the project, making the theories that were set out at the beginning less relevant or even irrelevant (as is the case in our results when stakeholders realised that they need to focus on networking and community-building rather than on digital game changers) (Kilelu et al., 2014). A different approach to PTB might start at the point where project theory is set out. Rather than taking a universal approach to these theoretical concepts and setting out these concepts at the start of the project, it might be necessary to become more flexible and to develop explanatory theories based on the results of the project.

5.5.2 Separation rather than co-production

Before concluding, we discuss how researchers in this project dealt with tensions between participation of stakeholders, PTB, and the project needs. Felt et al., (2016) have described the tensions between the varying needs of people active in participatory research processes. Slavova et al. (2023) analysed multi-actor projects specifically and indicate the tensions in these projects and that projects and local needs can clash. What we see in our research is that researchers combine forms of participation to achieve different needs. We see an extractivist approach that several researchers took in order to limit the time spent on aspects that are seen to alienate stakeholders. This is especially true for project needs and scientific aims, where extractive participation is used to get results, so that the 'real' participation can start to address the needs of stakeholders.

This fits with the analysis of Slavova et al., (2023) that compromises are constantly made to keep the multi-actor project functioning. Our results indicate that one pragmatic approach to compromise on are to separate local needs from the project activities. Researchers ascend and descend the participation ladder during the project, there is no specific level of participation that is achieved throughout the project, but rather varying levels of participation depending on the activity and the aims of the researcher (Arnstein, 1969; Galende-Sánchez & Sorman, 2021).

We describe this not to challenge these form of participation and extraction. Rather, it complicates binary views of participation as either extractive or as completely participatory and co-productive. Participatory methods have been critiqued as an extractive use of stakeholder knowledge as a source of data, to be constructed into scientific knowledge. Participation is often a name put on processes where diverse knowledges are still seen as data to be collected, to be used in the production of scientific knowledge (Boogaard, 2021; Latulippe & Klenk, 2020). In transdisciplinary research, there are different views on this, with some seeing this as a necessity to transform and refine the co-produced knowledge into scientifically relevant knowledge (Jahn et al., 2012) whereas others see this as a process that moves away from the societal relevance of knowledge, back into disciplinary boundaries (Felt et al., 2016). In reality we see that forms co-exist, knowledge sharing, linear knowledge transfer and co-production all exist in the participatory project. Linear, top-down models persist while other peer-to-peer learning or bottom-up knowledge systems develop (Sutherland 2017). This can also not be detached from the history of science, where old approaches have left a legacy, cementing the positions of stakeholders and researchers and what these positions ought to be (Doudaki & Carpentier, 2021).

5.5.3 Implications for future PTB

However, we find it difficult to claim that the approaches that researchers took to deal with tensions achieve the creation of co-produced theories between stakeholders and researchers. Things could be different, and as the final words of the results described, researchers realise that co-theorising is still a desirable aim. The question is to what extent this full co-production is also an achievable aim. This is something that many researchers have struggled with, and where consensus is missing (Djenontin & Meadow, 2018; Genat, 2009; Ludwig et al., 2021; Nowotny, 2003). This also leads us to our final reflection, to describe the implications of our results to the potential of PTB. Our article so far has indicated the various challenges and tensions in involving stakeholders in the construction of theories and theoretical concepts. This, to an extent, is specific to the structure of the investigated research project, which is limited in time and scale to four years with relatively limited participation.

Schikowitz (2020) calls for the option to allow scientists to fully engage in the production of societally relevant knowledge. This indicates that the role of theory in participatory projects needs to be looser, not defined at the start, as the knowledges needed in the living labs cannot be *a priori* defined. The question might also be whether the stakeholder needs to be involved in the production of concepts and theories, which is a fundamental question that should be asked at the start of the research project. A simple demand to co-produce all knowledge is too simplistic to us. It might be more beneficial to choose for specific elements where significant levels of participation are achieved and decide that other elements of the research project remain off-limits to the stakeholders. The approaches that researchers took in our research, and the compromises that they made in having stakeholders participate are fairly similar to this approach.

To a broader extent, this research also calls into question the whole idea of having a project framework and project theory. The use of it to the project is to allow researchers a comparative element, to link separate cases together and to provide unified results to project funders and other audiences. While this might work, our case study showed the limited connection that these concepts have to the reality on the ground. The formulation of theoretical concepts before allowing participation seems to fall into the trap that the projects and concepts claim to avoid, namely the transfer of universal technologies and theories to diverse and dissimilar contexts. A requirement for PTB, based on this analysis, is to start from the reality of the different living labs and to build theories on this, in a process that gradually compiles and integrates the different findings and results from the living labs. There is the potential to have overarching concepts and theories, which explain different contexts, but these cannot be predefined. The question that remains is whether the research project in its current form allows for this approach to theory building, as these project are restricted in time, deal with a large number of partners and actors, and their structure does not easily allow participation at early stages of the project (Cronin et al., 2022). However, like the flexible but imperfect approaches researchers took in this case study when dealing with tensions in participation, we believe that there are opportunities and potentials to do the same for co-theorising with participants. Imperfect, but making it work.

CHAPTER 6. DELIBERATIVE ASSEMBLING: TINKERING AND FARMER AGENCY IN PRECISION AGRICULTURE IMPLEMENTATION IN AUSTRALIA, FRANCE, AND THE NETHERLANDS

This chapter is based on:

Higgins, V., Van Der Velden, D., Bechtet, N., Bryant, M., Battersby, J., Belle, M., & Klerkx, L. (2023). Deliberative assembling: Tinkering and farmer agency in precision agriculture implementation. Journal of Rural Studies, 100, 103023.
https://doi.org/10.1016/j.jrurstud.2023.103023

Author contribution statement: Vaughan Higgins**:** Funding acquisition, Conceptualization, Investigation, Formal analysis, Writing - original draft, Writing - review & editing; Daniel van der Velden: Conceptualization, Investigation, Formal analysis, Writing - original draft, Writing - review & editing; Noemie Bechtet: Conceptualization, Investigation, Formal analysis, Writing - original draft, Writing - review & editing; Melanie Bryant: Funding acquisition, Investigation, Formal analysis; Jane Battersby: Investigation; Melissa Belle: Formal analysis; Laurens Klerkx: Funding acquisition, Conceptualization, Writing - original draft, Writing - review & editing.

Note: Vaughan Higgins is the first author of this work. Daniel van der Velden has helped write the first drafts of the introduction & theoretical framework, wrote the methodological frame of this study and developed and analysed the case study in The Netherlands. The formal analysis was a collaborative effort between the different authors.

Link with the other chapters and with the main research question

The third empirical chapter builds on the notion of digital technologies in agriculture and on agency in the digital transformation. Central to this chapter is an understanding of agency in the assemblage of precision agriculture on farms and how farmers make new technologies work while preserving local cares. A *choreography of care* lens provides an understanding of the forms of *tinkering* by which farmers attempt to make precision agriculture workable, and what these forms mean for farmer agency. These theoretical approaches fit within and build upon the relational ontology that is central to this work and that has been elaborated upon in chapter 3. Through our analysis, we show that much of the tinkering by farmers is aimed at holding together their own priorities, routines, and experiences with practices inscribed in precision agriculture technology, such as dependence on commercial advice, data-driven knowledge, and commitment to a single technological platform/company. Integral to this tinkering work are support networks that include agronomists, advisors, machinery dealers and farmer discussion groups. Together, these forms of tinkering provide new answers to how farmer agency can be understood and provides an understanding of how deliberate acts by farmers shape the use of precision agriculture.

6.1 Introduction

Assemblage thinking is becoming an increasingly important approach in critical research on food and farming (Dwiartama et al., 2016; Forney, 2021; Forney & Dwiartama, 2022; Jones et al., 2018; Konefal et al., 2019; Sutherland et al., 2023; Sutherland & Calo, 2020). Part of the broader 'relational turn' in agri-food studies, which dates back to the late-1990s, assemblage thinking is consistent with a relational approach in drawing attention to the contingency, indeterminacy and material heterogeneity in what might otherwise be conceptualised as totalising macro-structural patterns and processes (Carolan, 2017; Darnhofer, 2020). Application of this approach has been significant in identifying the diversity of human and material participants, and the distributed forms of agency and power, through which farming worlds are assembled – particularly in the context of new technologies (Comi, 2020; Forney & Dwiartama, 2022; Legun, 2015). However, in work to date there is relatively limited attention to assembling from the perspective of farmers (Klerkx et al., 2019), and specifically the work of farmers in 'assembling and reassembling socio-material practices that are diffuse, tangled and contingent' (Mcfarlane, 2009, p. 562).

Sutherland & Calo, (2020) provide a useful starting point in examining assembling from the perspective of farmers. Following Müller's, (2015) advice that there is much to be gained from bringing assemblage thinking into dialogue with other social theories and theorists, Sutherland & Calo (2020) integrate assemblage theory with the Bourdieusian-inspired concept of the 'good farmer' to highlight how new entrants to crofting in Scotland draw upon a range of actants in assembling the farming business and in establishing an identity as a crofter. Legun & Burch (2021) also examine assembly work from the viewpoint of farmers. Integrating a Responsible Research and Innovation Framework with assemblage thinking, they investigate the different ways in which New Zealand apple growers are practically assembling their farms to anticipate the introduction of new robotic technologies. Their research emphasises 'the central role of producers' practical and material worlds' in shaping apple growers' 'intentions, explanations, and visions for the future' (Legun & Burch, 2021, p. 381). The work of Sutherland & Calo (2020) and Legun & Burch, (2021) is important in highlighting the creativity, flexibility, and active agency in how farmers assemble their farms. For example, Sutherland & Calo (2020, p. 541) point to how crofters 'were creative in their mobilisation of new networks and opportunities for their crofts', while Legun & Burch, (2021, p. 389) identify a large number of growers in their research 'exhibiting deliberative assembling tendencies' who 'were industrious in how they navigated complex institutional, political, and ecological terrains in order to map their own trajectories'.

In this paper, we build on these deliberative conceptualisations of assembling by investigating how farmers assemble new technology and make it workable in the context of their existing support networks as well as farming knowledge, priorities, and practices. We do so through the application of post actor network theoretical work on *tinkering* (Law, 2010; Mol et al., 2010; Singleton & Law, 2013) to case studies of precision agriculture implementation within arable farming systems in Australia, the Netherlands and France. Precision agriculture – broadly defined as the use of information technologies to collect data on in-field variability, tailor input use to address that variability, and to monitor outcomes (Srinivasan, 2006) – is a burgeoning area of inquiry for social scientists interested in the future of food and agriculture (Eastwood, Ayre, et al., 2019; Gardezi & Stock, 2021; Klerkx et al., 2019). It also provides an important focus for this paper given the growing use of assemblage thinking in identifying the imaginaries and diverse forms of agency that the socio-material relations surrounding precision agriculture make possible or foreclose (Carolan, 2017; Comi, 2020; Forney & Dwiartama, 2022; Legun, 2015; Legun & Burch, 2021; Sutherland et al., 2023).

In applying theoretical work on tinkering, we address the following research question: *Which forms of tinkering do French, Australian and Dutch farmers employ in assembling precision agriculture to make it workable and what do these forms of tinkering engender for farmer agency?* In engaging with these questions, the paper builds on scholarly thinking related to assembling processes in precision agriculture in two key ways. First, recent work has been oriented to shifting debate from what technology is to what technologies do, or what they engender (Carolan, 2017; Ogunyiola & Gardezi, 2022). Such a shift is valuable in moving away from totalising narratives of technology towards more distributed accounts of power and agency. Nevertheless, it has had the consequence of prioritising the ways in which socio-material relations assembled beyond the farm shape the practices or options that are thinkable and do-able by farmers, including the possibility of alternative farming imaginaries (Comi, 2020; Legun, 2015). This downplays what Forney & Dwiartama (2022) refer to as 'everyday digitalisation', which includes the deliberative forms of assembling used by farmers (Legun & Burch, 2021) that make precision agriculture workable and practicable on-farm, something that we address in this paper through a tinkering lens. Second, the application of assemblage thinking to precision agriculture, and food and farming more broadly, has tended to focus primarily on examples within, or from the entry point of, a single country, such as the United States (Comi, 2020), the United Kingdom (Jones et al., 2018) or Switzerland (Forney, 2021; Forney & Epiney, 2022). We expand this focus by drawing upon case studies of precision agriculture implementation across three countries – Australia, the Netherlands and France. Our focus on the forms of tinkering involved with precision agriculture implementation in three countries provides important insights into the 'multiple spatial imaginaries and practices' (Mcfarlane, 2009, p. 566) involved in making precision agriculture workable. It also enables a multi-national grasp of the tensions and challenges involved as farmers navigate those practices, and a broader body of evidence to assess which imaginaries originating with farmers might have the potential for governing force across wider domains (Carolan, 2020a).

6.2 Theorising tinkering as deliberate assembling: holding together, separations, and experimentation

At face value, the notion of tinkering is similar to 'assembling' in its focus on the heterogeneous and experimental, yet also patterned, practices through which diverse socio-material relations are held together (Singleton & Law, 2013). Where tinkering builds on these concepts is in its explicit emphasis on the deliberative work of *human actors* in making new practices or technologies workable in the context of 'existing knowledge-practices and farming goals' (Higgins et al., 2017, p. 200). Significantly, tinkering is also conceptualised as *care-ful* work (Mol et al., 2010; Singleton & Law, 2013) in that it is oriented towards farmers engaging with practices and priorities beyond what they care for intrinsically or immediately, also what have been called 'non-local cares' (which vary from farmer to farmer). Farmers are expected to incorporate these non-local cares – such as food security, environmental management, and 'smarter' technology – in ways that fit with their existing farming knowledge, practices, priorities, and experiences (i.e., their 'local cares'). In this sense, tinkering is central in enabling farmers to make non-local practices, techniques, or technologies 'more acceptable and effective' (Krzywoszynska, 2016, p. 305). Yet, while tinkering is a potentially useful concept for exploring the deliberative assembling work of farmers, there has been limited effort to-date to provide a systematic conceptualization in the context of agri-food technology or precision agriculture more specifically. We argue that Law's work on 'care as choreography' is particularly useful for agri-food scholars in conceptualising the tinkering work 'that allows situated action' (Law, 2010, p. 67) on the part of farmers, and which in the context of this paper, enables precision agriculture to be made locally workable. For Law, managing wider cares in the context of localised farming practices, knowledge, experiences, and priorities is best conceptualised as *choreography*. Drawing from his research on veterinary practices, Law (2010, p. 67) defines the choreography of care as 'the intricate ordering and distribution of bodies, technologies, architectures, texts, gestures and subjectivities'. While in our paper we will not take care as a central concept, the relevance of the work on choreography of care for our analysis is that it involves three inter-related types of tinkering work which shape our analytical lens.

First, tinkering involves the use of routines (Law, 2010) or patterned practices (Singleton & Law, 2013) for *holding together* different elements and objects (e.g., bodies, technologies, architectures). These practices rest on situated expertise (Krzywoszynska, 2016; Legun et al., 2022) and forms of skilled craftwork – 'the application of knowledge through embodied skills and practical judgement, and skilled interaction via manual skills with the material world' (Higgins et al., 2016, p. 27). They provide the basis for making non-local sets of practices with which farmers are expected to engage workable on-farm. However, while routines are important for farmers in holding together wider sets of practices with their farming knowledge and priorities, they also give rise to tensions, often struggling 'with the flexibility and adaptation typical of farmers' activities' (Krzywoszynska, 2016, pp. 304–305). Such wider, non-local practices may produce ways of knowing that collide with or rub alongside local practices and ways of working (Gill et al., 2017) or they may not recognise local practices as being important at all (Higgins et al., 2016). In this way, farmers may find their experiential knowledge and practical skills colonised, punctuated, disembodied, and rendered invisible (Singleton, 2010, p. 250).

Second, tinkering also involves creating *distance and separations* between local farming practices and wider practices. Farmers are simultaneously managing multiple elements and objects, and these are not always compatible or coherent (Law, 2010). These 'disconnection rituals' (Singleton & Law, 2013, p. 269) shape what is to be kept outside of or away from their on-farm practices. For example, Higgins et al. (2018) draw on the concept of 'fluid engineering' to identify two key practices used by Australian beef producers to establish distance between their on-farm biosecurity practices and those sites and spaces off-farm perceived as posing a high risk to the health of their cattle. These are selective purchasing of cattle combined with isolation on arrival to the farm, and the use of physical materials such as fencing and restricted entrance points to the property to control human and non-human movement across property boundaries. While separation is central to tinkering work, as illustrated by the example above, Singleton & Law, 2013 (p. 272) argue that some separation practices may also be understood as a form of practical resistance to wider practices by enacting forms of otherness *within*, and '*attending* to that otherness without attempting to capture it' (emphasis in original).

Third, routines for holding together *and* separating on-farm practices and wider practices are experimental in character. According to (Law, 2010, p. 68), routines grow out of repertoires of past practice – 'but they are themselves a form of trial and error, involving the creation of new practices for separating and handling tensions between different subjectivities and objectivities'. Experimentation and adaptation are central to the concept of tinkering. This reflects the observation by (Mol et al., 2010, p. 15) that tinkering involves 'people willing to adapt their tools to a specific situation while adapting the situation to the tools'. Higgins et al. (2017) apply this approach to tinkering in their study of precision agriculture implementation by growers in the Australian rice industry. They use this distinction to highlight two forms of tinkering – adaptation of new technology to work with existing machinery, and the use by growers of other people's machinery with precision agriculture technology already installed. For Higgins et al. (2017), these forms of tinkering are crucial for growers in negotiating and working around wider modes of ordering.

Law's choreography of care approach is thus useful in capturing the three core dimensions of tinkering work which inform our analytical lens – holding together, separations, and experimentation. It also provides insights into the different distributions of agency that are involved in tinkering. In the remainder of the paper, we examine how the three dimensions of tinkering are applied by farmers across our three case studies to make precision agriculture workable, and what the relationships between these dimensions engender for farmer agency.

6.3 Methodological approach

We employ a comparative case study approach (Bartlett & Vavrus, 2017) in order to understand how farmers make precision agriculture workable and how they implement precision agriculture technologies on their farm. This paper is structured around three different cases studies, situated in different countries. The case studies analysed in this paper were developed independently, which result in a slight variety in contexts, methods employed, and actors involved. Differences can be seen in the analysis of precision agriculture through a focus on a range of technologies (Dutch and Australian cases) or through focusing on a specific precision agriculture technology (French case). This way of doing a comparative case study fits well with the process-relational turn in agri-food studies (Darnhofer, 2020). This follows the approach of Bartlett & Vavrus (2017) to case studies, which includes a broader variety of cases in order to trace the phenomenon of interest.

Rather than pre-determining cases and striving for generalisability, this approach is informed by a focus on a phenomenon (precision agriculture for our cases), where the case develops around the phenomenon and follows the research. Such an approach allows us to remain open to what arises from the cases, more than other case study approaches would allow (Yin, 2009). The approach of Bartlett & Vavrus (2017) to comparative case studies fits well with the process-relational perspective on farming, as it allows for new facts to emerge during the research process and as it enables us to trace precision agriculture as a set of material technologies across the different cases. Rather than starting with a pre-defined research plan and goal in mind, we took the understanding of precision agriculture as a goal, and traced precision agriculture through the context of each of our cases. This focus on precision agriculture as a set of technologies with material effects on farms allows us to focus on how the concrete material nature of precision agriculture is changing farms and farming.

This takes different forms across the cases, which shows the attention to particularities of local contexts, but also shows similarities across the cases on the use of precision agriculture, how actors engage with precision agriculture and how precision agriculture is transformed in practice. To trace the use of precision agriculture, the case studies employed similar methods, conducting semi-structured interviews, predominantly with farmers, across three countries – Australia, the Netherlands, and France. While there is a difference between the timing of the case studies (2015-2019 timespan), this did not significantly change the findings between the cases, and we do not assume that the use of precision agriculture has radically changed during this time. An overview of the case studies is provided in table 8 on the next page.

The Australian data used in this paper draws from a larger two-year project conducted between 2015–16 which aimed to investigate the social factors influencing technology adoption by Australian rice growers across a number of examples including (but not limited to): new rice varieties; precision agriculture; water management technologies and electronic communication. To explore the social drivers and enablers of change, qualitative research consisting of semi-structured interviews was conducted with 59 rice growers who were currently using or who had previously used some form of precision agriculture technology from across Australia's three main rice growing regions – Murray Irrigation Area (Murray) (25 interviews); Murrumbidgee Irrigation Area (MIA) (25 interviews), and Coleambally Irrigation Area (CIA) (9 interviews). A purposive sampling technique was used to ensure that a diversity of enterprises and growers were represented.

The Dutch data draws on research conducted between November 2018 and February 2019. This research explored how Dutch crop farmers apply and make precision agriculture workable on their farms. Qualitative research consisting of semi-structured interviews was undertaken with 26 participants. Included in the research were crop farmers actively using precision agriculture (CF) (14 interviews), (farmer-)contractors (CON) (3 interviews), researchers (RES) (3 interviews), and people working in the industry (IND) (6 interviews). A purposive sampling strategy was used to select farmers who had experience with precision agriculture to some degree, ranging from the adoption of auto-steering technology to what some would call agriculture 4.0 farms (Wolfert et al., 2017), which integrate a wide range of digital technologies and data streams.

Table 8: Overview of the case studies used in this research chapter

	Data/Interviews	Context	Timing	Technology
France	33 wheat and rapeseed farmers	Wheat and rapeseed farming in France	2018-2019	Users of a specific decision support tool
The Netherlands	26 interviews among crop farmers, farmer-contractors, researchers, and people working in the precision agriculture industry	Crop and arable farming in The Netherlands	2018-2019	Any precision agriculture technology
Australia	59 rice growers	Rice farming across the rice growing regions of Australia	2015-2016	Any precision agriculture technology

Finally, the French data was collected between 2018 and 2019 in the context of the European AgriLink H2020 project and focused on a specific type of precision agriculture technology: a decision support tool (DST) for fertilisation. The aim of this tool is to optimise nitrogen fertilisation for wheat and rapeseed by applying the optimal amount of nitrogen on the optimal spot on the field. Data were collected on farm structure, farm general management, precision agriculture adoption and the advisory environment. A total of 33 farmers (F) were interviewed: adopters (who had adopted DSTs and were still using them at the time of the interview), non-adopters (farmers who never used the innovation) and droppers (farmers who adopted the innovation but subsequently dropped it and were not using it at the time of the interview). Using a purposive sampling strategy, conventional farmers were selected for the research who grow wheat or rapeseed with different farm structures in one specific French region (Gers, NUTS3 level). French farmers involved in this study were all male between 21 and more than 70 years old. A large proportion of farmers had responsibilities in the farming sector: 30 per cent of farmers were affiliated with a farmer union and 18 per cent were board members of a farm cooperative.

The similarities and differences between the Australian, Dutch, and French cases allowed us to contrast and compare the cases for analysis. Through cases that have enough similarity (as in crop farmers from the global North who use precision agriculture), we can see how precision agriculture technologies are used across these different cases and how similar technologies in different contexts lead to locally situated practices. This form of analysis following Bartlett & Vavrus (2017, p. 52) classification can be seen as a homologous horizontal case comparison (taking similar groups as cases in dissimilar contexts that share corresponding features). We made analysis concrete by first developing short narratives (2–5 pages) that were written by the principal investigators for each of the case studies. The goal of these narratives was to highlight how farmers make precision agriculture technologies workable. The narratives were developed independently, organised around the core question: how and in what ways do farmers make precision agriculture technology workable? Through discussing these narratives among the authors and by comparing the narratives, similarities and differences in themes and trends were identified that showed how farmers make precision agriculture workable, and the implications for farmer agency. We discuss these themes and trends in the discussion. The narratives were shortened in order to fit within this paper and are presented in the following section.

6.4 Tinkering and precision agriculture implementation: case studies from Australia, the Netherlands, and France

6.4.1 Australia: the role of local agronomists in holding together precision agriculture with grower knowledge and practices

Based upon thematic analysis of the Australian rice grower data, two key practices were identified – standardising of machinery and retrofitting of existing machinery – through which growers seek to make precision agriculture workable on-farm. These practices are reflective of broader tinkering work by growers in holding together precision agriculture technology with their existing routines. At the same time, cutting across both practices is another form of tinkering – disconnection. Growers draw upon the expertise of actors external to the farm – principally local agronomists– who are utilised to support growers in making precision agriculture technology workable but also in enabling them to disconnect from sources of advice that are seen as unhelpful or unreliable.

The first practice for making precision agriculture workable is the standardisation of machinery brands, or the conversion of a farms' machinery to a single brand. Whilst used by a minority of grower-participants, standardisation was reported as enhancing grower control over the implementation of precision agriculture. As such, it enabled growers to keep the implementation of precision agriculture as simple as possible and to use technologies seamlessly across different pieces of equipment. For example:

It's less complicated [using one company's system]. It's compatible. Like you can take it out of the tractor and put it in the header, and then take it out of that tractor and put it in another one, and it's just all you have to do is plug it in. (CIA7)

We're 100 per cent John Deere. One hundred percent. I just find it's easier because trying to teach dad and other staff, if we just try to learn one screen and one system it's just easier. We're just trying to keep it simple, everything's plug and play. (MIA5)

Despite standardisation working well for some, most growers were hesitant to standardise under the one brand. The key concern for growers who had already standardised, or who were considering standardising, their equipment was the likely trade-off they would face between simplification and ease of use on the one hand, and potential technological lock-in on the other. Such a trade-off was judged to be too risky to grower's autonomy and flexibility: 'John Deere like to keep everything in-house so they won't share, they don't share …. Because we're dealing with electronics and codes and things like that, it's so easy to lock the technology up so you're captive to their product' (MIA8). These concerns were exacerbated by past negative experiences with the after-sales service provided by machinery companies:

Very rarely do [technicians] come out and fix the problem. They'll come out, half fix a problem and tell you you'll be right and then they're out the gate and you'll get a phone call from someone on a machine, this thing's gone down again. We are getting to the stage where we cannot work without it, and that's a big problem. Like your GPS goes down with your steering, you know you steer, but when we're doing stuff in row crop, if the GPS goes down, you stop, like you have to. (MIA10)

As a consequence of poor service and concerns about trade-offs, most growers opted to instead retrofit precision agriculture software on existing machinery. Retrofitting involves installing and/or modifying precision agriculture technology on existing machinery. This was judged by growers to avoid the high cost of investing in brand new equipment that has the technology already installed. A number of growers had experienced success in retrofitting and expressed pride in their ability to adapt new technology to older machinery. For example:

I've got a little tractor which has got the steering wheel and an early screen, I take it out of that and put in my 2000 year model Case header, *so I've got John Deere GPS in the Case header, it works alright. It's just a matter of adapting things. (MIA7)*

Retrofitting was reported as providing growers with greater flexibility in implementing precision agriculture technology at a pace aligned to their priorities: '*that's one of the really good things about precision ag, you don't have to do it all at once, you can do it bit by bit and you can update older gear*' (MVIA7). Nevertheless, the capacity to retrofit was widely observed to be hampered by challenges in the availability and reliability of support from machinery retailers and companies, an issue applicable also to those growers who had opted to standardise their equipment under one brand. For example:

But of course as soon as you're in the machinery thing and you sign the thing, yeah, mate, we'll look at it mate, we'll look after you, don't you worry about that. And you're out in the paddock and you're going oh shit, and you're on the phone. No, no, we're busy. Isn't there somebody else there? No. (MIA2)

The lack of support from machinery dealers and companies meant that growers tended to rely heavily on existing independent support networks, primarily advisors and agronomists, in making precision agriculture workable. Some growers observed that agronomists, and especially retail agronomists, do not always have the specific precision agriculture technical knowledge or skills: 'They're not necessarily up to speed on the engineering side of things and they don't want to make a commitment that might be expensive for them later' (MVIA18); and 'their business is weeds and chemicals and fertilisers' (MVIA21) rather than precision agriculture. Nevertheless, it was the trusted independent advice separate to the commercial interests of transnational machinery companies that was most valued in supporting growers in making precision agriculture technology workable. For instance:

[Our agronomist] comes out and he'll give you advisory information, but he's not telling you need to have, or trying to tell you anything's better than what you're doing. He'll come out and he might suggest what technology you've already implemented to use it while you're

there, but he's not trying to get you to upgrade or do anything to improve your technology. He'll work with what you've got. (CIA4)

My agronomist now runs on an I don't know what programme or format it is but he comes out and has a look and when we go round he's just got his computer and he's dot, dot, dot and he goes home and a couple of hours later, or whatever, it comes through on my computer and it's the paddock, the hectares, the picture of the paddock, the rates, the chemical, what I've got to do, everything called in under it. (MIA16)

As a consequence, independent advice and support from agronomists is critical in enabling growers to engage in two forms of tinkering work – holding together new technologies with their existing knowledge, routines and practices, whilst also enabling disconnection from those sources of advice that are viewed as unsupportive or unreliable. The support networks drawn upon by growers contrast with our Dutch case study below where machinery dealers and local ag-tech companies, rather than agronomists, are judged to provide the most valuable support in making precision agriculture workable.

6.4.2 The Netherlands: disconnections between farm advisors and farmers in the interpretation of precision agriculture data

Based on a thematic analysis of the Dutch data, three practices for making precision agriculture workable were identified: standardising under the one brand, modifying or retrofitting older machinery with precision agriculture technology, and the use of external actors such as advisors, machinery dealers, researchers, and other experts. These are outlined in more detail below. While these practices are similar to the Australian case study, in terms of their broader orientation towards holding together as well as disconnecting, we also find evidence of experimentation and trial and error by farmers in the process of navigating different support networks.

The first practice identified in the Dutch data is the standardisation of machinery brands. Because most Dutch crop farmers are typically not limited to a single brand of machinery, this is quite a radical step to take. Most of the Dutch participants discussed the *potential* of standardisation in solving connectivity and compatibility issues between precision agriculture technology and machinery. However, it was also generally dismissed as something that was either too expensive, or as something that would reduce their flexibility in purchasing equipment, two things that were seen as a large downside to this strategy. Nonetheless, two farmers in the research had taken the step of standardising their equipment, with all precision agriculture equipment from the same brand. One of them explained their rationale for standardising:

Well, the simple thing is, I am a John Deere man. That will not change in my life. And I would have to get my tractors modified and all that if I would use the auto-steering from the brand where I previously bought it. So I would constantly be playing catch-up because you have two systems running at the same time. That wouldn't work. (CF9)

While standardising restricted flexibility in purchasing new machinery, the farmers in question judged that this was the simplest approach for their farming operation. This was described in similar terms by other farmers, although not always connected to standardising equipment. For example:

The three-clicks-rule is a rule that my employees have implemented. If it's more than three clicks [to use a piece of software] they won't use it. Google and Facebook can do that right? […] And I remind the guys developing the software of that, they find me a pain-in-the-ass, but I will give them that feedback. (CF2)

Similar to the Australian rice case study, Dutch farmers were generally wary of standardising under the one brand. However, those that did so reported benefits in addressing compatibility issues and a more straightforward 'plug and play' experience. In contrast to the limited interest in standardising, most participants had experience in the retrofitting of older machinery and the modification of (new) precision agriculture machinery. Modifications often occurred in collaboration with machinery dealers and local ag-tech companies at the time of purchase. Farmers engaged these companies to customise and change the machinery to fit their farm management practices. Several of the farmers interviewed had been directly involved in modifying aspects of precision agriculture technologies. For example:

About five years ago I bought a second tractor with GPS. At the same time, I bought a new sprayer, but the issue was that I would have had to buy a second GPS system and section control for the sprayer. And I thought, I already paid 15,000€ for the GPS, I don't want to buy a separate one for the sprayer. Of course I was right, but in practice it didn't work like that. So I approached the dealer, an ag-tech company and the importer, and discussed whether we could connect that [the GPS across both machines]. Because of course it is nonsense that you have a tractor with GPS and five metres behind you have a sprayer with its own separate GPS. And then they managed to connect it all. And in spring it all worked and I could use a single GPS system. (CF7)

Concurrent with modifications to new machinery, farmers were also retrofitting older equipment and changing machinery to be able to use precision agriculture. The simplest example of this is the range of GPS systems that can be built into an older tractor, which most farmers had used at some point. However, farmers were also going further, modifying auto-steer and variable rate technology and installing it themselves without having to buy new and expensive equipment. The following conversation between the interviewer (INT) and a farmer (CF14) provides an illustration:

[INT] Yes, and the machines you have, were they ready to use?

[CF14] Well I modified them quite heavily actually. That might be my own stubborn side, because I believe I should be able to do it myself. So I built them myself, all the auto steering I built myself, but also some of the other technologies. Also because I like to do it. […]

[INT] And how does it work, to build a machine like that?

[CF14] Well, it is mainly looking it up on the internet, through Google. There is always someone who has done it before. […] And a lot of the variable rate applications, well it's just all electric motors that drive it and you can easily vary their speeds. So that is pretty standard and the rest you build yourself.

Specific to many of these modifications are the strong networks that many of these farmers had. Farmers often spoke about the key role for machinery dealers and local ag-tech companies in making precision agriculture useable. Ag-tech companies that cater specifically to the Dutch market were judged to be particularly important to the implementation of precision agriculture in Dutch cropping systems. This is something that was seen as important by the different interviewees, as it allows precision agriculture to work for the specific circumstances of Dutch arable farming. For example:

Trimble is American, a fairly decent program. But well, you can only ask so much as a Dutch crop farmer. And then there are companies like DAKON, which are very active on the Dutch market, and they see our challenges and can switch much faster. (CF4)

In contrast, farmers judged that when it came to the *interpretation* of data generated by precision agriculture technologies, support from local networks was far from adequate. There is evidence from the interviews that some advisors were integrating precision agriculture into their business:

What we saw is that farmers have to purchase data, through scans or through drone flights, but that in the end that data has to be understood by the crop farmer. And we thought that we should change that, that the crop farmer needs ready-made data that he can understand. And as an advisory service you need to prepare this for him and involve the farmer to understand how he wants to use it. (IND4)

However, this support was viewed as having a long way to go in providing the support needed to effectively interpret precision agriculture data. For example:

[INT] How do you see the advisors who work with precision agriculture?

[CF5] Their knowledge level? […] Terrible. Yes. They might know how to make a variable rate map, but they haven't got a clue of how to use it. […] My own advisor is more someone I can talk to. He knows what I can spray and when I should use it. […] But with precision agriculture, if I discuss that with him? Well, he'd go crazy. He doesn't get that.

This was something that many of the farmers had struggled with, having to ultimately find their own way of interpreting the data they received through various technologies.

The problem for our farm is really the agronomic interpretation. You have soil scans, organic matter, and you want to do something, but which algorithms should you use? And then I often do it based on my own farmers' feeling. But it's not very scientific then. (CF14)

Thus, whereas in the Australian rice case study agronomic advice was trusted in supporting precision agriculture implementation and data interpretation, in the Dutch case such support from agronomists was judged to be almost entirely lacking. In these circumstances, farmers fall back on their own experiential knowledge for interpreting data, and they draw upon the support provided by machinery companies and national ag-tech firms to adapt the technology to their own priorities and goals. The different and complex ways in which support networks are central to tinkering work, variously facilitating or complicating efforts by farmers to make precision agriculture workable, is highlighted further in our French case study below.

6.4.3 France: integrating different sources of support to fill gaps in local advisory services and make precision agriculture workable

Based upon the thematic analysis of the French farmers, we identified a specific form of retrofitting and seeking support from different local advisory organisations as the main practices for making precision agriculture workable. To identify these practices, we focused on the goal of fertiliser optimisation, which is central to precision agriculture (Lowenberg-DeBoer & Erickson, 2019). We analysed specifically the use of decision support tool (DST) technology for fertiliser application. This technology is intended for farmers growing wheat or rapeseed and consists of two parts: software (that generates nitrogen recommendation maps) and hardware (machinery that applies the maps on fields).

The first practice we identified for making DST technology workable is a form of retrofitting of existing machinery. Contrary to the Australian and Dutch case studies, retrofitting does not seem to emerge from explicit strategies of farmers. Instead, it results from the structure of the DSTs' market. Farmers buy the software separately from the hardware, directly from their local advisory organisation, with whom they have long-term trusted relationships. To make DSTs workable, farmers often have to retrofit to enable the connection of their existing machines to the nitrogen recommendation maps generated by the software. Also, contrary to the Australian and the Dutch case studies, standardisation logics under one brand are not specifically present to make DSTs workable on farms. In France, local advisory organisations sell to farmers DST software that is independent from machinery brands and thus standardisation is not possible.

Adapting existing machinery to connect hardware to software on-farm requires specific skills. Some farmers explained that they managed to achieve this due to past technical training. As examples:

Oh, it takes a little bit … how shall I put it: you have to have some electronics and computer skills, to make it easy to implement. (F25)

[I have connected it] by tinkering on internet. And then by tinkering, I used mechanical stuff that I used to do. (F26)

In general, most farmers expressed difficulties in connecting their machines to the maps. The first difficulty reported by farmers is that older machines cannot always be adapted to read recommendation maps, and this often leads to less accuracy for in-field application of software recommendations:

"We make an average dose [of what the DST software recommends]. If sometimes there are areas with big gaps of recommended dose as it can be the case possibly on clay rounds […] then we can make [the difference] manually, we make it only manually." (F10)

The second difficulty reported by farmers is that local advisory organisations to which farmers turn for support in the implementation of DSTs often lack competency, even if they are the suppliers of that software. Below is an extract from a conversation between one farmer (F8) and the interviewer (INT) that illustrates this lack of competency from traditional advisors.

INT: So at [the moment to implement DST] the most important information for you was everything related to the tractor?

F8: Yes, absolutely. That was what was essential for me. And the lack here is what made me stop [buying] the [DST] service.

INT: Did you get any help at this moment?

F8: No, frankly no. I thought that the guy who sold me the [DST] service, a technician from [name of cooperative], I thought he was going to find me solutions. But in the end he didn't. He didn't know! I said to myself: the guy wants to sell me the service, but not necessarily give it back to me.

This situation may lead farmers to rely on machinery dealers that specialise in selling the hardware part of DSTs. For example:

[The software] didn't send me the right format […], why I don't know. We had some problems at the beginning to read the maps. So I think that the first year even the first modulated contribution we couldn't do

it because we didn't have the right format, we only had it on the second contribution. We had the help of the machinery dealer to make the spreader work. (F27)

The third difficulty farmers pointed out is a lack of coordination between farm advisors (that sell the software part of DST) and the machinery dealers (that sell the hardware part of DST). Farm advisors and machinery dealers sell distinct parts of the same innovation, without consulting each other. The sales are made separately and rarely take into account the different possible formats of software and hardware. Several farmers had difficulties solving their connectivity issues because machinery dealers and advisors are not used to working together. The following quote is from Farmer 8 who did not manage to make precision agriculture work on his farm due to a lack of adequate support from traditional advisors. To solve his connectivity issue, he had to organise a meeting between his advisor and his machinery dealer during a fair.

I don't do the work anymore, I just manage it, I delegate the work to two other farmers […] one of whom is a bit sharp, he uses new technologies. That's why I went with [DSTs], because I thought he would be able to read the maps. But it was not the case. I am still followed by a technician from the Chamber of Agriculture so I asked him for support. The first year it was the trainee who suggested to me [to use DSTs]. Well, he didn't know how to use the interface between the console manufacturer and the distributor. He didn't know how! […] Finally we solved the problem at [name of local fair] where I had gathered myself [name of the advisor from the Chamber of Agriculture], the manufacturer of the console and the manufacturer of the tractor distributor. (F8)

When it came to the interpretation of the data generated by DSTs, farmers persisted in their interactions with advisors from local advisory organisations despite their lack of expertise on implementation. They questioned their local advisors about how to interpret data and use it on their farms. We observed variations in how recommendation maps were applied. These variations are relevant in that they are linked closely to the different local networks in which farmers are embedded, as we explain below. On the one hand, some farmers trusted the recommendation maps and applied them strictly on their land. For example, one of them explains that he let his machine apply the nitrogen dose as stated in the recommendation map: 'We put the USB key [on the machine], it's the USB key that does everything' (F10). In this situation, farmers are usually embedded in strong trusted relationships with advisors that sold them the software. The conversation below between a farmer (F10) and the interviewer (INT) illustrates this point.

F10: It was a lot with the technician, yes we are almost buddies, we get along very well so I trusted him on the system, on the principle and I am happy with it.

INT: Did you have any problems with the implementation, the accounting with your spreader?

F10: At first, yes […] But now that it's up and running, it's very simple, you put in the USB key, you go and get the plot and it's done all by itself.

On the other hand, making precision agriculture workable does not necessarily mean strict application of the recommendation maps. Some farmers modified the nitrogen dose drawing upon their experience and past knowledge. Farmers who are integrated in local farmer discussion groups put precision agriculture on the agenda of those groups. They discuss the data generated by DSTs in groups and use the experience of other farmers to interpret it differently, in this case modifying the recommended fertiliser dose.

We have the advantage of being [in a local group] where we are about fifteen farmers. We meet every two weeks, on Tuesdays, on different themes, on the seeds to use, on new technologies, new software, phone applications, on all that, and we have the advantage we all get along well, so we discuss everything that works for us, what doesn't work, and we pool our efforts. And since there are no phonies who think they can do better than the others, it goes well because everyone tells the truth, they say when they don't succeed in something, so *there's that too, we can discuss and know what to do, what not to do, what they tried. (F23)*

In conclusion, involvement in different support networks has a strong influence on the way farmers make precision agriculture technologies workable on their farm. Similar to the Australian and Dutch case studies, French farmers tend to rely on specific forms of support – in this case, local advisory organisations – to hold together precision agriculture with existing routines, even if those forms of support lack specific precision agriculture expertise. However, in the French case, trial and error in using different types of support is far more evident than in the Dutch case study, and the work of disconnecting evident in the Australian case study is entirely absent. Farmers continue to use local advisory organisations *at the same time as* utilising machinery dealers and local discussion groups to fill the gaps in knowledge and practical support that advisory organisations are seen to lack.

6.5 Discussion

This paper has drawn upon the conceptual lens of *tinkering* to investigate the research question: *Which forms of tinkering do French, Australian and Dutch farmers employ in assembling precision agriculture to make it workable and what do these forms of tinkering engender for farmer agency?* In engaging with this question, we have sought to contribute to the application of assemblage thinking in agri-food studies, and research on precision agriculture specifically, by giving greater attention to how precision agriculture is assembled from the perspective of farmers across different countries. In this section of the paper, we reflect on the ways in which the three principal forms of tinkering outlined by Law (2010) are evident across our case studies, and how our findings advance scholarly understanding of the role of farmers, and farmer agency, in assembling processes.

First, through our analysis we have identified that across the three case studies much of the tinkering work performed by farmers is aimed at holding together what they value – e.g., local cares such as experiential farming knowledge (Higgins et al., 2017; Ogunyiola & Gardezi, 2022), trust (Gardezi & Stock, 2021; Rijswijk et al., 2022), and farmer autonomy (Forney & Epiney, 2022) – with non-local cares inscribed in precision agriculture technology. These non-local cares include dependence on commercial advice, data-driven knowledge, and commitment to a single technological platform (Bronson, 2019; Carolan, 2018c; Rotz, Gravely, et al., 2019). This is consistent with the use of assemblage thinking in agri-food studies (Forney & Epiney, 2022; Konefal et al., 2019; Legun, 2015) that focuses on the processes and practices through which heterogeneous elements are provisionally held together. Our use of a tinkering lens builds on these understandings of assemblage by providing deeper insights into the *deliberative assembling work* of farmers (Legun & Burch, 2021) and the constraints they experience as part of efforts to hold together different elements.

The work of holding together is evident in the use of *practical judgement* by some farmers in the Dutch and Australian case studies to standardise their precision agriculture technology under the one brand. For these farmers, standardisation provided an efficient and simple way of making precision agriculture technology workable, or holding it together, with existing farming practices and priorities. Despite recognising the potentially 'intolerant and colonising' effects (Singleton & Law, 2013, p. 271) of using equipment from one brand in terms of reducing their autonomy, and risking technological lock-in, standardisation enabled farmers to establish distance from the potentially time-consuming work involved in connecting software and hardware from different brands. This recognises the constraints on agency built into precision agriculture, but despite these constraints, there remain possibilities for agency of farmers. Holding together is evident also in the use of farmers' *skilled craftwork* in retrofitting and/or modifying equipment across all three case studies. This shows how farmers deliberatively re-arrange relations with different technological platforms so that precision agriculture is assembled in ways that align with their existing farming priorities, practices, and experiences, instead of rendering them as subjects without agency vis-à-vis precision agriculture technologies as others have also argued (Brooks, 2021; Gardezi & Stock, 2021).

However, our analysis also draws attention to the challenges farmers face in holding different elements of an assemblage together. These constraints revolve primarily around accessing appropriate support. Previous research highlights the importance of support networks in facilitating learning and reducing uncertainty for farmers in using precision agriculture (Eastwood, Ayre, et al., 2019). Actors such as agronomists and consultants are argued to play a particularly important and trusted role in translating between the formal technical knowledge associated with precision agriculture technologies and the tacit and experiential knowledge of farmers (Ayre et al., 2019; Eastwood et al., 2012; Higgins & Bryant, 2020). To some extent, our findings reinforce these arguments. As we have seen, farmers across our case studies consult for advice and support in implementing precision agriculture technology those whom they trust, such as agronomists (Australia), local advisory organisations (France) and ag-tech companies (the Netherlands). Nevertheless, our results also reveal that these relationships are more complicated than what is documented in the existing research.

Each case study highlights how those actors who farmers trust to provide support also pose challenges in assembling precision agriculture, which connects with and deepens an emerging literature on how advisors adjust to digitalisation and are seeking and building new capabilities and alliances to deliver value to clients (Eastwood, Ayre, et al., 2019; Ingram & Maye, 2020; Klerkx, 2020; Rijswijk et al., 2019). Thus, in our Dutch case study, while advisors from ag-tech companies are important in making precision agriculture technology locally workable, they are judged to provide poor support in the interpretation of data produced by those technologies. In our Australian case study, agronomists are drawn upon to support precision agriculture implementation not because they necessarily have the technical expertise, but due to challenges in the availability and perceived quality of support from machinery dealers and precision agriculture specialists. Lack of on-ground technical support from local advisory organisations in our French case study means that farmers are forced to increase their reliance on machinery dealers. This is further complicated by a historical lack of coordination between these dealers and local advisory organisations. These findings show that while trusted support networks are important in making precision agriculture workable for farmers, this holding together is often partial and is also the result of compromises and trade-offs in accessing appropriate support, an issue that we expand on below.

Second, the use of a tinkering lens in this paper provides details on specific practices through which farmer agency is variously distributed in assembling processes. Applications of assemblage thinking in agri-food research show that distributed agency is central in understanding how farming worlds are assembled (Carolan, 2017; Dwiartama et al., 2016; Jones et al., 2018; Sutherland & Calo, 2020), and the actants relevant to that agency are often identified (Comi, 2020). However, limited empirical insight is provided into how different distributions of agency are assembled (although see Forney & Dwiartama (2022)). Our research identifies three key practices of tinkering through which farmer agency is distributed – disconnecting, trade-offs and compromises, and experimentation. Similar to Forney & Dwiartama (2022) all of these practices emphasise the relational nature of agency.

Evident in our Australian case study is the *disconnecting* (Law, 2010; Singleton & Law, 2013) from those actors who are judged by farmers as making limited or poor contributions in making precision agriculture workable for them – in this case machinery dealers and the transnational companies who supply the machinery and technical support. This form of tinkering theoretically opens options for farmers in choosing the support that fits best with their farming priorities and practices. Yet, in practice it can restrict their options by increasing reliance on local agronomists who may be trusted by farmers, but who lack the technical expertise in precision agriculture. Our French and Dutch case studies highlight how farmers turn to forms of *experimentation or trial and error* (Law, 2010) for addressing gaps in support. This can be a creative strategy for sourcing appropriate technical support and enhancing the capacity of farmers to make precision agriculture locally workable – for example, Farmer 8 (French case study) who, frustrated with a lack of connection among different support networks, organised a meeting between his advisor and machinery dealer. At the same time, it can also be a necessary fall-back where there is lack of adequate precision agriculture support, as in the Dutch farmers who reported falling back on their own experiential knowledge to interpret precision agriculture data.

All our case studies point to the significance of *trade-offs and compromises* by farmers in assembling precision agriculture. This is something that is little recognised in existing agri-food research using assemblage thinking. It is also an important dimension of tinkering that has been previously unexplored. Across our case studies, farmers persist in drawing upon the support of agronomists/advisors despite the reported limitations of their precision agriculture expertise, and, in the Dutch case, their lack of data interpretation skills. Similar to disconnecting, this ensures that farmers can access trusted advisory services in implementing precision agriculture. However, due to the lack of technical expertise it restricts what farmers can do in making effective use of precision agriculture technology on their farm and can lead to greater reliance on farming experience and farmers' tacit knowledge of technology. Trade-offs are evident also in the standardising of technology used by some farmers in the Australian and Dutch case studies. These farmers recognised the potential limitations of using equipment from the one brand in terms of reducing their autonomy, and risking technological lock-in (echoing arguments of: Carolan, 2020; Clapp & Ruder, 2020; Gardezi & Stock, 2021). Yet, this was a trade-off that they were willing to make because standardisation provided an efficient and simple way of making precision agriculture technology workable, or holding it together, with existing farming routines and priorities. It also enabled them to establish distance from the potentially time-consuming work involved in connecting software and hardware from different brands. However, this does not ignore the constraints designed into precision agriculture technologies, manufacturers can work towards building technologies that enable compatibility between different brands. The agency of farmers is expressed despite this design and remains constrained by these limitations.

Third, and finally, the use of a tinkering lens across our three case studies located in different countries extends agri-food research on assembling by enabling engagement with (Carolan, 2020a) call to identify alternative imaginaries that have the greatest potential for governing force (or 'extension') across wider domains. At face value, the practices of retrofitting and modification, used by farmers in all three case studies, have this potential as they enable farmers to make precision agriculture workable in ways that suit their priorities and needs. Their use demonstrates the significance of farmers' skilled craftwork in the deliberative assembling of precision agriculture technology on-farm. While these practices depend on the availability and adequacy of trusted local support, they engage with all three dimensions of tinkering. That is, they enable farmers to hold together precision agriculture implementation with existing on-farm practices in a way that is flexible, adaptable, and is sufficiently disconnected from the risks associated with standardising under the one brand. Indeed, these practices seem to provide what (Singleton & Law, 2013, p. 272) call 'alternative breathing spaces' or a form of 'practical resistance' for farmers that enable a degree of separation from the otherwise colonising realities but also inaccuracies of precision agriculture technology (Brooks, 2021; Carolan, 2020a; Clapp & Ruder, 2020; Stock & Gardezi, 2021; Visser et al., 2021). Nevertheless, because farmers were mostly reliant on various support networks to retrofit or modify, future research needs to assess how and to what extent different actants enable and/or constrain farmers' capacity to retrofit and modify equipment.

6.6 Conclusion

This paper contributes to the application of assemblage approaches in agri-food studies, and research on precision agriculture specifically, by investigating the forms of tinkering used by farmers to assemble precision agriculture across arable farming systems in Australia, the Netherlands, and France, and what these engender for farmer agency. Theoretical work on tinkering enables detailed insights into the deliberative assembling practices through which farmers make precision agriculture workable, and the constraints they face in doing so. Our analysis highlights the significance of practices of skilled craftwork and practical judgement in managing precision agriculture implementation in the context of localised farming routines, knowledge, and experiences. These practices are consistent with previous research showing how farmers are active agents in assembling farming worlds and are not passive subjects to precision agriculture technologies. At the same time, our research points to how that agency is contingent on the complex ways in which farmers navigate various support networks. Farmers across our case studies experience challenges in accessing adequate and/or appropriate precision agriculture support. This gives rise to a range of tinkering practices – disconnecting, experimentation, and trade-offs – that can both open-up or foreclose options for farmers in making precision agriculture workable.

We argue that a tinkering lens provides a conceptually coherent approach for teasing out the different ways in which farmers navigate and contribute to assembling processes, and the nuances in farmer agency that this engenders. We agree with previous research that farmer agency is enacted through different relations in an assemblage. However, application of a tinkering lens reveals the specific practices and forms of support through which those relations are variously held together, disconnected, experimented with, or traded off. As such, we conclude that tinkering provides a valuable approach for enabling agri-food scholars to tease out in greater depth farmers' deliberative assembling practices and how these are made workable in the context of other relations and actants.

CHAPTER 7. CYBORG FARMERS: EMBODIED UNDERSTANDINGS OF PRECISION AGRICULTURE IN DUTCH CROP FARMING

This chapter is based on:

Velden, D. V. D., Klerkx, L., Dessein, J., & Debruyne, L. (2023). Cyborg farmers: Embodied understandings of precision agriculture. Sociologia Ruralis
https://doi.org/10.1111/soru.12456

Daniel van der Velden: conceptualisation; methodology; investigation; writing—original draft preparation; writing—review and editing. Laurens Klerkx: conceptualisation; methodology; writing—review and editing. Joost Dessein: Writing—review and editing. Lies Debruyne: writing—review and editing.

Link with the other chapters and with the main research question

Building on the same case study as the previous chapter, this chapter takes as a starting point the use of precision agriculture by farmers. We argue that central to how farmers understand precision agriculture is the embodied knowledge that they possess. This provides a counterargument to the notion that data-driven knowledge is dominating and replacing farmers' knowledge. In building this argument, we provide examples of how farmers are connecting back to the land and how they are committed to building embodied knowledge while using precision agriculture on their farm. The examples we provide indicate a productive tension between knowledge-cultures, where the farmer has agency over how they combine these forms of knowledge, which we conceptualise as the cyborg farmer. This cyborg farmer, a play to Haraway's cyborg, indicates how technology is used in embodied ways and how different forms of knowledge can supplement one another. In sum, this article provides an answer to our questions about farmer agency and farmer knowledge in making precision agriculture function on farms.

7.1 Introduction

"As a farmer you need to enter your land. You need to feel it, to smell it. That will never change. But of course, farms get bigger. Back in the day you could see all your fields on an evening walk. But today's farmers cannot do that in one evening. So you need a tool to show you what's the matter, that when I take a walk I know where to go."

Farmer CF10, arable farmer in the Netherlands on a 800ha cooperative farm

To feel the land, to smell the land, these are not the terms you might expect when a farmer describes their use of precision agriculture. On the contrary, precision agriculture is often seen to alienate farmers, where they become office workers, far removed from the field (Gardezi & Stock, 2021; Stone, 2022). The connection between farmer and land in these scenarios is, figuratively speaking, little more than the fiberglass cable transmitting data between farmer, fields, and technology.

Techno-optimists describe the potential of these scenarios as something positive and desirable, seeing precision agriculture as the suite of technologies that will bring agriculture into the 21st century, increasing productivity while reducing environmental impacts (Bhakta et al., 2019; Marvin et al., 2022). In these imaginaries, tasks can be taken out of the hands of the farmer, and some (if not all) of the decision-making can be replaced by software and algorithms. Humans might be involved at higher levels of decision-making, but operational activities can be replaced with digital technologies (Wolfert et al., 2017). Decision-support tools, robots, drones and a host of other technologies would take the farmer out of the field and create the autonomous farm (Shamshiri et al., 2018). While this is a vision for the future rather than current reality, these imaginaries do structure development of technologies and future farm work settings (Daum, 2021; Lajoie-O'Malley et al., 2020).

In rural sociology, a large body of critical work has emerged on these same imaginaries of precision agriculture, taking a more cautious position. These more techno-critical, or dystopic scenarios of precision agriculture, describe the risks of precision agriculture for farmers, farm labourers and rural communities. These risks range from negative effects on labour relations and farmer skills, to broader concerns about power relations in the agri-food chain, which shift due to the entry of venture capitalists and software companies (Brooks, 2021; Duncan et al., 2021, 2022; Fraser, 2019; Miles, 2019; Prause, 2021; Rotz, Gravely, et al., 2019). These authors show the downsides of precision agriculture, especially when the visions of large agricultural corporations, big-tech and finance structure the development of precision technologies (Clapp & Ruder, 2020; Duncan et al., 2021, 2022; Miles, 2019). Precision agriculture in its current form is seen as excluding styles of farming other than large-scale mono-cropping, and forms of knowledge other than data-driven knowledge (Brooks, 2021; Gardezi & Stock, 2021; Gras & Cáceres, 2020; Miles, 2019).

These concerns are valid and key to understanding the impact of precision agriculture. At the same time, in these concerns there is often a view of precision technologies as disembodied and placeless tools. An emerging body of work has shown that such dichotomous thinking (i.e. precision agriculture per se excludes certain ways of farming), does not fit with the reality of farming. Instead agriculture has been characterized as a highly embodied practice in which farmers' corporeal and sensorial experiences, and the multiple connections between the farmer and the material and non-human elements in the farm are central (Carolan, 2017; Ditzler & Driessen, 2022; Higgins et al., 2017; Legun & Burch, 2021). Different engagements with precision technology are possible, which can for example include partial use and retrofitting on existing equipment (Rose et al., 2022). These studies connect to a broader call in agri-food studies to attend to the lived experience on the farm and the assemblage (and assembling) of the farm in making agriculture (Carolan, 2016b; Darnhofer, 2020). This calls attention to the micro-politics and small interactions on the farm and its materiality, rather than to broader, deterministic power structures. Beyond looking at visions and imaginaries of the future, it shows how the technology is experienced here and now and shows the messy and improvisational nature of using precision agriculture.

However, despite an emerging body of work on precision agriculture assemblages detailed studies on how farmers embody precision technologies are still scarce, and this is where this paper aims to make a contribution (Comi, 2020; Higgins et al., 2017, 2023). We will show that precision agriculture can be a further expansion of the embodied farmer, not an element apart from the farmer but part of the whole. Precision agriculture becomes an extension of the farmer, where farmer, precision technologies and agro-ecological context are integrated. This is developed through the concept of the '*cyborg farmer*', coined by Klerkx et al. (2019) and Klerkx (2021), but not yet further developed or explored in detail. This concept is based on a posthumanist understanding of precision agriculture, where the body of the farmer is centred as the site of understanding precision agriculture. This is a novel way to think about how farmers engage with precision agriculture, connecting to approaches that show ways of engaging with precision agriculture that go outside of the aforementioned dominant corporate model imposed by ag-tech companies (Ditzler & Driessen, 2022; Higgins et al., 2017; Legun & Burch, 2021). The question that guides our enquiry is: *How does the embodied use of precision agriculture by Dutch crop farmers take shape and what does this mean for the formation of cyborg farmers?*

To answer these questions we draw upon semi-structured interviews with Dutch crop farmers, contractors, ag-tech companies, advisors, and researchers all working with precision agriculture. The respondents were required to have experience in working with precision agriculture.

To further explore this research question we will provide a theoretical framework introducing the key concepts that supported our analysis. We start with a description of how embodiment has been conceptualised in a broad literature on knowledge, digital technologies, and cybernetics. The theoretical framework is followed by the methods section, the findings and a discussion and conclusion.

7.2 Conceptualizing the cyborg farmer

We seek to unravel how precision agriculture is combined and integrated in the socio-material context of the farm and the mechanisms of how farmers use precision agriculture by connecting this to embodied knowledge.

Embodied knowledge and the role of embodied knowledge in agriculture has ties to a broader movement in rural sociology that seeks to understand the diverse knowledges of farmers. Experiential, traditional, local and tacit knowledge are terms that describe the knowledges that farmers develop over time through the physical act of farming (Burton & Riley, 2018; Carolan, 2008; Higgins et al., 2017; Lundström & Lindblom, 2018). In this article we use the term embodied knowledge, which stresses the corporeal aspect of knowledge and highlights the more-than-representational nature of this knowledge (Maclaren, 2019; Phillips, 2014). More-than-representational knowledge can be understood as attuned to the lived experience where the representation of this knowledge, such as in this text, is never able to fully represent this knowledge as this knowledge based on everyday experience, routines, encounters and embodied experience (Carolan, 2008; Lorimer, 2005).

While other understandings of knowledge forms might also understand knowledge as more-than-representational, embodied knowledge makes explicit the role of the body in knowledge production (Carolan, 2008). This means that we see knowledge as a relational achievement that is produced through the body, meaning that knowledge is produced through the extended self, in an assemblage of human and non-human actors (Brians, 2011; Clark, 2008; Gieser, 2008; Heersmink, 2012). This follows a broader relational-material and process-relational turn in rural sociology (Comi, 2019; Darnhofer, 2020; Roe, 2006).

The more-than-representational approach we engage with understands all knowledge as produced through the body, where the body is central to knowledge production. This assumes the integration of mind, body and broader lifeworld, where knowledge is not produced in the mind, but is an inherent quality of the body situated in the world (Gieser, 2008). The mind should not be seen as a separate or single organ, where knowledge is produced based on inputs, but rather as an element in the production of knowledge, where knowledge is produced through the lived body, which simultaneously experiences, acts in, and is aware of the world (Clark, 2008; Cutler & MacKenzie, 2011). The body provides us with access to the world, and tactility and other senses provide this access. We understand and learn about the world through embodied experiences (Hansen, 2006).

In understanding embodiment, our work connects to the work of Ihde (2012) and Verbeek (2006, 2012, 2016). Seeing embodied technologies in terms of prostheses (following De Preester, (2011) and Ihde (2012)) understands technologies as extending the embodied subject but also as consisting of compromises and trade-offs. We follow this understanding, which allows us to see technologies as adding something to the body, but at the same time potentially reducing the functioning of the body in other ways. This is the amplification/reduction structure, where an amplification to one of the senses might reduce the sensorial experience of the other. In this research our main focus is on the perceptual prostheses, through sensor technologies that produce data that can provide new forms of vision to farmers. This is particularly relevant as Ihde (2012) notes that these technologies mediate what is visible, they determine what becomes visible to the farmer, as we will soon show in the findings section. Verbeek (2016) has built on this through the concept of technological mediation, which stresses the non-neutrality of technologies in mediating between humans and the world (Verbeek, 2016). Especially relevant however and helpful to this research is the understanding of mediation theory that technology mediates between humans and the world, and that this mediation is not neutral, leading to opportunities for more ethical technology design.

This addition to the body through technology is integral to the formation of the cyborg farmer. In rural sociology there has been limited attention to the potential of technologies and tools in embodied knowledge production, as the emphasis is usually on landscapes, countryside and nature (Maclaren, 2019; Phillips, 2014;

Roe, 2006). An exception is Carolan (2007, 2008) who emphasises the role of technologies in shaping the body and how technology leads to particular ways of knowing the world. This is for example linked to the use of the tractor by farmers, which provides a unique kinaesthetic experience and viewpoint, placing the farmer inside the field and allowing them to see and feel the land through the tractor (Carolan, 2008). A further example of embodiment of technology is provided by Merleau-Ponty (2002), who described the blind man's stick, which: "ceased to be an object for him, and is no longer perceived for itself; its point has become an area of sensitivity, extending the scope and active radius of touch, and providing a parallel to sight" (Merleau-Ponty, 2002, p. 165). The body is born anew through every interaction with technology, as it is chimeric in nature, forming a new whole through human-technology interaction. Humans and technology have long been intertwined, where it is difficult to tease out where the human starts and the technology ends (if one can do so at all) (Heersmink, 2012). The knowledge available to us is co-determined by the technologies we use, which are integrated with our body (Heersmink, 2012).

Krzywoszynska (2016), who describes care in vineyard growing, helps understand what embodiment and embodied knowledge look like in agriculture. It is a knowledge developed in the agro-ecological context of the farm, developed and shaped through lived experience. To understand embodied knowledge is to understand the impact of taste, smell, feelings, sounds and views in agriculture on the production of knowledge. This embodied knowledge determines which branch is pruned in a vineyard (Krzywoszynska, 2016) and allows people to form a connection to the countryside (Carolan, 2008). We would stress that integral to this formation of embodied knowledge are also the technologies (whether a specific shape for pruning, secateurs, or tractors) that mediate the interactions between farmer and agro-ecological context. These encounters between technology, humans and environment form the farm and inform the embodied knowledge of farmers.

This understanding of how knowledge and technology are intertwined is essential to our understanding of digital technologies. Lundström &

Lindblom (2018) have shown how farmers make sense of decision support systems by connecting the data and information afforded by measurement and modelling technology to their existing embodied knowledge. We take this a step further, where we do not see technology merely contributing to knowledge production. Instead an integration of human and technology, a cyborg, constructs and informs embodied knowledge (Heersmink, 2012). In our view, this perspective synergizes with the recent interest in relational approaches in rural sociology. The embodiment perspective expands on the relational approach that was also used in chapter 6, by providing an understanding of the body as an unstable assemblage, formed through the relations in which it enters with other objects and technologies. The body itself is an assemblage in a constant state of becoming (Brians, 2011; Currier, 2003), entering into relations with its broader agro-ecological context and with other human and non-human actors and assemblages.

This follows broader posthumanist approaches, which have set out the intertwined nature of humans and technology, where these collectives are hybrids, or cyborgs of nature and technology (Bear & Holloway, 2019; Finstad et al., 2021; Haraway, 2006). The collective of human and non-human actors active in farming shapes how we understand the cyborg farmer, developed out of humans and technology (in our case precision agriculture) and showing the relationships between humans and farming environment. Bear & Holloway (2019) and Finstad et al. (2021) explored similar developments between farmers, cows and milk robots, highlighting the more-than-human entanglements that develop. They use the terms hybrids to explore how human and non-human actors are part of mutualistic relationships, existing through the relation to one another. As Søraa & Vik (2021) show, this hybrid is a cyborg, existing through its connections to other actors, through human and non-human animals and through technology.

The cyborg farmer is an embodied collective of human and non-human actors, conceptualised through the body, where the physical presence of the farmer matters. The farmer becomes a cyborg through the extension and augmentation with technology but remains present and embodied in an agro-ecological space. Precision technologies are mediated by the cyborg farmer, which in turn augment and aid the farmer in understanding their fields and crops. Precision agriculture opens up these new spaces, for example through new spatial dimensions provided by drones and augmented reality, new tactile and motorial dimensions provided by automation and robots, and cognitive dimensions triggered by artificial intelligence (Comi, 2020; Klauser & Pauschinger, 2021; Klerkx, 2021; Klerkx et al., 2019). This integration between farmers and precision agriculture, and the implications of this integration has so far mainly been on a conceptual level, where the cyborg farmer is a potential development. In the rest of this article, we set out to show that cyborg farmers are already a reality, and that it is the farmer using precision technologies in an embodied way.

7.3 Methodology

The initial aim of this research was to understand how precision technologies are used and adapted by Dutch crop farmers. In researching this, we based ourselves on the work of Higgins et al., (2017) who show how the adoption and use of precision technologies are ordered by commercial-technological and biophysical factors. Our aim was to understand how farmers adapt precision technologies, how they adapt their farm to precision technologies and how they use these technologies. We (authors DV, LK) opted to use semi-structured interviews with farmers and other actors in the precision agriculture industry to study this. The question list is provided in appendix 7.

It was later, while analysing the data, that we realised the relevance of farmers' sensory experiences in how they understand precision agriculture. These embodied experiences are by nature more-than-representational, which are challenging to capture through representational methods like interviews (Maclaren, 2019). These experiences can also not be fully captured in a codified account (Carolan 2008). Nevertheless, this does not mean that it is impossible to describe the more-than—representational embodied experience of farmers, but rather that this account is but a partial representation of the more-than-representational (Maclaren, 2019; Sutherland, 2021). As Carolan (2008, p. 412) describes "we cannot literally feel in these pages what respondents truly experienced in their lived experience. But this does not mean that we cannot at least get a taste of their world through their words".

Respondents were selected through a purposive sampling strategy combined with snowball sampling. We (authors DV, LK) opted for this approach in order to select respondents that had experience with the use of precision agriculture, which is still relatively new to Dutch farms. The interviews were held with crop farmers (some of whom also did precision agriculture contracting work on the side) (CF, 14 respondents), contractors (CON, 2 respondents) agronomic advisors and researchers (RES) (5 respondents) and people working in the ag-tech industry (IND) (4 respondents), for a total of 25 interviews. Separate question lists were used for people working in the industry and for researchers (see appendix 7). Including broader actors than just farmers allowed us to determine the potential for integrating farmers' knowledges with precision agriculture. The interviews took place from November 2018 to February 2019 and took place on the farm and at the workplace if possible, except for 5 interviews that took place by phone.

The farmers involved in this research varied in their use of precision technologies, their farm size, and in their farming operation. Details about the farmers are provided in appendix 8. Farmers were all male and between the ages of 30-60. Our sample included more young farmers than is typical for the population of Dutch crop farmers, considering the statistic that 70% of farm owners are over 50 years old (Berkhout et al., 2022).

The use of precision agriculture varied between farmers, who to varying degrees used GPS for controlled traffic farming, variable rate applications of inputs, soil and crop scans, and satellite and drone imaging. Farm sizes ranged from about 40 hectares to ca. 800 hectares, which captures the range of crop and arable farms in the Netherlands quite well, although farmers in this research generally have larger than average farms. The farms spanned the different biophysical contexts and crops grown in the Netherlands, including flowers, grains, and root crops. Most farmers grow a relatively standard rotation of potatoes, sugar beets and grains.

Two aspects where our sample differs from the general population of crop farmers are correlated, which means that larger farms are, on average, operated by younger farm managers (Berkhout et al., 2022). We speculate that this is related with the use of precision agriculture.

Extensive use of precision technologies requires capital investments, made possible by having a larger farm. This does not explain why our sample is all male. We did not select for this characteristic, but respondents that replied to our requests for interview were all male. We also asked during the interview whether other people on the farm (e.g. wives, employees, etc.) were involved with the use of precision agriculture but this was typically not the case. A more in-depth exploration of gender in relation to precision agriculture is outside the scope of this article.

Participants in the research were interviewed using a semi-structured interview guide. Interviews took between 30 and 90 minutes. Audio recordings from interviews were transcribed using a clean verbatim style in NVIVO 12. Transcription and data analysis was done in the native language (Dutch). Quotes used in the article are translated from Dutch by the first author. Throughout the research and fieldwork, inductive coding was used to form a broad categorisation of the incoming data. Following the fieldwork, the framework that we set out in the theoretical background was used to develop a list of codes. This set of codes was used to code all transcripts and formed the main part of our analysis. Both lists of codes are presented in appendix 9.

7.4 Integrating and validating precision agriculture with embodied knowledge

In this section we show how Dutch crop farmers integrate precision agriculture with their existing embodied knowledge. Precision agriculture consists of multiple technologies, some of which are sensor technologies. These sensor technologies can augment the farmer, as they form an addition to the existing senses of the farmer. Now the farmer can see through different forms of vision, mediated by technology, which augments and aids the farmer in understanding their fields and crops. Sensor technologies become an extension of the vision of farmers, allowing them to know their fields in new ways and to help them understand what is happening in their soils and crops. It allows farmers to see things that are not visible to the naked eye and to integrate this with their knowledge, as a crop farmer (CF5) describes:

"So you can see by eye whether something is wrong with the crop. But once you realise that a certain spot is not as green as the rest, well you are already too late, because you only see a 10% difference by eye. With cameras we can look much deeper and far better. You can anticipate [issues such as nutrient deficiencies, diseases, etc.]*"*

Precision technologies allow farmers to see and perceive things in new ways, extending the farmer and the farmer's eye. At the same time, farmers connect this to their existing knowledge of the field, as the data often says very little without connecting it to their historic embodied knowledge of being in the field. During one of the interviews, the interviewer had the opportunity to look at the soil and harvest maps of one of the fields. Generally, precision agriculture data is presented to the farmer in terms of different maps of the field, where the field is divided in zones with different values for certain parameters (i.e. pH, soil conductivity, biomass). Farmer CF12 highlighted several aspects that were visible to him (but not to the interviewer) in the field maps:

"So you can recognize some things in the map, like this spot is a wet spot where they had to dig a pipe through the land. [visible as a line in

the field that had lower yields and that stood out in the soil maps]. […] *So you also get moisture, yield, and dry mass. Look, you even get to see the temperature of the grain. So that's really great. […] And it's funny to see that, because you can see that there is another wheat grown in the outer edge which we harvested later. And what you can also see in the data, here we harvested first and then we had some dinner so when we returned to harvesting, we got a different temperature."*

These interpretations of precision agriculture data may not always relate to farm yields or operations, but they shed light on an important aspect of precision agriculture. As the maps remained meaningless for the interviewer while being very revealing for the farmer, we realised that simply having data is insufficient. Understanding the reasoning behind differences in data is crucial. Farmers' first-hand experiences on the land are invaluable in comprehending the meaning of the data. As the farmer describes, this is an embodied knowledge that develops over time, where previous actions in the field are used to make sense of the data that is presented.

This embodied knowledge develops in relation to precision technologies. We present a quote of farmer CF4, who uses NDVI values (showing biomass and increases in biomass) of his fields to decide where to go for the evening walk and relates this to the fact of spreading fertilizer. NDVI values can show reduced growth, but the underlying cause (e.g. disease, nutrient, and moisture deficiencies) can only be identified by seeing the crop itself.

"That remains important, but over the years that has changed. I now go through all the parcels by NDVI values. That means I already know where I need to go in the field, like, here I see something and there I see something else, and the rest doesn't interest me as much. Related to that, I also always spread fertiliser myself

Interviewer: Why is that?

Because with spreading fertiliser I can take 30 hectares at a time, you go 10 kilometres an hour, so it goes fast. And with the height you have you can see every bit of the field. So you can look around to see what you see, to visualise it for yourself."

The evening walk, influenced by NDVI values and the spreading of fertilizer are related in embodied knowledge formation. In a way reminiscent of Carolan (2008), the fertilizer spreader, provides the farmer with height and speed to see every corner of the field in a limited amount of time. NDVI values direct the sight of the farmers to certain spots, where seeing the crops and the causes of poor growth can be understood. The importance of sight, to see what the data actually says is stressed by CF4. The wish of the farmer is not to sit in his office and to collect and interpret data on its own. Rather, the farmer explains that to understand the data is to walk to the field and combine the various forms of data with the physical experience of being in the field.

This is important to the farmer as the various forms of data do not provide the rich experience of the physical sensory experience in the field (seeing and feeling the soil, crops, weather etc.). The farmer might look at the land and dig the soil to see what is going on in order to understand what the data is saying. As CF11 indicates, the feeling for it, the feeling for which spots are wet or dry, why they are this way, and to go and look (and dig the soil) at these spots is important to validate the data:

CF11: "Well it's not like you reduce the feeling for the soil. For sure you don't. No, no, no.

Interviewer: That also has to stay?

CF11: Yes, yes! It's not like, I do not see how it would work if I sit here in the kitchen and I send the tractor into the land and that's that. I do not see how that would work. Because you have certain spots that you know when you prepare the land, it could be a wet spot, you don't see that in the computer.

Interviewer: You don't think that that could come?

CF11: No, I don't think so. Because you'll always have to come out and see how dry it is, and you see a bunch of things. You can see that with the phytophthora decision support tool, that works well as a *supporting tool. […]. But you still have to go and take a look, you have to use your farmers' wisdom.*

These quotes highlight the embodied knowledge of farmers in connection to precision agriculture. Farmers go to the land in response to the data they receive, to see the plants, dig the soil, and get a general feel for how their crops are looking. However, data is not just interpreted on the spot, but is also connected to farmers' wisdom as CF11 states. This wisdom is broader than the single experience of going into the field but involves the repeated experience of farming the same fields over a number of years. The recurring embodied experiences of being in the land, getting to know the land and its wet spots, its dry spots, which spots are growing better and why, develops over the years. Farmer CF2 and farmer CF7 describe how their historically developed embodied experience play a role in decision making:

CF2: *"You know exactly where the risks are through experience. But you still have to go to those places to see what's the matter. […] With phytophthora for example you know that there are some sure spots* [places that have recurring infections] *and some spots were it could also be [*present*].*

CF7: *"I am not someone who blindly follows the numbers, but I use my own knowledge and insights. And maybe I'm wrong, but I have been farming for 22 seasons now. So I think I can sense which way it goes and connect the dots. I understand what happens and why."*

Farmers choose to follow this more-than-representational, embodied knowledge over blindly trusting precision technologies. Decision-making, even if based on precision agriculture data, takes place in the field. Precision agriculture does not mean the farmer can sit back and decide at a distance, but rather means that they enter the field and start with a look at the crops to see how they are performing. This is connected to experiences build over years of varying environmental conditions. Crops, weather, and moisture are compared to previous embodied experiences of years past. These embodied experiences make precision agriculture data concrete and allow for decisions to be made. This is also recognized by people in the industry, as voiced by

IND6 who describes the need to provide advice based on this embodied approach, by taking an auger to dig a soil pit:

"I have had words with some advisory services, who described that they still needed 5 years of extra research [in order to make sense of, and to provide advice on precision agriculture data]. *And I said: "Well, take an auger and take the farmer into the field."*

The experiences and practices above indicate a certain approach of engaging with precision technologies in an embodied way. To take an auger and to enter the field, to dig a soil pit and see the state of the soil and to experience it. This is how farmers work with precision technologies and how advisors can connect to the needs of farmers in using precision technologies. The use of this embodied knowledge is to an extent also in tension with the data-driven nature of precision agriculture. There exists an approach to precision agriculture that seeks to highlight the need to base decisions on data and to remove the 'feeling' for it. For RES2 for example, the embodied aspect of using precision agriculture go counter to a purely data-driven form of reasoning:

"So you learn to see your crops and soils in a different way. You learn to count the numbers and to base your decision-making on those numbers. And that is a different mentality than waking up in the morning and deciding how you'll farm that day. I exaggerate a bit, but that is what you will often see in practice."

This view, of transforming farming purely into a number of data-streams, is in tension with making precision agriculture work in an embodied way. Those espousing this data-driven approach indicate that one learns to see the farm in another way. It is about counting the numbers, about data that decides how farming gets done. This approach is not unique to any particular group, as farmers and people in industry and research also describe this. This is illustrated when farmer CF14 describes his need for algorithms in deciding how to use variable rate application:

"We bought a lot of [precision technologies] *and I have created prescription maps, even for others. So I know how to work with the*

technology, that is not the problem. Our problem is rather the agronomic underpinnings. You have a soil scan, organic matter levels, and you want to do something, but which algorithms to use? And then I play it by ear, but that is not scientifically proven."

We describe this to show that there is a tension between embodied experiences and the drive to make agriculture data-driven. A purely data-driven approach would eliminate the potential to 'play it by ear' and to do 'unscientific' farming. Embodiment, and 'the feeling for it' is not necessarily trusted. Farmers are working with precision technologies in an embodied way, but there is a balance, where some of them do seek to codify decision-making and to base their decisions more on data. Between the two forms there is a tension between data-driven, algorithmic farm management styles and more embodied farm management styles. At the same time, there are people in the ag-tech industry, like IND2 who emphasize the need to make technology work with the feeling for it that farmers possess:

"Yes, and farmers find that [being able to see how a decision is made] *is important right? Because you can make a closed-off decision, but that is not what they want. They want to keep the feeling for it. To retain the insight, it's very important to preserve that, the insight. [...] Because in the end the basis is agronomy, and that remains. We only deliver a tool that can aid the farmer. But it does not make a bad farmer into a good farmer. It can only help bring a good farmer further."*

Despite the desire for a data-driven approach, there is the realisation that embodied knowledge is essential in making precision agriculture work. Farmers want to retain autonomy over decision-making and want to be able to see what decisions are based on. Precision agriculture cannot be a black box if farmers want to integrate it with their embodied knowledge, as they need to understand how decisions are made and need to be able to link the underlying data and information to their own embodied understanding of their farm. There is no way to get around the embodied knowledge that is needed in agriculture, as farmer CF2 also sets out when we discussed the future use of precision technologies on his farm:

"Farmer: So we want a live dashboard, right in the canteen."

Interviewer: "Spray Now!?" [the conversation before had been on the potential for precision technologies to make decisions about spraying]

Farmer: "No, not like that. Rather, something is the matter and what are we going to do? Who decides when to spray? Not the computer".

And, after the interviewer asked whether he would trust a computer with these decisions, the same farmer describes:

"Well, yes, but you would need to provide the computer with a lot of input. I would have to be connected to a plug and you'd have to implant my employees with a chip. So the computer can read their minds and see what they think, and translate that to tasks. It will not be a black box."

To this farmer, precision technologies will ultimately not make the decisions without the input of him and his employees. The embodied experience is central, and in this somewhat futuristic scenario becomes integrated with precision agriculture. The technology itself becomes embodied, implanted in the farmer and farm workers in order to understand the embodied experience of the people working the field. Even a vision of fully data-driven, algorithmic farming needs the embodied experience of the people working the field.

7.5 The cyborg farmer - Mind, body and tool on intimate terms

We provide a discussion of our empirically grounded account of cyborg farmers as farmers embodied with precision agriculture. This is the farmer who connects data interpretation to the multi-sensory experience of being in the field. Knowledge develops through the body, extended through technologies and situated in a broader space/environment. This conceptualisation responds to questions on how precision agriculture is changing farms, farmers and farm work and how knowledge is mobilized (Klerkx, 2021; Klerkx et al., 2019; Prause, 2021; Rotz, Duncan, et al., 2019).

By providing empirical underpinning of the concept of the cyborg farmer we highlight how precision agriculture only functions as a collective of farmers' knowledges, precision technologies and agro-ecological context. Precision agriculture (through satellite data, drone shots and soil maps) allows for new ways of seeing the land and provides an extension to farmers' knowledge. This extension is reminiscent of ideas of Klauser & Pauschinger (2021) who describe how drones open up the air as a new dimension in agriculture ('volumetric agriculture'), and connects to ideas on emerging forms of 'augmented agriculture' (Klerkx, 2021) in which technology enhances human senses. Precision technologies allow for an extension of the body, providing new dimensions to farming and associated knowledges.

With our findings we confirm earlier work of Legun et al. (2022) and Lundström & Lindblom (2018), who show the importance of farmers' knowledges in relation to autonomous robots on farms and for decision support systems respectively. In our case, the use of embodied knowledge can be recognised in how farmers interpret data. The data that is provided through precision agriculture is calibrated with embodied knowledge by the farmer entering the field, walking through the field where the senses are used to make sense of the data. This centres the farmers' body as the site of knowledge production while linking to the materiality of precision agriculture and agro-ecological space. The farmers' body and senses link the data-driven elements of precision agriculture with an embodied understanding of agro-ecological context (Currier, 2003).

Embodiment thinking has been developing in the margins of rural sociology (Carolan, 2007, 2008; Krzywoszynska, 2016; Maclaren, 2018). As our research shows this approach can provide an exciting way to link embodiment thinking to a relational account of technology use (Darnhofer, 2020). This provides a way to go beyond mind-body dichotomies in which the cognitive is not understood as primary, as emotions and the materiality of the body are taken seriously, i.e. the farmer is understood as a being who thinks and senses. Our research shows the importance of the material body situated in agro-ecological space as a focal point for understanding, theorising and critiqueing digital technologies (Brians, 2011; Krzywoszynska, 2016).

As we showed in our results, there is tension between the data-driven elements of precision agriculture and the embodied and intuitive understanding of agro-ecological context. At the start of the century, Tsouvalis et al. (2000) wrote about the tension between knowledge-cultures in precision agriculture. While farmers use precision agriculture data to a far greater extent, similar issues still exist and there are similarities in how farmers mobilise knowledge in order to make sense of data. To understand data is to link back to situated and embodied experiences (Tsouvalis et al., 2000). In response to research on precision agriculture that has emphasised harmful conflicts between knowledge-cultures ((Bell et al., 2015; Carolan, 2017; Miles, 2019), we set out how the tension between knowledge cultures is productive. We see this tension as productive because farmers are situated between these different knowledge-cultures and take elements from different forms of knowledge to come to decisions. Our results show that the cyborg farmer develops when data from precision agriculture is integrated with the embodied experience in the field. Farmers make decisions after the two forms of knowledge have been re-calibrated with one another. This shows the potential for agency in precision-agriculture decision-making, confirming findings of other authors who highlight farmer agency in the use of precision technologies (Higgins et al., 2017, 2023; Legun & Burch, 2021). This agency of farmers ensures that precision agriculture does not come to dominate the knowledges that farmers use. They keep a diversity of knowledges, of which precision agriculture is one.

However, this is not to say that knowledge is not transforming under the embodied use of precision agriculture. Technology is not neutral, and as other authors have shown, new technologies change how information is perceived and how the body functions (De Preester, 2011; Ihde, 2012; Verbeek, 2006). Our research has shown how precision agriculture allows farmers working relatively larger farms to stay connected to embodied sense-making, but this does not remove the issue that these technologies do function more on larger farms, where this technology is required to make sense of all the information provided by the farm. Equally, we have focused on the current effects of precision agriculture on knowledge-formation, and while farmers have stressed that they do not see their use of embodied knowledge in precision agriculture changing in the future, this is also uncertain. Future digital technologies might futher impact knowledge production and shift the cyborg farmer further to a differently embodied type of farmer, where the desirability of this change needs to be taken into account.

Our account of precision agriculture does however nuance authors who describe the potential of precision agriculture as an algorithmic lock-in, or as a domination of algorithmic rationality over other forms of knowledge (Carolan, 2020a; Gardezi & Stock, 2021; Miles, 2019). There are different approaches to this integration of knowledges. Some of the farmers in our results highlight the limitations of precision agriculture and base their decisions to a larger extent on experience and intuition. Others are looking for ways to farm 'algorithmically' and to base their decisions on a far more data-driven approach. There is a spectrum between the two approaches, a scale of possibilities between data-driven and intuitive farming.

Through these approaches, our findings suggest that there may be different sorts of cyborg farmers, i.e. farmers who use embodied knowledge in the use of precision agriculture in different ways and with different intensity. In a sense the cyborg farmer is a play on the virtual farmer described by van der Ploeg (2003). The cyborg farmer is a persistence of the local art of farming in the face of the virtual farmer constructed by the expert, sensor and data driven knowledge system embedded in precision agriculture. This goes against farms without farmers that can be run through algorithms and digital technologies, as the cyborg farmer presents the potential to resist these futures, where the embodied knowledge of farmers and farm workers have a key role to play in the development of precision agriculture.

Conversely, human observation, experimentation, and calibration by the farmer can counteract possible inaccuracies or ‘precision traps’ within precision farming (Visser et al., 2021), and connect existing farming practices with new possibilities afforded by precision agriculture (echoing Rose et al., (2022). What our findings add to this earlier work, is that the different ways of engaging with precision technologies and intensity of being a cyborg farmer, could lead to what have been coined as ‘digital farming styles’ (Klerkx et al., 2019). As our findings suggest, these may range from a rather light engagement and embodiment of digital technologies, to a heavy engagement and embodiment, which may include several forms of wearables (e.g. sensor gloves, exoskeletons, augmented reality glasses) and digital twins. This could provide a new avenue in a long tradition of farming styles research in rural sociology (e.g. van der Ploeg, 1994; van der Ploeg, 2012; Vanclay et al., 2006).

7.5.1 Practical implications for precision technology development

Not all precision technologies are equally suited to the needs of farmers, with some authors wondering whether some of these technologies were ever intended for farmers at all (Duncan et al., 2021, 2022). Venture capital and agricultural technology firms developing technologies that have no use to farmers are well-known in the literature (Fairbairn et al., 2022). In the development of precision technologies it will be worthwile to focus on the potential of embodied technology use. Multiple scholars have already stressed the need for responsible innovation approaches, or more radical emancipatory innovation processes (Bronson, 2018, 2019; Eastwood, Klerkx, et al., 2019; Fraser, 2021; Rose & Chilvers, 2018). An approach that is focused on embodied learning would fit well with these Responsible and Emancipatory Innovation processes but would need to better emphasise the inclusion of embodied knowledge. In this we can learn from innovation approaches that have sought to include different, often indigenous knowledges in innovation processes (Peddi et al., 2022; Sayarer et al., 2019; Verran et al., 2007). These approaches would support the development of technologies that can function within the diverse biophysical contexts of farms and farmers. In this our findings support (Ditzler & Driessen, 2022) who have called for a broader mindset in the development of digital agriculture technologies so that these can be used in a wider variety of farming systems. They emphasise the presence of the farmer in the field as essential to embodied knowledge production for novel styles of farming, something that we recognised in our research involving (much more conventional) crop farmers.

For advice and extension providers, connecting precision agriculture to the embodied knowledge of farmers can help advisors and farmers in understanding and using these technologies. Research has shown the importance of tactile and embodied spaces to learning processes (Cooreman et al., 2020; Cowan et al., 2015; Klerkx, 2021; Krzywoszynska, 2016) and this can be explored further in future research. For learning about precision agriculture this can be as simple as entering the field together with the farmer and connecting the data inputs from precision agriculture to sensory experiences in the field. This would allow for the integration of precision technologies with embodied knowledge, providing avenues for advisors and farmers to improve their understanding of both their soils and crops and of precision agriculture.

7.6 Concluding remarks & further research

The cyborg farmer is the farmer with agency, using precision technologies in an embodied way, balancing between knowledge-cultures. The cyborg farmer is not an active form of resistance against current capitalist agricultural systems, but neither is it the wholesale acceptance of its dominant forms of knowledge. Cyborg farmers are neither luddites disavowing technology, nor are they completely bound to a high-tech farm that is built on precision agriculture.

Instead, the cyborg is the in-between, the farmer who makes precision technologies work on their specific farm, accepting certain elements while resisting others. It is following certain recommendations by a decision support tool while ignoring others because it makes more sense to follow intuition. It is the interpretation of data with embodied senses while sharpening embodied knowledge with the same data. The cyborg farm is a balance between agro-ecological context, precision technologies and farmers' embodied knowledge.

Considering this conclusion, it will be important to involve the embodied aspect of precision agriculture in research, technology development and for advice and extension. This would allow farmers to further integrate the finesse, control and adaptability precision agriculture has on offer with their bodily and sensory affordances. Further research can help identify essential elements of precision agriculture that help develop embodied knowledge and enable the cyborg farmer.

Our interviews represented accounts of practices of farmers, but did not show all the precise mechanisms that farmers use in integrating precision agriculture and embodied knowledge. This was limited due to our use of an interview based approach. While this does give insight in the practices and engagements of farmers with precision technologies and how these relate to embodiment, this did not allow for getting the detailed insights and logitudinal analysis needed for describing mechanisms of embodiment.

We follow other authors in arguing that future studies on this topic need to integrate different ethnographic and technographic methodologies are needed in understanding embodiment in precision farming, such as work shadowing, focus groups, deep mapping, mapping and photo elicitation, video data analysis and technographies (Cooreman et al., 2020; Sutherland, 2021; Vellema et al., 2011). Further in-depth accounts on the formation of this embodied knowledge creation can help investigate in more detail the range of cyborg farmers and explore ‘digital farming styles’.

CHAPTER 8. REMOTE GOVERNANCE: THE USE OF DIGITAL TECHNOLOGIES IN THE GOVERNANCE OF THE CAP ACROSS EUROPEAN MEMBER STATES

Authors: Van der Velden, D., Klerkx, L., Debruyne, L., Dessein, J.,

Daniel van der Velden: Conceptualisation; methodology; investigation; writing—original draft preparation; writing—review and editing. Laurens Klerkx: writing—review and editing. Joost Dessein: Writing—review and editing. Lies Debruyne: writing—review and editing.

Link with the other chapters and with the main research question

Our last empirical chapter balances the accounts in the previous two chapters on the agency of people in the digital transformation of agriculture. The technologies we describe in this case study (remote sensing and other digital monitoring technologies) are currently not expanding the agency of people in the digital transformation of agriculture. In contrast, the transparency that these technologies provide help expand the existing audit culture in the CAP. This audit culture, focused on transparency and accountability, reduces the potential agency of both farmers and bureaucrats working at paying agencies. Through this technologies, farmers are held accountable, with monitoring ensuring that they follow regulations. This in turn reduces their discretion over farm practices. In answer to this, we provide potential solutions, where these technologies can be used to increase agency, allowing farmers discretion over farm practices, while also helping to achieve the aims of the CAP. This would allow the further development and use of farmer knowledge in the digital transformation of agriculture.

8.1 Introduction

The industrial modernization of agriculture has brought about the need for the environmental governance of agriculture. Seeking to prevent disease, antibiotic resistance, pollution and greenhouse gas emissions, regulations and technologies of control are essential to the modern governance of agriculture. Diverse forms of knowledge are mobilized to make both human and non-human populations knowable and governable in an attempt at managing these negative impacts of agriculture (Estrada Bonell & Vaccaro, 2022). In Europe, the common agricultural policy (CAP) forms part of the governance of agriculture, where farmer subsidies are partially structured in order to deal with environmental harms.

The CAP has seen multiple reforms over the last decades, attempting to address the previously mentioned concerns, with increased attention for environmental standards, public health and animal welfare and with attempts at simplification and reductions to bureaucracy (Estrada Bonell & Vaccaro, 2022). An expansion of controls and audits is needed to ensure that farmers meet environmental standards, despite a desire to limit the administrative burden on farmers (Carey, 2019; European Court of Auditors, 2017). The court of auditors has identified that still more data is necessary to determine the impact of the CAP and that environmental impacts need to become further quantified through indicators (European Court of Auditors, 2017, 2020). They also conclude that the greening of the CAP has so far added complexity without delivering impact (European Court of Auditors, 2017, 2020).

In ensuring compliance to standards set in the CAP and in determining the impact of the CAP, remote sensing technologies and a broader suit of digital tools and technologies are increasingly used across Europe (Aksoy et al., 2010; Schmedtmann & Campagnolo, 2015). This fits within a broader development where digital technologies are of increasing importance as the tools of modern government in making environmental problems visible (Ehlers et al., 2022; OECD, 2019). These technologies are seen as a way to deal with the difficulty of governing the CAP, allowing governments to achieve the targets set out in the CAP and to measure the impact of the CAP (Chellasamy et al., 2016; Dumitru, 2021). The uptake of remote sensing technologies has been ongoing since the 1990s, but the implementation of big data processing techniques has allowed for the further integration of these technologies in ensuring compliance by farmers to measures in the CAP (Copăcenaru et al., 2021).

Digital technologies and data for governance have been described as having great potential in changing agricultural policies (Ehlers et al., 2022; Ehlers & Huber, 2021; OECD, 2019). There are descriptions of how farmers can have increased discretion over the choices they make on the farm, while still achieving policy aims (Ehlers & Huber, 2021). Governments can use these technologies to monitor policy outcomes and policy impacts, providing more rapid feedback on how to tailor policies (Ehlers & Huber, 2021). At the same time, there is a risk in using these technologies for monitoring and nudging farmers, especially when policy decisions are made unilaterally or are dominated by powerful actors in the agri-food supply chain (Brooks, 2021; Stone, 2022).

It will be important to assess the direction that the governance of the CAP takes in the use of remote sensing and other digital technologies. Currently, a body of work exists on the policies developed in the CAP, and on the effects of the CAP on European agriculture (Bojnec & Fertő, 2022; Carey, 2019; Czyżewski et al., 2021; Kiryluk-Dryjska & Baer-Nawrocka, 2021; Pawłowska & Grochowska, 2021). Equally, there are some early works that set out the development of digital policies in agricultural policy-making, where digital technologies are used to monitor farmers (Ehlers et al., 2022; Ehlers & Huber, 2021; Klauser, 2018; Prause, 2021; Stone, 2022).

Despite this, there are distinct gaps in the literature on how digital technologies are used for the execution and implementation of the CAP in different member states. One of these gaps are the compliance mechanisms in the CAP, which functions through regional or national paying agencies, and where digital technologies are increasingly used (Beblavý, 2009). The paying agencies are the bureaucratic arm of governance that make the CAP function, by managing the funding and by ensuring the compliance of beneficiaries (farmers) with the CAP. The execution of these tasks is vital to the functioning of the CAP and has been the focus of several previous authors, who highlight the effects of monitoring compliance from the perspective of farmers (Aistara, 2009; Estrada Bonell & Vaccaro, 2022; Kovács, 2015, 2021). These studies focus mainly on the ordering effects of the CAP and on the resistance of farmers to the bureaucracy and administrative burden inherent to the CAP. However, aside from these articles, little work has been done on the monitoring and compliance mechanisms present in the CAP, especially as it relates to the use of remote sensing and what this implies for those implementing these monitoring and compliance mechanisms and those subjected to them.

This work aims to explore this aspect further, especially focused on the introduction of remote sensing and other digital technologies in paying agencies for the governance of CAP subsidies. This highlights the functioning of compliance and monitoring from the executive side of governance, and the role of so-called 'street level bureaucrats' (Lipsky, 2010) in this process. This leads us to our research question:

What is the impact of digital monitoring technologies, especially the use of remote sensing technologies, on the governance of the CAP across European member states?

We analyse this question by first providing a theoretical background, focused on the functioning of bureaucracy and governance. We then provide an overview of the case study and a methods section. This is followed by the findings and the discussion and conclusion.

8.2 Theoretical framework

8.2.1 Measurementality in the governance of the CAP

A significant body of work has highlighted the governmentalities (or environmentalities) at work in making environmental problems visible and governable (e.g. these studies describe how the environment is represented through the discourses, practices and visibilities of modern governance (Wang, 2015). There is a strong emphasis in this literature on the knowledge produced on environmental objects (i.e. how the environment becomes understood; in this research through digital technologies that make fields, field activities and other environmental parameters knowable) and on how people come to act as environmental subjects (i.e. how the knowledge on environmental objects affects people and their behaviour, and how this knowledge becomes internalized) (Sletto, 2005; Wang, 2015).

There have been several authors who highlight these processes in relation to the CAP and the notion of compliance in the CAP. Estrada Bonell and Vaccaro (2022) highlight the environmental turn of Spanish shepherds, who despite initial resistance, come to understand themselves as environmental stewards when CAP subsidies reward them for environmentally beneficial activities. Both Aistara, (2009) and Kovács (2015) indicate the impacts of CAP subsidies in Eastern-European member states and the disciplinary and neoliberal governmentalities intertwined with the CAP. They highlight how farmers come to understand their land and farming, and how the CAP orders farming in these countries to conform to universal views of what European farming should be. For the CAP, this is recognized in repeated attempts to make farmland and farmers legible to governance, producing knowledge on defined field boundaries, land ownership and animal movement (Aistara, 2009; Estrada Bonell & Vaccaro, 2022). Kovács (2015) lists the notions of the audit culture in the CAP; as governed from a distance through audits, where farmers are accountable and responsible for their own performance. Vital to this audit culture is the expansion of knowledge and the possibility to standardize monitoring to increase transparency and accountability over how funding is used by government agencies (Brooks, 2021).

Logically, the knowledge produced through remote sensing is not neutral. It makes visible the spaces over which government is to be exercised (Rose-Redwood, 2006). Digital technologies increase the knowledge available to governments for control (Klauser, 2018; Stone, 2022). This is the link between power and knowledge, where knowledge is intertwined with power and allows for the functioning of power (Van Assche et al., 2017). Turnhout et al. (2014) describe this as measurementality, a form of neoliberal governance that emerges when scientific techniques for measuring the environment are privileged. The environment becomes a set of standardized units which are stabilized through policy and discourse. Remote sensing technologies provide the techniques and knowledge for measuring the environment, determining how the environment is known. The tools, instruments and discourses for the management of farmers have expanded once again, as new knowledge is made available to govern the European population of farmers and land (Kovács, 2015).

Despite the fact that several authors have described this as surveillance agriculture and have noted the potential negative impacts of this (Klauser, 2018; Stone, 2022), other authors have highlighted the potential of these forms of technologies for governance. Digital technologies have the potential to create forms of governance that are more flexible, providing farmers with agency over how they comply with policies while also informing government bodies on policy impacts (Ehlers et al., 2022; Ehlers & Huber, 2021). This remains a choice for policymakers, as digital technologies provide multiple opportunities for the direction of governance.

8.2.2 Paying agencies as street-level bureaucrats.

We set out in chapter 8.1 that paying agencies play a central role in the bureaucracy that makes the governance of the CAP possible. In analysing this, we start out from the position that governance and bureaucracy strive to function for the public good, and that this has the improvement of the public good in mind. This is different than the common (negative) reading of bureaucracy, which in agriculture is often seen as the cause of a heavy administrative burden on farmers (Mack et al., 2021). We use the concept of desire as an analytic for the exploration of how the public good is strived for, taking from several recent authors who have theorized a desire for bureaucracy and the desire for good governance (Billaud & Cowan, 2020; De Vries, 2007; Lea, 2021). To these authors, the central aim of governance is to be effective, to be good governance, even if this is constantly out of reach. We combine this with the concept of street-level bureaucracy to discuss agency in the functioning of bureaucracy, to later discuss how digital technologies are affecting this in the governance of the CAP.

We take as a first focal point the bureaucracies that make governance possible. Bureaucracy is not exclusive to governance, but in this article, we only deal with the bureaucracies that make governance of the CAP possible. We understand and analyse bureaucracy as the body of non-elected officials that execute the agri-environmental policies of the CAP. Previous literature has highlighted the relevance of lower-level bureaucrats to these processes, sometimes called street-level bureaucrats (Lipsky, 2010; Ricks, 2017; Sevä & Jagers, 2013). This builds on the concept of Lipsky (2010) and originally aimed to capture the autonomy that bureaucrats have in making decisions, analysing how teachers, police officers, clerks and welfare workers make decisions that diverge from official policy. What street-level bureaucrats have in common is daily contact with citizens and high autonomy in decision-making, with significant distance to higher authorities. This allows them to interpret policies, rules and regulations and be flexible in making decisions.

This concept has been broadened to also include environmental bureaucrats, who might not have face-to-face contact with citizens and who might have less autonomy over decision-making (Sevä & Jagers, 2013; Sevä & Sandström, 2017). This broadening of the concept includes all bureaucrats at the end of the policy-chain, who make and execute the policies and retain a certain level of autonomy in making these decisions. This covers the respondents in this research who are often not involved in making the policies, but who ensure that farmers comply with policies. Central to this is the notion that bureaucrats have a certain level of autonomy and discretion over the decisions they make, and through this can influence the execution of policies (Ricks, 2017; Sevä & Jagers, 2013).

This also understands bureaucracy as opposed to the Weberian ideal type of bureaucracy. This ideal type is based on the notion of sovereign people who govern themselves through representative democracy, where bureaucracies are neutral instruments aimed at implementing the will of the people (Hilbert, 1987; Sevä & Jagers, 2013). In this ideal type, bureaucrats logically have limited agency in interpreting and executing policies, as they should follow the will of the people (through their political masters, and superiors). This ideal type is far removed from how we understand bureaucracies, where policies and regulations change as they move through the bureaucratic body. In executing the policies, street-level bureaucrats interpret and change the policies, executing them with a certain level of freedom.

8.2.3 The desire for expanding effective governance through digital technologies.

Lea (2021) suggests that in the common critique of bureaucracies there is an inherent desire for better forms of bureaucracy, which have a higher level of ethical functioning. It is a yearning for reassurance that bureaucracy at its core can be functional. In the critique of a failing bureaucracy there is hope that bureaucracy can be redeemed, that it can be functional (Lea, 2021). Several authors state that this is the underlying logic why people, whether bureaucrats, academics or farmers, keep participating in failed governance programs and logics, where people understand these failings but do not come to engaged opposition (De Vries, 2007; Lea, 2021). Their answer to this question is that people’s desire completes the incoherent arrangements of bureaucratic formations. Criticism and hope co-produce one another in a search for functional bureaucracy (Lea, 2021). This understanding of bureaucracy provides a reasoning for the functioning of bureaucracy in governance. There is a constant need for a new project to repair bureaucracy whenever it discovers the inevitable failure of bureaucratic routines (Hilbert, 1987). The desire for things to be better authorizes bureaucracy's license to continue, where despite imperfections there is hope that a higher level of ethical functioning can be reached (Lea, 2021). This belief authorizes the imperfect functioning of bureaucracy, which can always be redeemed for higher aims.

The notion of this has ties to techno-utopian ideals in the development and implementation of digital technologies (Callen & Austin, 2016). This is the belief that large-scale dissemination of appropriately designed technology can provide solutions to social problems. In bureaucracies this is also tied to the view that the use of modern technologies provides the appearance of being ever increasingly rational, modern and up to date (Hilbert, 1987). Large-scale social ambitions and technological fixes are intertwined (Prince & Neumark, 2022). While any technology has shortcomings and failures, policymakers and other actors involved in the promise of techno-utopian ideals only acknowledge these failures to the extent that they can be used to avoid the same difficulties for the next technology (Callen & Austin, 2016). To Prince and Neumark (2022), failures are built into the schemes, where failure is anticipated from the start, even celebrated. The failure of a techno-utopian promise is not the end, but rather the point which legitimizes the next techno-utopian project. The promise of technological utopia does not get questioned. In this sense, the same notions drive the bureaucratic project and the techno-utopian project, where despite recurring failure, there remains a desire for the next project that will bring about salvation.

This provides our basis for understanding the adoption of remote sensing and other digital technologies in the CAP. There is a basis of measurementality, or the knowledge that is created through technologies, which can structure farming and where subjects come to understand themselves through this knowledge. This has strong ties to an existing governance culture or auditing culture that currently exists in the governance of the CAP. Our understanding of street-level bureaucrats provides an analytic for understanding the agency of respondents in the functioning of CAP governance and its associated bureaucracy. Bureaucracy and the use of remote sensing and digital technologies in bureaucracy will be analysed through a lens that understands this as driven by a desire for good governance, where technologies are seen as the solution to larger problems.

8.3 Methods

8.3.1 Overview of the case study

This case study is focused on how paying agencies use remote sensing and other digital technologies to ensure compliance with CAP measures. Paying agencies differ in organizational structure, where in different member states they can be part of different government ministries and organizations. Equally, in some countries (e.g. Spain, Germany, Belgium) there are multiple paying agencies that function at a regional level. What unifies them is that they all have the same responsibilities, governing CAP funding and monitoring compliance. The main technology in use by paying agency for this monitoring is the use of satellite images (mainly sentinel-1 and sentinel-2 data). Data produced by these satellites is freely available, accessible through various data platforms. Additional technologies that are at different levels of adoption and implementation across the paying agencies are geotagged images (images that farmers send to paying agencies and that have identifying information, including GPS coordinates), aerial and high-resolution satellite imagery (increased resolution compared to the 10 meter resolution of Sentinel satellites but also with increased cost for the paying agency) and the use of farm machinery data (which is at an experimental stage and is generally not used by the paying agencies involved in this research). The unifying elements of these technologies are the increased use of digital technologies and data, often in collaboration with sophisticated algorithms to make sense of this data. These technologies are used in unison to verify that farmers comply to measures and standards of the CAP.

This sets the scene for our research, which focused on paying agencies and people involved in the implementation of the monitoring of farmland through remote sensing. In the CAP these developments have had several names: the area monitoring system (AMS), checks-by-monitoring (CBM) and on-the-spot-checks using remote sensing (OTSC). Generally, despite this not being defined by the European Commission, respondents in our research worked for paying agencies that use a system similar to the checks-by-monitoring system. This system uses remote sensing data to classify compliance by farmers according to a traffic light system set to certain parameters (red – non-compliance, yellow – uncertain compliance, green – compliance).

Important to note is that this research takes place in an uncertain context for the monitoring of farmer compliance through remote sensing. Until 2023 the EC was much more involved in the governance, monitoring and auditing of the CAP and had a significant role in determining the compliance mechanisms at the member state level. From 2023 onwards this has changed to become a member state mandate. Member states now develop national strategic plans that set out the aims and governance mechanisms for the CAP. In the new CAP, the monitoring system (AMS) is used to track indicators that show the performance of member states, with member states providing annual reports on their performance. This limits the power of the EC over the CAP and in the development of these technologies compared to previous years. This context is important, as respondents were still used to the old system, where they had some experience in this new setting but where they still described elements that were part of the previous governance structure. Their perceptions thus largely speak to, and of, a system that is currently no longer in place.

The monitoring systems that paying agencies use, works through a combination of remote sensing data (generally collected through satellites) and sophisticated algorithms that determine whether a certain parameter is true. To give some examples of conditions and associated parameters that can be checked with remote sensing; these can be the crop grown, the existence of farming activity, ploughing, mowing, or harvesting. These conditions are useful to determine general compliance to the CAP (e.g. farming activity and crops grown) but can also be used to determine compliance with environmental measures (e.g. ploughing of permanent grassland and mowing dates). Paying agencies either develop these technologies themselves or outsource this work. Additionally, several respondents worked for companies and organizations that develop software tools for the paying agencies.

8.3.2 Research methods.

Fieldwork took place in the summer of 2023. Respondents were selected through a purposive sampling strategy combined with snowball sampling. We (author DV) opted for this approach as we actively searched for respondents working for paying agencies who also worked on the implementation of remote sensing in the controls. Additionally, we also interviewed people who work for companies and institutes that develop the technology for paying agencies. Twelve interviews were held with engineers, developers working on remote sensing and people working for paying agencies. Respondents were selected across Europe, seeking a balance between different European regions. The same question list was used for all interviews. This question list was provided to the interviewees before the interview. Interviews took place online via video-call.

Participants in the research were interviewed using a semi-structured interview guide which is provided in appendix 10. Interviews took between 30 and 90 minutes. Audio recordings from interviews were transcribed using a local copy of whisper.ai (to ensure compliance with GDPR). Following automatic transcription, the first author verified the transcription and edited as needed. Transcription and data analysis was done in the language used for the interview. Quotes used in the article were translated to English by the first author if needed.

Following the fieldwork, the framework that we set out in the theoretical background was used to develop a list of codes. This set of codes was used to code all transcripts and formed the main part of our analysis. In forming our coding list we focused on 'lean' coding, coming to a relatively short list of codes to categorise the data (27 codes) (Creswell, 2007). For our data analysis we focused on interpreting data through an open lens, emphasizing reflexivity and transparency (Madill et al., 2000; M. Ryan, 2009). The analysis itself was formed through going back and forth between data and theory, forming a coherent narrative that links data and theory (A. Ryan, 2006).

8.4 Findings

In setting out this case study so far, we have described that we see the governance of the CAP and the bureaucracy that makes this governance possible as driven by broader ideals. Ideals that strive for better governance, to achieve the ideals set out for the CAP. We use the findings to show how certain ideals are expressed by respondents, how they seek to achieve these ideals in the governance of the CAP and how they deal with failures in achieving these ideals.

8.4.1 The ideals of governance by remote sensing

In the governing of the CAP there are a number of ideals for governance that the respondents ascribe too. They articulate a focus of more complete control, to ensure that money is spent the right way, that the administrative burden to farmers is limited and that the policy targets are reached (mainly around environmental targets). To an extent, these ideals can be seen as extensions of the broader CAP regulation, where these same ideals are highlighted. Remote sensing technologies are intertwined with these developments and are seen as a way to achieve the ideals that have been set out before. One of these ideals, the reduction of administrative burden is expressed by RS11:

"*I think it's the intention of the commission to evolve to a system […] where we can see a lot more. Everything that we can know through satellites or databases, that we no longer request that [from farmers]. Where the farmer now has to make a claim, that in the future we can just see, this is what the farmer did and that is how much money he gets.*"

This ideal, of building a claimless system was first launched by certain member states, later taken on board by the commission and is thus not necessarily an ideal from the respondents themselves. But interesting is how respondents ascribe to the ideal, as a way to reduce the administrative burden to farmers and to move to a new form of governance. They are placed between farmer and the commission as street-level bureaucrats. This move to a claimless system coincides with remote sensing which makes the shift possible, where remote sensing allows the paying agencies to check what a farmer has done over the year. In this, paying agencies become able to organize compliance controls without delays, where they do not depend on individual checks that are extrapolated to represent the system. As RS1 describes, speaking on using remote sensing for the conditionality checks in the CAP (basic requirements that all farmers need to follow):

"It's the solution, because technically you move from 'impossible to find' to 'impossible to miss'. Because, if you don't look at every last meter but instead you want to know; did that farmer burn his stubble? Or did he plough when he was not allowed to? […] So you can organise the guidance of the farmer in a non-intensive way, without limitations for your assurance model."

This response sets out the overarching ideal of the use of remote sensing. It creates a situation where (certain forms of) non-compliance is impossible to miss. Additionally, there is the ideal that farmers are guided, in a non-intensive way, while the assurance model is intact. Implicit is that farmers do not need to experience the strong hand of the government, but that guidance of the farmer is possible while the pervasiveness of satellite imagery ensures that controls are accurate and complete. Good governance is assured. Interestingly, two ideals are intertwined here, where monitoring compliance remains the main goal but where respondents also seek to move to forms of ensuring compliance that guide farmers rather than disciplining them. Respondent RS9 explains this further in describing the aim of the system:

"The AMS [latest iteration of the remote sensing system, area monitoring system] is not meant as a form of control, but it's much more to work together with the farmer in getting the application right. So now the farmer does their application in May, where he describes what he has planned. And what we do with the AMS is to monitor, to see, this was planned, this is what you signed up for, and do we see that in practice? And if that is not the case, we connect back to the

farmer and that can be a reason for him to change his application. So the goal is to raise the quality of the data that the farmer delivers."

The goal of the control system is to improve the data quality of the farmer, to ensure that everything is correct and where punishment is non-existent as long as the farmer repairs their application (in the words of the respondents, also described as modifying the application in the regulation). As we will show in the next section, this is rather a vision of how the system should perform rather than a reality in practice. However, it does indicate a desire to shift in the governance of the CAP where the contact with farmers is meant to be a near-collaboration, with farmers and governments working together towards good governance of agriculture. Despite this, remote sensing remains tied to an audit culture and an ideal of having control, where the ultimate aim is to ensure that money is spent on the right things, as RS1 indicates:

"*The story of the past thirty years is one of accountability. How do you know the money goes to the right place. Are they the right kind of farmers? Do they get enough for the land they have under cultivation? […] and that is what the control system is built for. Because there are audits that show that money has been spent on farmers who aren't farmers. Maybe they were retired, or it was actually a golf course, or an airport."*

This brings up the audit culture, where the quote describes how there was a search for ensuring that money was spent right. This audit culture is pervasive throughout the CAP and throughout the descriptions of our respondents. Especially in previous iterations of the CAP, where paying agencies were monitored on their accuracy in monitoring compliance, respondents describe how they were under pressure through top-down controls, as RS7 does:

"And since the paying agencies were always under the strong pressure from the audit, I mean from the European Commission audits, we were always, we were always focused on the as much as high accuracy as possible. Only 2% like a buffer was allowed. So for some people it's now difficult to take the risk of saying we go for the implementation of, for

example, this specific use case knowing that the confidence level is not 98%."

Remote sensing technologies and other tools are part of this system, of getting closer to the optimal auditing culture, which promise high performance but also allow for flexibility and which allow farmers to 'repair' their claims. Ensuring compliance remains the main driver for respondents, but underneath this there are underlying ideals, of protecting the environment, of removing animosity between farmers and the paying agency and of disciplining farmers. Not all of these underlying ideals came up for all of the interviewees, and respondents were generally more concerned with a functional control system, rather than discussing specific aims that the control system might achieve.

8.4.2 Unachievable ideals of governance through remote sensing and the acceptance of failure

Despite the promises and ideals made for the use of the technology, as listed above, failure of these ideals gets built into the technology. While describing the potential of remote sensing technologies for good governance of the CAP, respondents also describe its failure. In the promise to achieve control there is the realization that control remains elusive. Several factors combine to reduce the promises that the technology offers. While remote sensing technologies are increasingly being used, respondents describe how certain measures in the CAP are unmonitorable, how animosity remains and how the ideal of having control over farming remains elusive. As RS3 describes in relation to an eco-scheme where they are trying to use remote sensing to check for compliance:

"We are doing a pilot project and hope to have at least a reliability of 80 percent of the cases, I think we could manage a 20 percent of uncertain cases in this particular scheme. We can. Yeah, we can cope with that. But we don't have a marker yet. […] This campaign, we have to go to the field. We have to declare that requirement as non-

monitorable and carry out field visits on one percent of the beneficiaries who declared that eco scheme. And that's a lot of work. You see, we have no choice."

Despite the promises of technology, control returns to on-the-spot-checks, where compliance has to be determined by physically going to the field. Eco-schemes, which promise to improve the environmental performance of farming, are of particular interest as respondents were having a difficult time in determining compliance to eco-schemes. While determining if farmers actually farm the land and what crops they grow is now a fairly standard task for the respondents, the more intricate and detailed aspects of eco-schemes are a challenge, as RS7 notes:

"There are also some operations that are difficult to be monitored because of the resolution. Consider for example the narrow bio strips, or the agro-environmental measures where we have conditions on the structure of the grassland. This is something that is not monitorable with the use of current technology. So yes, there are definitely some issues that it would be helpful if we could also monitor them through the use of remote sensing. But the technology is not yet advanced enough or there are technical limitations."

Aside from measures that are difficult to measure, the algorithms used to determine compliance are affected by weather, by climate change, and they need maintenance to accurately determine compliance, as RS10 describes:

"Algorithms are customized to a specific weather condition and location. And it's a kind of overfitting and they are not generalized algorithms that run correctly in the whole Europe. So, from season to season and from year to year we have problems because there are variations in the weather conditions. […] So, we always have to assess the result and the algorithm should be under supervision."

The idea of having control over agriculture and of having good governance of the CAP does not last long when confronted with the messy reality of farming, the environment, technology and politics. While certain measures are monitorable, for a large number of potential measures the respondents have to return the verdict that they are non-monitorable and that they cannot determine if farmers are eligible for the payments using remote sensing technologies. When it comes to the use of remote sensing technologies to control farmers and determine eligibility, the ideals of reducing animosity between farmers and paying agencies are also difficult to reach. Despite the fact that farmers can now change their application if they are found to be non-compliant, respondents indicated that the relation with farmers still retains a disciplinary element, where control is paramount, as RS12 describes:

"I don't pay them; I don't pay the declaration of the farmer so I can control it. So, I see with remote sensing his behaviour, I don't pay the basic payment and thus I address environmental issues. You will tell me it's a stupid way, but it's effective. It's an effective way to check the environmental challenges. […] Of course the best way is to change the mentality of the people and to educate them in order to have environmentally friendly behaviour. […] but in my real life you just don't pay them, so it's very fast and very effective."

The notion that digital technologies subjectify farmers is not entirely lost here, but the real control, as RS12 notes is the disciplining through basic payments. This in effect reduces the freedom of farmers, as RS12 notes as well. The discretion over farm management reduces for farmers, as monitoring ensures that they have to comply with certain (monitorable) measures. As RS12 notes in response to a question why he described farmers as being afraid of the technology:

"Because they [farmers] think that they can cheat, probably they can cheat something, I don't say that they cheat, probably not. But the idea of being able to cheat is attractive. I do so many checks on these people, thousands every year, so they cannot really cheat. But the idea of being able to do that... But now with the satellite, it sees everything as they say. I see you when you go to your field so be careful."

This quote does not indicate that ‘cheating’ the system did occur, but rather indicates that the perception of freedom, which comes along with being able to ‘cheat’ is important to farmers. The loss of freedom over being able to not comply is listed as the reason for resistance among farmers. A loss of discretion over being able to make farm management choices that go against the rules. This can lead to improved environmental conditions, as farmers now have to follow rules that do often have a positive impact on the environment, but this is not necessarily the case, as RS4 also indicates:

“I did some reflections like; we are looking for agricultural activity. So if you do tillage, we detect it because there is no green cover or whatever. So it's like we promote the use of more tillage because with tillage it’s easy for us to detect agricultural activity. And I was wondering if... I don't know if it's good for the environment. Let's say to... Because at the end, when a farmer set the land aside for one year as a fallow land or two years, we may detect that it is not agricultural activity, but at the end for the environment, it's fine to have cover crop.”

The policy that RS4 relates to, of having to have agricultural activity to be eligible for subsidies is checked by remote sensing. If farmers do not show agricultural activity on their land, they are not eligible for these subsidies, but as RS4 relates, this can promote behaviour that has a negative impact on the environment. This is not to say that monitoring necessarily leads to these types of situations, but rather that monitoring and ensuring compliance do not, on their own, lead to better environmental outcomes in farming.

This completes the difficulties of monitoring farmers. Ideals of environmental protection cannot be guaranteed, ideals of collaboration boil down to a disciplinary element with resisting farmers. Despite the promise that the system shifts to collaboration, where the farmer can repair their claim, the central element of the system is that the paying agency can retract subsidies from the farmer. Despite the promises of technology providing control, this control remains elusive in practice and is limited by nature. The ideals of good governance have failure built in. The ideals of reducing bureaucracy, improving environmental standards and accurate control systems are still impeded by the existing socio-techno-legal-natural environment.

8.4.3 More technology as a solution to the failures of technology

The previous segment shows how failure of the system is anticipated by the respondents. However, there remains a hope that further technological advances will provide the utopic ideals that we sketched out in chapter 8.1. The ideals are not to be given up, and despite the realization that they cannot be achieved, respondents remain committed to the roll-out of further technologies that might achieve the goal. Further digital technologies, including geotagged pictures and artificial intelligence provide the inspiration for the next project to reach the ideals of good governance. RS12 describes:

“Where I see the technology going? I have told you; it absolutely goes to AI and as I said, everything will be done by sensors, satellite images, tractor sensors, geotagged pictures and whatever. So the technology goes to […] combining all this information, this chaos of the sensors in order to produce information for the people of the paying agency.”

The hope is still that technology will be able to help achieve better forms of governance of the CAP. The ideals we listed at the start are not yet achieved, but with more technology these ideals might be reached. One of the technologies that is currently increasingly seen as promising to the paying agencies is the use of geotagged pictures, which involve farmers taking pictures to prove that they are complying with certain measures, as RS3 describes:

In fact, we have a new policy, we call them preventive geotagged photos. So, farmers can send us photos without it being requested [by us]. So, they can do it in advance. And we’ve noticed that the number of preventive photos that we have received has [doubled]. Yeah. So […]

if you're a good farmer, you're not a cheater. Why not send a photo and avoid problems, you see? Yes. We do not have many cheaters. You know, most of the farmers are good farmers and they comply with the rules. So, if they send you the photo, they facilitate your work. And that has been quite successful.

The roll-out of further technology promises to make the ideals of good governance achievable. The farmer does not have to be a cheater and does not have to be disciplined if only they comply to the rules. What it takes is further technological innovations that promise to make control achievable, as RS11 also describes when they are describing the future of data use by the government:

"I think we want to evolve to a hundred percent monitoring, so that we can see everything on the basis of data. But that is not just satellite data, right? That is all available data sources, public, government, private, depending on the aim and on consent. […] And a system where the farmer can make changes at the end of the line. To fix small mistakes that are currently punished, which he will then be able to change."

The changes to governance cannot be seen from an age-old ideal of governing. Control over agriculture and farming through the utopian ideal of the panopticon lives on in digital technologies. Increased access to data reinvigorates the ideal of having totalizing vision over agriculture. The farmer no longer needs to be disciplined in this system, as the all-seeing eye ensures that punishment is no longer really needed. Farmers can repair their mistakes without fear of punishment. At the same time, these ideals are not actually achieved, and respondents doubt whether they are able to reach this form of governance for the CAP.

8.5 Discussion of the findings

As a reflection on our findings, we answer the research question posed at the beginning, asking what the impact is of digital monitoring technologies and remote sensing on the bureaucracy at work in the governance of the CAP. We link this to previous writing on the governance of the CAP and the effects of the CAP on agriculture. We also indicate how remote sensing technologies influence the governance of the CAP and how this relates to the audit culture in the CAP. Lastly, we expand on the notion of desire for bureaucracy and for governance, and highlight how this is relevant for this empirical case and how this notion might help improve the governance of the CAP.

8.5.1 Changing audit culture

Previous work has emphasized how farmers deal with the monitoring of CAP compliance (Aistara, 2009; Estrada Bonell & Vaccaro, 2022; Kovács, 2015). These articles were written in the light of previous periods of the CAP, and they indicate how control and audit culture are central to this monitoring work (mostly for the period 2014-2020). Our findings show that the further introduction of remote sensing for monitoring is not causing a radical transformation of the CAP so far. The notion of control, of assurance and its connected audit culture that previous authors have mentioned remain (Aistara, 2009; Kovács et al., 2021). The monitoring of CAP compliance is tied to surveillance technologies (Kovács, 2015), and the use of remote sensing can be seen as a further extension of this.

Audit culture, understood as a culture of transparency that seeks to ensure that each euro spent can be traced and is accounted for, is central in the monitoring of the CAP (Kovács, 2015; Power, 2003). This culture is a top-down performance, where the respondents in our research determine compliance by farmers, while they need to ensure that these technologies are effective enough through further audits (Delegated Regulation 2022/127; Delegated Regulation 2022/1172). There is no avoiding the systems of monitoring for non-compliance.

This clashes with the notion of our respondents as street-level bureaucrats, who have a certain autonomy over their decisions and who are free to interpret official policies. What is visible in the roll-out of these technologies is that the audit culture becomes more pervasive, reducing the autonomy of both farmers and paying agencies, as non-compliance becomes transparent. This begs the question of how much autonomy the respondents have as street-level bureaucrats in pushing through their own ideals, of having a high-quality monitoring system, of protecting the environment, and of removing animosity between them and farmers in the bureaucracy and governance of the CAP.

To an extent the results indicate that these ideals of the respondents are largely steered by top-down developments. There is no choice but to use technology as a monitoring platform, to allow farmers to repair claims, to measure compliance to the rules, as can also be read through successive EU regulations (Delegated Regulation 2022/1172; Regulation 2021/2115; Regulation 2021/2116). The notion of reducing punishments of farmers is enshrined in EU law (Delegated Regulation 2022/1172). Respondents and PA's do not have much autonomy over the control system. The roll-out of technology can be sped up or slowed down, but its roll-out is enforced regardless. This contrasts with the auditing culture of previous CAP periods, where inspectors working for paying agencies had more leeway in determining compliance, by being further removed from higher level bureaucrats (Kovács, 2015). The street-level bureaucrat has been taken off the streets, and through remote sensing the audit culture hierarchy can determine if compliance has actually been reached.

This create a situation where the monitoring through remote sensing is not a monitoring of the farmer alone. It allows for an indirect monitoring of the people working at paying agencies, where decisions have become transparent, a central aspect of the auditing culture of modern governance (Turnhout et al., 2014). This links to the literature in digital agriculture studies, where there has been a recurring notion that digital technologies limit the agency of farmers (Brooks, 2021; Gardezi & Stock, 2021; Stock & Gardezi, 2021). Brooks (2021) for example classifies digital technologies as lending themselves to monitoring, nudging and correcting farmers, leading to a reduced potential for farmers to make their own decisions. Prause (2021) notes that especially farm workers are the targets of surveillance in agriculture, where digital technologies are used to monitor their performance. Our findings expand this critique to digital technologies used for governance, and we show that this monitoring extends to other actors, where also low-level bureaucrats at paying agencies are involved in the monitoring. They are not just doing the monitoring, but remote sensing also allows the monitoring of their performance.

8.5.2 A potential shift in governance

At the same time, the development of the CAP, as told by respondents and as is visible in official policy (Delegated Regulation 2022/1172) provides a more lenient approach to farmers, where they are able to avoid fines and other punishments by repairing their claims. The leeway that was previously created through inspectors on the field being relatively autonomous street-level bureaucrats, is provided for by enshrining this in official policy. An attempt is made to create universal rules and regulations in bureaucracy that still provide openings to keep these policies workable at the local level.

This can be read as an attempt to reduce the animosity between farmers and paying agencies, as our respondents also indicated. While this ideal of reducing animosity exists, the relationship between farmers and paying agencies remains determined by the fact that the paying agency controls the funding (and a significant portion of the income of farmers). The power relationship is uneven (Aistara, 2009). Additionally, the respondents themselves indicate how control remains essential and how part of their work is disciplining farmers (through withholding payments). This power relationship is inherent to the auditing culture that paying agencies need to adhere to. As both our results and previous writers have indicated, controls and inspections are central to CAP governance (Aistara, 2009). Previous authors have stressed the relevance of disciplinary power in the governance of the CAP (Aistara, 2009; Estrada Bonell & Vaccaro, 2022).

Our findings provide an interesting aspect to this, as respondents were hesitant to talk about the notion of control and bureaucracy. They acknowledge the control they have, but with reluctance.

One could question whether this indicates a shift to new forms of governance, less dependent on disciplinary governance. New forms of digital agri-environmental governance have been listed that can increase the discretion on the side of the farmer over farm management choices that might go against official policies (Ehlers & Huber, 2021). As one of the respondents indicated, there is some doubt that official policies actually achieve the aim that they said out to do, and whether monitoring leads to better environmental outcomes. What we have found is that despite changes to governance, there is no real shift to forms of governance that are less prescriptive, where farmers gain agency over how they farm. Equally, despite the desire to move to forms of governance that are less likely to create animosity between farmer and PA, the universal rules of the CAP still structures farming, with farmers dependent on the CAP for a significant portion of their total income (Estrada Bonell & Vaccaro, 2022). This creates a structuring element, a directional force that steers farmers and structures farming (Kovács, 2021). While digital technologies offer opportunities in governance to leave farmers more discretion in on-farm decisions (Ehlers & Huber, 2021), the approach that respondents describe remains focused on monitoring compliance. This reduces opportunities for farmers in evading rules or departing from regulations or quotes, as monitoring becomes precise enough to prevent this. While this is valuable in ensuring policy compliance, it does not guarantee environmental benefits, as one of the respondents also noted.

8.5.3 Achieving better bureaucracy or a techno-utopian trap?

Considering the discussion so far, we have highlighted how the governance of the CAP remains tied to an audit culture, and how this affects paying agencies as street level bureaucrats in using digital technology. Throughout these developments, respondents retain a desire for forms of governance that can achieve the ideals that have been set out, and for new (and better) technology that can achieve said governance. This brings us both to the topic of desiring bureaucracy and to techno-utopian thinking. Lea (2021) sets out how the desire for bureaucracy should not be disparaged out of hand, but that this should rather be seen as a form of desiring higher ethical functioning. Bureaucracy, and the expansion of bureaucracy is seen as a way to achieve the ideals inherent to the governance of the CAP.

The ideals that respondents listed in the results (achieving control, assuring that money has been spent right, removing animosity between PA's and farmers, ensuring environmental protection, removing administrative burden) are tied up with digital technologies, and technology becomes the promise for achieving said aims. Despite the acceptance of shortcomings and failures in current technological developments, respondents show how further technological change will be able to achieve said aims, indicative of a broader techno-utopian thinking, where the main line of thinking is not questioned (Callen & Austin, 2016).

At the same time, respondents contradict this belief when they describe the uncertainty inherent in the technologies they use. As we showed in chapter 4.1, there is a promise that these technologies can go to certainty. While this promise is described by respondents, they also note how agri-environmental conditions create uncertainty that limits their potential of control. Visser et al. (2021) describes this uncertainty in relation to digital agriculture as imprecision farming, indicating that despite the promises of digital technologies, uncertainties limit its potential. Respondents understood these limitations, realizing that their indicators do not fully capture the environment and that uncertainty remains. The technology that is promised to bring about the ideals of good governance fails to bring about these ideals because it's not able to fully capture the complexity of farming in the natural environment.

We find this relevant, as the governance of the CAP, despite its failures and sometimes limited achievements (European Court of Auditors, 2017), retains a promise to achieve environmental aims, to support farmers and to support food security. Authors on digital governance have listed opportunities for digital technologies to drive new and better forms of governance (Ehlers et al., 2022; Ehlers & Huber, 2021). There is potential to use these technologies for forms of governance that might not fulfil every desire that is placed upon them, but that do lead to better governance. The desire for higher ethical functioning of bureaucracy lives on (Lea, 2021). The failures of achieving these aims do not limit the desire to achieve these aims. In this sense, bureaucracy draws back on utopian ideals, presenting the efforts made by respondents as searching for this higher ideal (Billaud & Cowan, 2020; Mathur, 2020). It can however be questioned whether the further introduction of technologies of control to the CAP supports these ideals. The roll-out of technologies seems to follow a techno-utopian trap, where the further development of even more advanced technology is seen as the main solution to the governance of the CAP.

8.6 Conclusion & further research

Technologies come with great promise, to transform policy, government-farmer relations, and environmental conditions but do not seem to achieve the goals that have been set out by the EC or the respondents in this research. The technologies in their current state are useful to the monitoring of compliance but remain within an auditing culture that provides little agency to either bureaucrats or to farmers. Moreover, we see these technologies as limiting the agency that was available to these actors, as increased transparency and monitoring mainly provides more opportunities for top-down controls.

The challenge is then to find ways to free remote sensing and other digital technologies from the existing trajectory of the CAP. Despite the potential of these technologies, the use of them remains within the trajectory that the CAP has taken so far. While the EC has shifted the governance of the CAP down to the member state level, this is a shift in responsibilities but not in the forms of governance. Our interviews with respondents indicate that a culture of auditing and finding non-compliance remains dominant. It will be relevant to see if in time member states will make a shift in governance in the CAP, redirecting the use of remote sensing technologies. However, in this it is important to note that the use of the technology alone is not enough to shift current policies. To shift policy, it needs to be realized that a shift in governance is needed. This is the real trap that the CAP has landed in, where novel technologies are adopted, but where these are not yet used to transform governance to make use of the opportunities that these technologies provide.

For further research, studies can further focus on the relationship between paying agencies and farmers, especially as mediated by remote sensing technologies. Where we focused on the paying agencies, a research combining this with the perspectives of farmers can be valuable. Case studies in different member states can help elucidate how farmers become involved in the surveillance technologies used for CAP monitoring (in terms of implementing them, tinkering with them, resisting them), as different member states will most likely produce different results (between countries and European subregions). Especially the use of geotagged images is interesting in this context. This can also be an interesting avenue for research on how the same technologies are implemented across different member states, related to the context of the member states. With the CAP national strategic plans, decision-making is increasingly delegated to the member state level. Both the broader structure of the agricultural sector and political choices made at the member state levels guide the development, adoption, and implementation of these digital technologies.

A separate, controversial, and sensitive topic that we noticed in our study are the political aims of the member states vis-à-vis the commission. Respondents hinted at the fact that member states are seeking to steer the development of both the CAP and remote sensing technologies in a different direction than the commission, but little data was available as respondents did not want to be quoted on the politics of controls in the new CAP. Further research might help elucidate these developments.

CHAPTER 9. GENERAL DISCUSSIONS AND CONCLUSIONS

9.1 Introducing the discussion

While the articles differ in focus, in theories used, and in perspectives, there are recurring themes between the five empirical chapters that allow us to answer the main research question. To remind the reader, this research question was: *What is the current role and potential of diverse forms of agency and knowledge in the digital transformation of European agriculture, and what impact do participatory approaches have on including these diverse forms of agency and knowledges?* To answer this main research question, we return to the concepts and theories that we described in the first two chapters use this to discuss the findings of the empirical chapters. In the introduction we noted the uneven impacts of the digital transformation of agriculture. We described how existing uneven power structures are affecting this transformation, and that this might pose risks to the diversity of knowledges in agriculture. We also noted the potential for agency in this digital transformation, where different people and groups of people can affect the digital transformation. Closely tied to this agency is the potential for participatory approaches in involving stakeholders in the development of digital agriculture.

The research in our case studies is essential in setting out how agency, power, and knowledge function in the digital transformation and how this relates to participatory approaches. We begin our answer to the main research question by discussing the agency of different actors in the digital transformation of agriculture and how this agency is enabled or constrained in the use of digital technologies. We follow this with a discussion on diverse knowledges in agriculture, including those made available through digital technologies. We also link the functioning of knowledge to power, agency, and resistance in the digital transformation of agriculture. Finally, we discuss the role that the participation of diverse stakeholders can play in addressing issues that have come up throughout the results and the discussion, and note how a deeper understanding of power, knowledge, and agency can support these participatory approaches. We complete the discussion by addressing the implications of our findings for policymakers, for research, and for agriculture and society.

9.2 Agency in the digital transformation of agriculture

In this work we highlighted human agency and the forms that this agency can take in the digital transformation of agriculture. As we described in the theoretical background, we understand agency as distributed but not symmetrical. Certain approaches in the field of (digital) agriculture studies have advanced an understanding of agency as fully distributed (Comi, 2020; Darnhofer, 2020), limiting an understanding of power and ignoring the (human) intentionality behind agency (Elder-Vass, 2008). Throughout this work and in the empirical chapters, we largely opted for an approach to agency that accords a specific type of intentionality to human agency, as is made especially clear in chapter 6 (Elder-Vass, 2008; Flatscher & Seitz, 2020). Without this, it becomes challenging to assign responsibility for actions, or to study power structures (Bowden, 2015). The capacity to take responsibility for harm in a reflective way is unique to humans. This means that only human actors can intentionally change the trajectory of the digital transformation of agriculture when these trajectories are likely to cause harm. This agency cannot be afforded to non-human actors.

This human agency does take different forms throughout our work, varying both in what actions are possible for people to take and in the intentionality behind human agency. This is illustrated by the work in chapter 6, where we understand farmer agency in assemblages as a search for making digital agriculture workable, linking up with other research that has focused on the assemblages of digital agriculture (Legun & Burch, 2021). This both indicates the constraints on the agency of farmers through technology design (as is the case when farmers standardise) but also shows how farmers use this approach to preserve (other) local cares. Technology design can and does constrain agency to an extent, but farmers have ways of working around these constraints, which is where agency is expressed.

This is also recognised in our work in chapter 7, where farmers have varying responses to data-driven knowledge. Agency is expressed through interpretation, through changing how the technology becomes accepted on the farm and shaping the technology in the act of adoption, something that was also a central element to chapter 6. These ways of working with the technology are often not explicitly designed into precision agriculture, but users (farmers) do shape how the technology becomes used and what is possible with the technology. Equally, we see notions of rejection in our case studies, where farmers in chapter 6 disconnect from elements of digital agriculture when these do not work for them. This same rejection, although not explicitly for digital agriculture, is also visible in chapter 4, where technology developers reject official interpretations and knowledges and instead claim legitimacy for their own forms of knowledge.

Together, these chapters show how agency can be recognised in both acceptance, adaptation, and in rejection. Whether farmers adopt digital agriculture, shape it to their specific needs, or reject this technology, there is agency in these actions. Through these actions the digital transformation is (re-)shaped. However, we need to caution against seeing this as a complete agency over the digital transformation. The argument can be made that this agency might be true at the micro-level (at the farm, at a company and between small networks of actors) but that this agency does not translate to the macro-level, to changes in broader (power) structures (Bantwal Rao et al., 2015).

This is true to an extent. Broader market relations and the structure of relations on farms are remarkably stable. Yes, farmers in chapter 6 are partially disconnecting, but this does not seem to have an impact beyond their direct environment. Similarly, chapter 9 shows that the expansion of remote sensing technology in governance does not fundamentally restructure governance itself. Instead, the technology conforms to current modes of governing. These outcomes are linked to the focus on conventional (and often large-scale) agriculture that we studied in the empirical chapters. As other authors have written, precision agriculture functions precisely for conventional agriculture (Carolan, 2020a, 2020b; Duncan et al., 2021). In that sense, our accounts need to be seen in the light of farmers and other actors involved in the current agricultural system (and often benefitting from it) who adapt technologies and show agency in adjusting elements of the system to work for them.

This provides a situated understanding of agency in this work. This work has in several chapters (chapter 4, 6, 7) focused on the 'winners' of conventional agriculture (in so far as there are winners) and agency needs to be seen in light of this. For example, the farmers involved in this research have the digital skills to transform, retrofit, and adapt precision agriculture and in doing so have agency over the digital transformation. The same can however not be said for those on the other side of the digital divide (Rotz, Gravely, et al., 2019). This did not come up as such in discussion of the empirical chapters, but came up as a recurring element of this broader reflection. This also means that alternative options did not seem realistic, a finding that came up in chapter 4, but where chapter 6-8 also took the direction of technological progress as a given.

9.3 Agency as responsibility in the digital transformation

In further exploring the consequences of this understanding of agency, we return to previous studies on digital agriculture. Our understanding of the diverse forms of agency adds to the relational and materialist approaches that have been used to study digital agriculture. These works, often through utilizing a distributed agency lens, have highlighted the diverse and distributed actors at work in making precision agriculture workable (Carolan, 2020b; Comi, 2020; Finstad et al., 2021; Higgins et al., 2017; Legun & Burch, 2021). While these accounts are helpful in showing the diverse actors at work in the digital transformation, there remains a challenge of ascribing responsibility.

That is, it is challenging to define who is responsible for uneven impacts in the digital transformation. If agency is distributed across human and non-human actors, should all actors not carry equal blame (Knudsen, 2023)? By explicitly addressing the limits of agency and highlighting how different actors vary in their agency, this work helps assign responsibility for addressing these impacts (Prutzer et al., 2023; Rijswijk et al., 2021).

This responsibility begins at the design of precision agriculture technology, where most of the responsibility lies. Uneven power relations means that manufacturers, input providers and other (large) corporations have a large impact on how precision agriculture becomes implemented (Bronson & Knezevic, 2019). However, what our work adds is that this trajectory of control by large corporations is not fixed and that potential change might start by adapting and modifying these technologies (as can be seen in chapter 6 & 7). We believe that these small acts of agency do matter, as it shows that the digital transformation is not all-determining. Farmers are developing technologies themselves and making these technologies their own (Finstad et al., 2021). They own the technology and integrate it with their local cares, as we showed in chapter 6. The same can be said for the concept of the cyborg farmer developed in chapter 7, which further highlights how both precision agriculture and farmers are changing through the introduction of digital technology on farms. The cyborg farmer stays with the trouble, as it shows how farmer agency can transform a universal technology, developed by large corporations, to the local context with the accompanying local cares of farmers (Haraway, 2016). This speaks to the diffuse power of different actors in making and changing the digital transformation, where the technology changes through interactions with farmers and other actors in the agri-food chain (Finstad et al., 2021; Kitchin, 2017).

This is not to say that every act of agency indicates a radical and positive change towards a better future for precision agriculture. As we indicated before, precision agriculture in chapter 7 is also used to provide the capacities for relatively large-scale farmers to remain informed about their fields. This does not question the basis for having large-scale farms in the first place. In a similar way, the agency of technology developers in chapter 4 is used to try and get their technologies approved and sold to farmers, but as we also described in the same chapters, these technologies are unlikely to be a real solution to the agri-environmental impacts of agriculture. Technological change is not neutral, and the technologies in this research are largely intended to keep current forms of agriculture viable.

However, what we have attempted here is to provide an understanding of agency that nuances between accounts of fully distributed agency and between works that follow a political economy lens, where power and agency are fixed and where the digital transformation is dominated by large corporations. Our works do show that there are limitations to what is possible in the digital transformation, but more significantly, also show how people have agency to transform these power relations. Significantly, this agency also becomes possible through diverse forms of knowledge, where this knowledge is employed in claiming agency over the development of digital agriculture. This intertwining of knowledge and agency is a second recurring theme, and the focus of our next section in the discussion.

9.4 The digital transformation of agriculture and diverse knowledges

In the introduction and in the theoretical background we set out how knowledge relates to processes of agency. Knowledge conflicts, legitimacy claims over knowledge, and processes of subjectification are processes where power, knowledge, and agency intertwine. We also set out that there is a tension between knowledges in digital agriculture, or even knowledge conflicts (Tsouvalis et al., 2000). We understand knowledge as situated, contingent on the context in which it is produced (Haraway, 1988; Simandan, 2019; Turnhout, 2018). The use, credibility and validity of knowledge are situated in this context, not universally true. In this chapter, we connect our findings on knowledge to the agency of different actors and to power relations.

We use this to further our call for productive knowledge conflicts, which already came up in chapter 4 and 7. This provides avenues to construct knowledge that responds to existing tensions between agency and power structures.

An understanding of knowledge as situated is essential to this. Tensions around scientific knowledge and data-driven knowledge show how actors understand knowledge as situated, which was especially prevalent in chapter 4 and 8. In chapter 4, scientific knowledge is used to classify the performance of emission reducing technologies and data-driven knowledge is applied in monitoring the compliance of farmers to certain standards in chapter 8. However, this knowledge fails to fully capture or represent that which has been set out to be measured (Hale et al., 2019; Turnhout, 2018; Turnhout et al., 2007). In digital agriculture, concerns have been raised about the reliability, accuracy, and quality of data-driven knowledge (Rotz, Gravely, et al., 2019; Visser et al., 2021). The objectivist accounts prevalent to scientific and data-driven knowledges do not actually capture reality all that well. Technology developers in chapter 4 realize that the performances ascribed to their technologies have uncertainty built in. In chapter 8, bureaucrats working at the paying agencies wonder about the effects that their indicators have, where environmental outcomes are not guaranteed.

This partially confirms existing concerns about the reliability of data-driven knowledge (Rotz, Gravely, et al., 2019; Visser et al., 2021). However, the fact that this knowledge does not fully represent reality does not mean that the knowledge is not useful or valid. Rather, this knowledge is incomplete and needs validation with other knowledges, as farmers in chapter 7 described. We described this validation as a productive conflict, or a productive tension between knowledge systems, where new (data-driven) knowledge is partially accepted but also becomes incorporated in the existing knowledge base. In our view this conflict between knowledge systems allows for a strengthening of both forms of knowledge.

Intriguingly, the potential to work with diverse knowledges seemed to be more natural to farmers, technology developers, and other actors working with 'diverse' knowledges. Actors working with 'objective' forms of knowledge set boundaries, separating them from other forms of knowledge. In chapter 5, researchers have difficulty in opening up their processes of knowledge production to the diversity of other knowledges. Instead, boundaries are set when diverse knowledges are brought into a participatory process. Equally, there is no space for the knowledges of other actors in the 'official' knowledge of chapter 4. There are justifications for closing off knowledge production, for not including diverse knowledges and experiences. Generalisable results might be required (Berthet et al., 2016), epistemologies do not match (Boon & Van Baalen, 2019) and the legacy of objectivism means that *other* forms of knowledge are quickly seen as a resource rather than being seen as equally valid (Felt et al., 2016; Schikowitz, 2020).

However, this does not mean that we do not need to find knowledge that is more open to a diversity of insights and to work towards this as researchers and scientists. Finding knowledge that does a better job at explaining reality, while also opening up spaces to address inequitable assemblages is one solution (Hale et al., 2019). Turnhout (2018) indicates that central to holding scientific knowledge accountable are the productive connections between scientists who do the representing and the actors (human and non-human) who become represented. This boils down to the participation of diverse actors in the process of creating indicators, a common response to the challenges of modern knowledge production (Buuren, 2009). Turnhout (2018) also indicates that these processes often fail, a point that we will return to later when we discuss persistent power structures and knowledge hierarchies in participatory approaches.

9.5 Resistance through situated knowledge and agency.

We use this section to provide a final reflection on knowledge, power, and agency for digital agriculture before discussing the potential for participatory approaches in digital agriculture. We link this final point of the discussion to the potential for resistance in and to the digital transformation, which includes the different forms of agency that we found and the potential for both intentional and everyday forms of agency in resistance.

How knowledge is produced and used is determined by the different actors in this research, which provides opportunities for everyday resistance (Turnhout, 2018). Actors in our research, whether they are bureaucrats, technology developers or farmers have the power to apply knowledge; to name, classify, and to control (Sinclair, 2019). How categories and standards are applied determines how knowledge and indicators hold power, as street-level bureaucrats working at paying agencies also show in chapter 8. Each performance is both an act of subjectification and an opportunity for change (Sletto, 2005; Turnhout, 2018). Knowledge, and the use of knowledge is not deterministic, but functions through the various actors who develop, apply, and use these knowledges.

The use of knowledge to structure agriculture is broadly recognised in the field of digital agriculture studies, where visions of the future have a performative effect on the developments today (Carolan, 2022; Fairbairn et al., 2022; Legun & Burch, 2021). An understanding of overpopulation and food insecurity that can only be addressed through raising yields, will have profoundly different implications for the development of agriculture than an understanding that stresses the potential for diverse farming systems to feed people (Carolan, 2020a; Ditzler & Driessen, 2022). This is not just true for future visions, but also for the use of digital technologies here and now, where users can intervene in how these technologies are 'domesticated', or in other words, how they come to be used (Finstad et al., 2021; Kitchin, 2017). Which of the futures and uses of technologies become real is determined by the knowledges and categorisations that are seen as valid, but the actors in our research (and our research itself) help determine this.

In determining this, and in acting on their agency, actors in our research show the potential to resist interpretations and classifications and challenge how formally established knowledge is used. This resistance is made explicit in chapter 4, where technology developers resist the knowledge of scientists as used by the government and seek to disrupt official classifications of knowledge. Farmers in chapter 6 and 7 are resisting the data-driven knowledge and expensive digital agriculture technologies by retrofitting and through understanding precision agriculture in an embodied way. This is not a wholesale rejection of digital agriculture, but rather a resistance through finding new ways of working with digital agriculture. Following Bantwal Rao et al. (2015), we understand this resistance as subjects who shape and transform their "technically mediated subjectivity", taking into account their existing relations to their environment. What logically follows is that resistance can be a form of democratization of technology design, formed by subjects (whether farmers, bureaucrats, or others) who resist by shaping and transforming technologies (Bantwal Rao et al., 2015). This form of resistance has implications for participatory design, as it shows the existing participation in design through resistance that already occurs, a topic that we will return to in chapter 9.6.

Returning to studies on digital agriculture, several authors bring up the notion that there is also a need for resistance to the performativity of digital technologies and systems (Carolan, 2018c; Daum, 2021; Ditzler & Driessen, 2022; Lajoie-O'Malley et al., 2020; Legun & Burch, 2021; Miles, 2019). In other words, there should not be a singular digital transformation but instead there should be multiple potential futures where data and digital technologies can potentially play a role. The digital should not be the driving force in these scenarios, but rather needs to be a potential element of diverse food futures (Carolan, 2018c). Our work adds to this literature by setting out specific strategies and cases of resistance and by providing empirical evidence of current forms of resistance. Through disrupting dominant knowledge claims (chapter 7 & 8), through relying on embodied knowledge (chapter 7), through retrofitting and adapting technologies (chapter 6), different actors are resisting the norms inscribed in current digital technologies. They might not always be conscious acts of resistance, but they do show how everyday agency can change the digital transformation. This is how agency is embodied in productive resistance, an end to itself but also the starting point for potential larger changes, which can affect the dynamics of digital agriculture (Ettlinger, 2018). People have the potential to change digital systems that drive the transformation of agriculture. Not every farmer will be aware of this potential, as is especially visible in chapter 7, where some farmers desire an algorithmic form of farming.

A move to more intentional forms of resistance might be essential in furthering this resistance, where participation can play a role in critically reflecting on the digital transformation. This can help build awareness of how to situate resistance to sustain more communitarian and democratic values in technology development. While these strategies do not directly correlate to political change, they can (and will) over the long term produce effects that will change repressive governance and power structures (Ettlinger, 2018). Equally, this requires researchers to help strengthen the relations with diverse forms of knowledge, helping strengthen the assemblages of these knowledges to provide the potential to actors to assert their truth (Van Assche et al., 2011), a point that we will return to in the last section of this discussion.

9.6 The potential for participation to address issues around power, knowledge, and agency in the digital transformation of agriculture.

In our work we have set out some of the ways that power, agency, and knowledge function and how this changes through the digital transformation of agriculture. We have described how the agency of farmers affects and is affected by the digital transformation of agriculture. We set out that there is a potential to change the direction of this transformation, which lends itself well to participatory approaches (Legun & Burch, 2021). However, this does not mean that participatory innovation approaches necessarily support beneficial changes to digital agriculture. While we believe that the developments of participatory innovation are encouraging, we also argue that there is sometimes a relatively naïve approach to power, agency, and knowledges, where the diversity of forms of power, knowledge and agency are only partially addressed.

In this, we do not only point to other authors, but also reflect on our own work. Our reflection on participation in chapter 5 showed the imperfections of the participatory innovation project we were involved in. While we respect the efforts of all researchers involved in this participatory project, we also question whether the drawing of boundaries between research and participant and between project activities did not exclude more meaningful participation. This boundary drawing prevented a more fundamental reckoning with power and knowledge hierarchies, as the reflection on these hierarchies and dynamics was only made after the participatory exercise. Similarly, in chapter 7 we recognize our tendency to seek the integration of the diverse knowledges of farmers with digital technologies. This aligns with other authors who have written about diverse knowledge forms in digital agriculture, where the notion is often that this knowledge should be embedded in the digital system (Gardezi et al., 2022; Lundström & Lindblom, 2018). While this does involve other forms of knowledge in the development of data-driven knowledge, and allows these forms of knowledge a seat at the table, it also risks the reproduction of knowledge hierarchies (Boon & Van Baalen, 2019; Latulippe & Klenk, 2020). Equally, this approach also risks ignoring what makes diverse forms of knowledge work. An integration of embodied knowledge risks ignoring the embodied nature of this knowledge and might ignore that this knowledge is situated in a specific context (Haraway, 1988; Leino & Peltomaa, 2012).

We do not want to set out a problem without providing a possible solution. In setting out this solution we hold a normative position, where we use our findings and discussion to set out a normative approach to participation. This approach critically reflects on the digital transformation, seeks to subvert and resist repressive power structures, and seeks to builds alternatives to existing trajectories of digital agriculture. In doing so, we believe a return to the beginning of our empirical work will be valuable. In chapter 4 we noted the potential for agonistic pluralism. Participatory and inclusive approaches tend to be focused on reducing conflict, on working away the tensions between different forms of knowledge, between hierarchies of power and knowledge (Edelenbos et al., 2011; Purcell, 2009; D. Scott, 2021). In our view, and following other authors, we believe that more attention should be paid to productive forms of conflict, where hierarchies are made explicit and can be a source of tension and conflict (Mouffe, 2007; D. Scott, 2021). Equally, this allows us to account for incompatible visions. Sometimes there seems to be a belief that with enough participation and inclusion a diversity of forms of agriculture can be ensured (Klerkx & Rose, 2020). While it is commendable to encourage a diversity of forms of agriculture, it is fairly naive to believe that deliberative approaches focused on inclusion can achieve this aim (D. Scott, 2021). An agonistic pluralism perspective that acknowledges power relations and incompatible visions, and seeks to come to productive conflict might be more helpful to embracing this diversity (Popa et al., 2021; D. Scott, 2021).

A challenge in building on a more agonistic approach is that this conflictual approach might hinder the participation of certain actors. A normative approach to participation that seeks to address power imbalances might fail at involving powerful actors in the agri-food chain (retail, input providers, large machinery manufacturers). At the same time, the inclusion of powerful actors is itself often cause for unequal power relations that impede the transformative potential of participatory projects (Turnhout et al., 2020). Our view in this is that it is better to be come to productive conflict that might exclude larger corporations and other powerful actors from a participatory project than it is to include these players at the cost of transformative potential. Alternatives to current digital approaches do not have to include these powerful actors and can be built by networks of actors that do not hold power in the current agri-food system (Bantwal Rao et al., 2015; Carolan, 2018b; Ettlinger, 2018). This links to the resistance described in chapter 9.6, as farmers and other actors are already showing that they are re-shaping the technology in using and adapting precision agriculture. Building on this with participatory projects can produce further alternatives to the current direction of the digital transformation without requiring the involvement of powerful actors within the agri-food system.

However, participation alone is not enough to address existing power imbalances. Monopolistic corporate power will need to be broken up and regulation is needed to regulate dominant corporate players in the agri-tech system (Bronson, 2019). While the power and agency of farmers does subvert and change the direction of the digital transformation, there is no reason to believe that this agency of diverse actors might not benefit from disrupting dominant power structures. Further opportunities come from productive resistance to the digital transformation, where authors describe alternative technologies, subversive strategies, and the use of digital systems to undermine repressive power (Carolan, 2018c; Ettlinger, 2018; Fraser, 2021). This might not require conflict between the actors in a participatory innovation project, but might produce conflict between the project and the status quo (Ettlinger, 2018; Fraser, 2021; D. Scott, 2021). In summary, researchers in participatory innovation projects need to become more comfortable with conflict.

This also does not have to be led by the researcher alone. There is already existing agency on the part of farmers, on the part of bureaucrats, on the part of technology developers. There is existing knowledge in diverse forms, there are networks that build alternatives to repressive power, to knowledge hierarchies and to closed digital systems. It is a matter of linking up these networks, further developing them and joining in on the struggle, rather than creating new participatory systems where people might join in on co-theorising. This requires giving up leadership over participatory projects and requires a mentality that contributes to existing assemblages rather than seeking to develop new ones. However, this does have the potential to build on the existing knowledges of diverse people, to further the use and recognition of embodied knowledge in farming, to increase agency in using remote sensing technologies for governance and to create awareness of how knowledges (including data-driven knowledge) subjectify, in order to resist this subjectification.

CHAPTER 10. CONCLUDING REMARKS

To begin the concluding remarks, we return to the research question we posed at the end of the introduction; *What are the current and potential roles for diverse forms of agency and knowledge in the digital transformation of European agriculture, and what impact can participatory approaches have in enabling these diverse forms of agency and knowledges?*

We have described how the agency of technology developers, of farmers and of low-level bureaucrats is impacting the development of digital technologies in agriculture. This agency is expressed through farmers standardizing, retrofitting and adapting digital agriculture. Agency is also shown by farmers who reinterpret advice received from decision support systems and by other actors who reinterpret and restructure the digital transformation of agriculture. Diverse knowledges are used in this, and actors in our research show how these diverse forms of knowledge come to be used. Tensions and conflicts between knowledges are present in the digital transformation, but these tensions and conflicts can be productive. Moreover, we view these tensions and conflicts as essential, and believe that researchers, scientists, and technology developers might benefit from involving and accepting this tension and conflict, especially when they involve other actors in knowledge production and technology development.

We are critical of participatory approaches, but remain hopeful that these approaches might play a part in enabling diverse forms of agency and knowledge. This research shows the need to be attentive to diverse forms of power, agency, and knowledge in participation. We ourselves point to the potential of using participatory approaches to disrupt dominant power structures and hold this as a normative aim that participation should strive towards. There is potential to find ways that strengthen the agency of diverse groups of people, through acknowledging their diverse knowledges and by linking up to networks and assemblages that can change the direction of the digital transformation of agriculture.

10.1 General limitations and future research

Limitations specific to the empirical chapters are described in their respective empirical chapters. These limitations generally concerned the involvement of different actors, where we respectively did not involve government agencies and local stakeholders in chapter 4 and 5. The involvement of these actors could have strengthened these respective studies. For chapter 6, data was collected before we (authors VH, DV, NB, LK) decided to compare case studies, which limited the overarching themes and concepts. A choice for more diverse methods could have improved several case studies. In chapter 7 the mechanisms of embodiment could have been explored through observational methods. For chapter 4 and 8, a policy document analysis would have strengthened our understanding of the politics involved in these studies. These limitations provide avenues for further research.

There are also overarching limitations in our work, which provide potential for future studies. Our findings in this work are specific to the European context. In our work we described agency on the side of farmers and perceived less dominant power structures than authors writing in the context of agriculture in the Americas and in other continents (Brooks, 2021; Miles, 2019; Rotz, Duncan, et al., 2019). Regulation in the EU is increasingly addressing the dominance of tech firms, and the European context of agriculture might also lend itself more to technologies that address the needs of farmers. We noted this in chapter 6 when describing the national ag-tech landscape of the Netherlands, where farmers and technology developers are collaborating in technology development. This creates a different context compared to agriculture in other regions of the world, and our findings need to be read in this context.

The timing of this research also creates a specific element that does not automatically translate to future processes of digitalisation in agriculture. New technologies and other changes to agriculture will create specific conditions that might lead to different outcomes and uses of digital technologies. At the same time, the core elements of this work will likely stay relevant. There is agency over the digital transformation, diverse forms of knowledge will remain relevant, even in data-driven agriculture, and the critiques and findings over participation are unlikely to change in future participatory projects.

Lastly, our empirical studies are diverse, and address fairly different case studies, which provides a diversity of insights and interpretations for the digital transformation of agriculture. This has left considerable space for further studies to explore specific questions that the case studies brought up, especially for chapter 4 and 8. Embodiment of technology use still remains underexplored for digital agriculture. Equally, remote sensing is increasingly adopted for environmental governance, but relatively few authors have written about this. More research is needed to provide further in-depth accounts of these topics and what this means for the digital transformation of agriculture.

10.2 Implications for research

Our work is mainly relevant to the field of (critical) digital agriculture studies. With a background in rural sociology and STS we have built on a body of existing work in digital agriculture studies that seeks to explore the underlying assumptions and beliefs that steer the development of digital agriculture (Carolan, 2018c, 2022; Fairbairn et al., 2022; Miles, 2019). This also links up to a growing body of work that showcases the agency and diverse knowledges of farmers in making precision agriculture workable on their farms (Comi, 2020; Ditzler & Driessen, 2022; Higgins et al., 2017; Legun & Burch, 2021). This works helps build on this literature by emphasizing deliberative agency in assemblages, in conceptualising how embodied knowledge plays a role in digital agriculture through the concept of the cyborg farmer, and by exploring how digital technologies are shaping agriculture. We use these findings to nuance some of the more radical takes on digital agriculture, where we see digital agriculture as not necessarily steering agriculture in a specific direction. Through our everyday accounts of the digital transformation of agriculture we also help build an empirically grounded case for how digital agriculture is affecting farmer agency and farmer knowledge, something that few existing studies have touched upon. Through this we link different fields of study and theory, linking different understandings of power, knowledge, and agency and making this more explicit. This also helps build the case that increasing attention is needed to the small acts of diverse actors that show how diverse forms of agency and knowledge impact larger societal transformations.

Equally, our work describes the potential for participatory approaches to involve productive knowledge conflicts, and productive conflicts in general. This allows participatory research approaches to move beyond a search for consensus. In general, we believe that a focus on productive conflict can help make visible existing power structures and can prevent the risk of integrating diverse forms of knowledge into scientific knowledge. We also make the call to focus more on existing assemblages that seek to build alternative (potentially digital) futures, which has previously come up in the literature but where further progress is required (Carolan, 2016a, 2018b; Ettlinger, 2018).

10.3 Policy and practice implications

Throughout this work we have been critical of the techno-solutionism that is present in agri-environmental policies (especially in chapter 4 and 8). This critique stems from the fact that technical solutions rarely achieve the aims set out, as is also made visible in these respective chapters. The technologies put forward to solve agri-environmental issues do not tackle the root causes of agri-environmental issues in agriculture. We believe that this techno-solutionism stems from the notion that technological fixes can be rolled out without controversy. At the same time, as chapter 4 shows, controversy exists even in techno-fixes, with conflict over which technology might function best as the techno-fix. What our work offers to policy and practice is to accept this controversy and to accept the conflicts around technology, or more concretely, not to adopt a techno-fix without letting this controversy and conflict over technology play out. In even more concrete terms, this means not subsidising expensive technical solutions when a variety of other approaches might also solve the larger agri-environmental issues.

What this work also indicates is that there is not always a need for policies or regulation, as there is potential for people and groups of people to address the impacts of digital technologies themselves, as can be seen in chapter 6 and 7. However, as we also noted, there is potential for regulation to support the more even distribution of benefits from digital technologies. In this, there have been more hopeful developments, as several recent acts have sought to address the monopolistic impacts of large tech firms across Europe (Atik, 2022). We can only encourage these developments.

Considering the attention that funders in Europe have for multi-actor and participatory approaches in research, our research (mainly based on chapter 5) also has implications for this. We encourage a more critical lens towards participation, including a more selective approach to where participation of stakeholders is beneficial, helpful, and effective. Just like the techno-fix, participation is no silver bullet that will solve societal issues. Additionally, based on the work in chapter 4 and 5, there might be potential for productive tensions and conflicts in participation, where a broader diversity of stakeholders with conflicting views on certain issues are involved. In taking this approach, it should also be accepted that there might not be a common ground in addressing 'grand challenges' and 'wicked problems' and that participation might not solve these conflicts.

For broader society, we acknowledge the diverse forms of knowledge and agency that are expressed in the digital transformation. People have a choice in using data, and a choice for how they choose to engage with digital agriculture. We do not and cannot make the decision for how they choose to engage, but our findings (especially those of chapter 6, 7 & 8) indicate that there is potential to engage with digital technologies in an embodied way, with agency over how digital technologies are used. Modifications, rejection, and acceptance are all possible while retaining agency over digital agriculture. It is however worth speculating how different technologies afford this agency, as not every technology affords the same potential for diverse uses in diverse contexts. Large, capital-intensive technologies are much more likely to create path dependency for society and agriculture, which will make future change more challenging. Smaller, adaptable, and affordable technologies afford the potential to change these technologies and to do away with technologies that turn out not be worthwhile.

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APPENDICES

Appendix 1: Interview questions for chapter 4

For technology developers

Question topic 1: Discussing the development of technologies

Can you tell me more about the emission-reducing systems that your company has developed?

Can you tell me about the development process of this technology?

Can you tell me about the functioning of this technology? What is the mechanism that is used to reduce ammonia emissions?

What level of reduction does this technology achieve?

What do you think about the reduction percentage that was assigned to your technology?

Question topic 2: Discussing the fit of the technology with the livestock farming sector

How does the technology fit with livestock farms and with livestock farmers?

Why do farmers choose your system, or your technology?

What do you think the farmer wants out of this technology?

How much demand is there from farmers?

Who are the people adopting these technologies?

Question 3:

How do you see other technology developers who develop ammonia-emission reducing technologies?

How do you see the other technologies that are being developed (e.g. air scrubbers when interviewing a developer of floor systems)

Question topic 4: The role of emission-reducing technology in agriculture

What role do you see for emission-reducing technology in agriculture?

What are the impacts of this technology on livestock farmers?

Question topic 5: Innovation processes

Are there innovations that you are currently working on?

What would help to make these innovations available to farmers?

What actors are important for the development of your innovations?

Question topic 6: Role of the government

Can you tell me about the process of getting your technology on the approved list?

What role does the government play in emission-reducing technologies, and on your innovations?

How do you see emission policies at the moment?

How do you see the future, both for your company and for emission-reducing technology?

Interview list for other stakeholders

Question topic 1: General emissions

How do you see the current state of (ammonia) emissions in livestock farming?

How did this (current state) develop?

What do you think about the current measures taken to reduce emissions?

What would be needed for further emission reduction?

Question topic 2: Policy and government

How do you see the current government policies (at EU/Flemish level)?

What do you see as important for government policy?

How do see the current approaches in relation to that?

Question topic 3: Emission-reducing technologies

What role do you see for emission-reducing technology in livestock farming?

What is the impact of these technologies on livestock farming?

How do different technologies compare (e.g. air scrubbers vs low-emission barns vs feed technologies)

What potential do you see for emission-reducing technologies?

Question topic 4: Monitoring of emissions

How do you see the monitoring of emissions?

What do you think could/should change about the monitoring of emissions?

How do you see the current models to track emissions?

Question topic 5: Future of livestock farming

If we look at the future of livestock farming, what do you see?

Why do you think this scenario will happen?

What would be the ideal scenario for you?

How would this scenario be reached?

What is the role of (emission-reducing)technology in this scenario?

What would have to change to make this ideal scenario happen?

Appendix 2: Workshop methods for chapter 4

Workshop 1 (online)

Goals: Providing context to technologies developed for reducing ammonia emissions, gaining stakeholder feedback and insight, developing systematic lens on context.

Methods:

To introduce the topic, a technology developer presented new technologies in ammonia emissions. Stakeholders (researchers, advisors, permit bureaus, people from research farms) were given space to ask questions about these developments. This allowed us to see how stakeholders related to technology developers and to study the relations between stakeholders and technologies developed to reduce ammonia emissions.

Following this, we formed two break-out groups to discuss technological developments in ammonia emissions. A SWOT-analysis was used to discuss the various aspects of technology developments among stakeholders and technology developers. After these discussions, a systematic overview of ammonia emissions was provided (including both human and non-human actors). This overview was used to discuss the network of actors around ammonia emissions between stakeholders and technology developers.

A final plenary discussion was used to discuss the themes discussed in each group and to conclude the workshop.

Workshop 2 (in person)

Goals: Discussing scenarios for the future of ammonia emissions and of technologies in ammonia emission reduction, gaining stakeholder feedback and insight.

Methods:

A timeline of past developments in ammonia emissions was used as an ice-breaker for the participants of the workshops. This timeline mainly focused on regulatory developments in ammonia emissions and was developed by the participants.

Following the ice-breakers, stakeholders were asked to name drivers of change in livestock farming, related to ammonia emissions. Drivers of change were identified by participants and discussed. Based on these drivers of change, participants were asked to provide 2-4 assumptions for how these drivers of change might develop over the next ten years, ranging from positive to negative scenarios of change. This process allowed us to identify the positions of stakeholders and their perceptions on ammonia emissions and ammonia emission reduction.

Appendix 3: List of codes used for analysis for chapter 4

Reductive Codes	References (not exhaustive)
Category: legitimacy	
Cognitive legitimacy	(W. R. Scott, 1995; Suchman, 1995)
Regulative legitimacy	(W. R. Scott, 1995; Suchman, 1995)
Normative legitimacy	(W. R. Scott, 1995; Suchman, 1995)
Pragmatic legitimacy	(W. R. Scott, 1995; Suchman, 1995)
Gaining legitimacy	(Binz et al., 2016; Geels & Verhees, 2011; Harris-Lovett et al., 2015)
Losing legitimacy	(Binz et al., 2016; Geels & Verhees, 2011; Harris-Lovett et al., 2015)
Category: legitimation strategies	
Negotiating	(Binz et al., 2016; Geels & Verhees, 2011)
Re-framing	(Geels & Verhees, 2011)
Building coalitions	(Binz et al., 2016)
Knowledge claims	(Jain & Ahlstrom, 2021; Montenegro de Wit & Iles, 2016)
Conforming strategy	(Markard et al., 2016)
Lobbying	(Jansma et al., 2020; Marberg et al., 2017)
Contesting institutions	(Jansma et al., 2020; Marberg et al., 2017)

Inductive codes	Link to reductive codes and article
Category: emissions	
Subcategory: emission policies	
Verifiability of policy measures	Links to contesting institutions and knowledge claims
Farmers and policy	-
Accuracy of data on emissions	Links to knowledge claims
History of emission policies	-
Government oversight on emissions	Links to regulative legitimacy
Regulation on emissions	Links to regulative legitimacy
Subcategory: solutions for ammonia emissions	
European policies	-
Generic vs individual approach	-

Local and bottom-up approaches	-
Government policy and visions for future of farming	Links to regulative legitimacy and contesting institutions
Holistic policies	
Use of emission-reducing technology	Links to contesting of legitimacy of technology
Subcategory: emissions general	
Variability of emissions (per farm)	Links to knowledge claims
Relation farmers-citizens	-
License to produce	-
Odour	**-**
Future of farming in Flanders	**-**
Farmers and emissions	-
Category: Process of developing emission-reducing innovations	
Current technologies	Provides context
Slow and difficult innovation	Provides context
Influence of regulation on innovations	Links to regulative legitimacy
Certification of technology	Links to regulative legitimacy
Variability of emission-reduction	Links to knowledge claims
Reasons to adopt technology	Links to pragmatic legitimacy
Reasons to not adopt technology	Links to pragmatic legitimacy

Appendix 4: Descriptions of PTB for chapter 5

PTB: A method to generate, organize and test ideas through interaction with societal actors.

Through PTB, the ‘cloud’ of concepts reviewed in the literature will be discussed and filtered into a first version of the *Conceptual and Analytical Framework,* that will provide main ideas, key hypotheses of the project and the related analytical questions. The second phase of the process will involve researchers of the consortium and stakeholders into an organized PTB effort to ground the conceptual framework into the empirical findings of the project, leading to a *Refined Conceptual Framework*.

Two transdisciplinary, reflexive seminars will be organized to critically discuss the [conceptual framework] in the light of empirical evidence collected in WP2, WP3 and WP4, and to adapt these accordingly. Online discussion on the conceptual framework will be organized on the VRE in between the two meetings. Based on the insights of the PTB the conceptual framework is finalized (D1.2).

Appendix 5: Interview questions for chapter 5

Question list for first round of interviews

- In your opinion, what worked well during the living lab workshop, in relation to the use of the main concepts?
  - How did you use the concepts of the conceptual framework in the living lab and what terminology did you use? (think of the SCP system, digitalization/digitization, digital game changers etc.)
  - Were your expectations for using these concepts met? And in what way?

- In your opinion, what did not work?
  - How/What would you change this to make it work next time?

- What were the main positive and negative points of feedback obtained from the participants, and what were suggestions for improvement?

- Did you observe LL participants using/adopting this terminology too and if they did, in what way (same or different meaning/understanding)?

Question list for second round of interviews

Based on discussions during the reflections workshop, we have identified three main focal points for PTB linked to WP3.

They are:

1) How is the digital game changer (DGC) concept used, understood, and applied in practice? Where and how is the connection made with the technological drivers of change as part of the scenario planning methodology? What types of technologies do people see as (potential) DGCs (finding examples)?

2) There was the question around (social) implications that come into view (especially linked to social aspects) of using new technologies through using the socio-cyber-physical (SCP) concept. This is about finding stories related to power relations, gender, (in)justice, …., which can be linked to the concept of socio-economic impact.

3) Enriched understanding of the concepts system complexity, access, and design. What are the key issues at stake for each of these concepts, and how does this differ across LLs?

Through the discussions during the scenario planning workshops, reflections can be gathered around these three main focal points. This will not require specific changes to the proposed scenario planning methodology. However, it may require asking some triggering or clarifying questions during the actual workshop, to more clearly elucidate participants' perceptions on the different elements.

In the following sections, some short background (based on the conceptual framework) is provided for each focal point, together with a number of related interview questions. These are the questions that will be used for the interview after the workshops between the PTB team and LL coordinators. These interview questions can also be used, with slightly adapted formulation, during the workshops to trigger discussion/reflection with the participants. It is important to take notes/record discussions carefully, with the different focal points in mind.

Use of DGC:

Digital Game Changers refers to both hardware and software components of digital technologies that deeply reconfigure routines, rules, actors, and artefacts of social and economic life.

In the scenario planning methodology *DGCs are described as a particular type of driver of change (DOC).* Drivers of Change are dynamic factors that shape the future. There are two broad categories, namely: i) c*ritical uncertainties*, i.e. DOCs which are unstable and difficult to estimate in terms of their future effects, which may be either external (not to be controlled by actors in the scenario) or internal (to be influenced by actors in the scenario) to the scenario environment, including behaviours and choices of influential actors; and ii) *predetermined factors*, i.e. DOC which are relatively stable and predictable over the period under consideration.

Link to the scenario workshop methodology: Information on this is expected to emerge during the discussion of the scenario outlines, but possibly also already during the preparation of the workshop (“Identify drivers of change (DOC): possibly with some validation from key members of the LL”)

Interview questions

- How were the abovementioned concept(s) used during the scenario workshops? What terminology was used?
- In your view, how did participants understand and engage with these concepts?
- How did you identify/classify the DOC? Who was involved in this identification?
- How do you see the connection between the DOC’s and the DGCs?
- How did these concepts affect your understanding of the living lab and the context of the living lab?
- What was the relevance/importance of DGCs in comparison to other DOC? What was the role they played in the different scenarios (e.g., critical uncertainty vs. predetermined factor), and did this change significantly between the draft scenario outlines and the final scenarios developed during the workshops? If so, in what way, and what/who triggered/initiated the change?
- *What digital technologies were seen as DOC/DGCs? How were they perceived by different actors (more positive or more negative perceptions/associations; more stable/unstable; within our outside of the scope of control – also note for different perceptions in different actors)?*

Focal point 2: Implications and impacts of using new technologies.

Definitions - background

As indicated in the definition for DGCs, digital technologies have the potential to deeply reconfigure routines, rules, actors, and artefacts of social and economic life. In the conceptual framework and the DESIRA proposal, this impact has been further defined as “the opportunities and threats of digitisation which has deep repercussions on people’s lives, and generates losers (marginalized by the changes), opponents (who resist and elaborate alternative rules of the game), and winners (who benefit from the change).

We want to further our understanding about these reconfigurations/repercussions, and thus the socio-economic impact of processes of digitisation and digitalisation.

Link to the scenario workshop methodology: Examples and stories can be captured during discussions/stories around the review of past events (actual impacts), and during the further development of the scenario outlines (anticipated impacts).

Interview questions (follow-up interview with the LL coordinator)

- What were social (and/or economic) reconfigurations and changes through use of new technologies identified by different actors (distinguish between changes/reconfigurations that actually happened, and anticipated changes/reconfigurations)?
    - How are these reconfigurations perceived by the participants?
    - Did you introduce examples of such reconfigurations into the workshop? If so, which ones?
- Did you use the concept of winners/losers/opponents/proponents in the living lab (in the workshop or in later analysis)
    - How did this concept affect your understanding of the impact and implications of using new technologies in the context of your living lab?
    - Who were identified by the participants as winners/losers/opponents/proponents in your LL)?

Focal point 3: Conditions influencing impact.

Definitions - background

As described in the conceptual framework, impact can depend on three conditions: access, design, and system complexity. Access (i.e. the distribution of physical, social, and human capital necessary to get access to digital opportunities) determines how much a given person/type of actor or stakeholder can benefit from digital technologies. Lack of access can lead to exclusion, and marginalisation of the excluded. The assessment of access should consider who are potential actors of the system, and who will be possibly excluded; what the different (social, physical, cyber) requirements for accessing the technology or its outputs; how are the outcomes of the system distributed; … Second, there is the design of digital technologies. Digital technologies are designed to achieve certain outcomes (i.e. have intended consequences). However, poor design can also lead to unintended, and possibly harmful, consequences. When thinking about design, different kind of vulnerabilities need to be considered (fundamentally flawed design; vulnerable to physical elements (heat, wind, …); vulnerable to social elements (espionage, cyber-attacks, …)). Third, we have system complexity. The more digitisation proceeds, the stronger the need to connect system entities to each other. Increasing connectivity adds to complexity because of the multiplicity of ways that each entity interacts with others. Complexity raises a number of issues on which each outcome of the system can depend and decreases the manageability of the system. Assessing system complexity should consider the outcomes of changes of entities and activities of a system in relation to the connections with other entities and other domains. For example, new operating systems of a laptop are not fit to old computers, and this implies that old computers become obsolete. When devices need to communicate with each other, emerging problems can be only fixed by specialists. In complex systems, choice of the right technology may be a problem in itself, as it requires skills and time.

All three conditions pose threats and opportunities when considering the socio-economic impact of digitisation and digitalisation:

	Opportunities	Threats
Access	Increase equal access to digital technology	Digital divide
Design	Solutions that anticipate unintended consequences	Design-related risks
System Complexity	Synergies between digital game changers	Digital traps

As such, the discussions around the conditions are very closely linked to the discussions in the previous section. While the previous section aims to capture more specifically different kinds of socio-economic impact, this section zooms in on the conditions affecting the impact. It is expected that during the workshop, discussion on this (i.e. impact and conditions affecting impact) will be intertwined. It is also expected that certain conditions will be more prominent in some LLs than others.

Link to the scenario workshop methodology: Information is expected to emerge during the development of the scenario outlines, and also during the backcasting exercise.

Interview questions

- How did you use these concepts in the living lab? During the workshop or for analysis?
- How did you go about using this concept in a future-oriented scenario? What were steps you took to understand how these conditions would be affected?
- What were possible opportunities/threats mentioned regarding access? Were there differences in participants in how these were perceived?
- What were possible opportunities/threats mentioned regarding design? Were there differences in participants in how these were perceived?
- What were possible opportunities/threats mentioned regarding system complexity? Were there differences in participants in how these were perceived?
- Which of the elements of this concept is most vital for your living lab? And how is it vital in understanding the living lab?
- What are possibly other conditions affecting digitization/digitalization in the context of this LL?

Question list for third round of interviews

Translating and understanding knowledge

Introduction of questions: We saw in the data analysis that there are different aspects to understanding and translating theory. I think the translation of different theoretical concepts ties into this, where we seek to focus on how we create concepts out of the theory that can be grasped by all participants. This could be seen in several comments about digitalization where stakeholders took certain things for granted that researchers wanted to study. We would like to know more about this process through the questions below:

Interview questions:

I would like to start with a question about your position in the living lab, and how you see your role in the living lab:

How do you see your own position as a scientist in the living lab? (this ranges from coordinator to facilitator to more objective researcher, I am mainly wondering how you would describe your role as a researcher in the living lab)

What do you focus on when translating theoretical concepts for use in your living labs? (from theoretical concept to practical use)

How do you see the understanding of theoretical concepts among participants in living labs compared to your understanding of them?

(for example: have you ever noticed that you were talking about different things while using the same concepts)

How do you respond to differences in understanding between living lab participants and researchers?

Equally, we saw that there are (perceived) divides in understanding of theory linked to this. This references to education levels, perceived interests but also broader ontological differences and divides between stakeholders and researchers. We use the following questions to reflect on this divide:

Interview questions:

What role does the type of stakeholder (e.g., their education level, their interests etc.) play in how you bring theory into the living lab?

How do you determine the interests of participants and their interest in more theoretical concepts?

What knowledge do you think the participants bring to the living lab?

What knowledge do you think the participant needs in the living lab?

What knowledge do you think the participant gains from the living labs?

In this section we would like to reflect on the use of theory in living labs, the use of theory to stakeholders and how theory is introduced to stakeholders. We focus this on the social and economic theories that informed the conceptual framework and the DESIRA project. In earlier results we see reflections on how pragmatic and practical needs in the living labs need to be balanced with broader theoretical reflections.

Equally, there are reflections on what the role of theory is in living labs and how it should be used. For example, we noticed that many living labs say that there is sometimes little use to certain concepts and theories (for example the difference between digitization and digitalization, or whether a farm should be seen as a physical concept or as a social concept) With these questions we would like to explore this more in-depth:

How do you see the contribution of living labs to theory?

What use do you see for theory in living labs?

> And to the lives of living lab participants in general?
>
> Is theory in general applicable to people's daily lives?
>
> What role should theory play in living labs?

How could living labs, and living lab participants play a greater role in the production of theory and is this desirable?

What do you think are the implications for (the development, quality, use...) theory in general? (depending on the answer given in the previous question)

As a last set of questions, I would like to discuss your position as a researcher in the living lab and whether this influences the use and development of theory and knowledge in the living lab. This refers more to broader ideas of how and what knowledge develops in living labs and what the impact of living labs is on scientific knowledge production.

Let us return to the question I asked in the beginning, about how you see your own position as a scientist in the living lab. I have two questions in relation to this:

> How does this position influence the role of knowledge and of knowledge production in the living lab?

What role would you want to take in a living lab?

Appendix 6: List of codes used for analysis in chapter 5

Inductive coding:

- Developing and adapting theory
  - Adapting theory
  - Mining information and knowledge
  - Need for theory
  - PTB
    - Role of participant in developing theory
    - Role of researcher in developing theory
  - Testing theory in practice
  - Views on theory
- Goal of the living lab
  - Defining living labs
    - Social vs Technical living labs
  - Living labs should bring change
- Learning stakeholders
- Project limitations
- Translating and understanding knowledge
  - Divides in understanding
  - Language and theory and boundary objects
  - Power of researcher in translating
- Use and role of theory
  - Do stakeholders need theory
  - Introduction of theory to stakeholders
  - Practical needs

Purpose of theory

Deductive coding

Causes for alienation

- Different understanding of the world
- Digital irrelevance
  - The digital is not radical
- Projects needs come first

Non-alienation

- Theory linking to audience
- Theory should be used
- Theory used in collaboration

Reasons not to use theory

- Theory is for researchers
- Theory is boring
- Theory is too complex
- Theory mismatch
  - Different ways of thinking

Target audience

- Needs on the ground
- Translation

Theoretical reflections

- Epistemological reflections
- Knowledge sharing
- Defining PTB

Appendix 7: Interview questions in chapter 7

Interview questions farmers

- Introduction
- Which precision technologies do you use on your farm?
- How did you start using these technologies?

Main questions

- How has the use of precision agriculture changed over time?
    - What were your reasons to change the use of precision agriculture?
- Have you adapted certain elements of precision agriculture since you started using these technologies?
    - *Examples provided if the question needed clarification: Retrofitting older machinery, ensuring compatibility between machinery, adapting software*
    - What were your reasons to adapt this?
    - How would you change your machinery if you had time and opportunity to do so?
    - What would you not change?
    - Have you contacted the manufacturer in order to make changes? How do you see the role of the manufacturer?
- How do you see the use of data, and the companies that use precision agriculture data? 2
- What has promoted or hindered the use of precision agriculture on your farm?
    - How does the set-up of your farm play a role in this?
- Has your farm changed since you started using precision agriculture?
    - Has your way of working changed since using precision agriculture?
    - How has precision agriculture impacted decision-making on your farm?

- Do you follow recommendations made by precision agriculture systems?
    - Do your own ideas on farming fit with precision agriculture?
    - Would you go back to working without precision agriculture?
- What have these changes (since adopting precision agriculture) meant for you as a farmer?
    - How do you see yourself as a farmer? Does this change you as a farmer?
    - How do you see the future of your farm in using precision agriculture?
- Would the farm of the future work without a farmer?
- How did you learn to use precision agriculture?
    - (For example, manuals, other farmers, advisors, other?)
- Have you also used these same sources when adapting precision agriculture technologies?
    - Who is important to you in your use of precision agriculture?
    - How is the work involved in precision agriculture divided on your farm?
    - (For example, does your partner do this, employee, advisors?)
- Has your network of advisors changed since using precision agriculture?
    - How has this network changed over time, was this different when you started?
    - Do you use advisors in the use of precision agriculture?
- Do you have any other remarks or comments on the use of precision agriculture?

Interview questions industry

- Can you tell me how your company is involved in precision agriculture?

- How do these technologies fit with farmers?
    - Do they buy individual machines, is it a package deal?
- How has the use of precision agriculture changed over the years?
- What are the reasons for farmers to adopt precision agriculture?
- What does the process of adoption look like?
- Are adaptations made after adoption, or is it all ready-made?
    - How does this work with the tools that your company offers?
    - Is support provided if a farmer wants to adapt a technology that you offer?
    - What are reasons for farmers to adapt technologies after they adopt them?
- Are there currently any elements of precision agriculture that you would want to change, but that are not possible to change?
- What future changes will happen in precision agriculture?
    - How will the field develop?
- Are there certain farmers that adopt precision agriculture?
    - Why these farmers? What is particular about them?
- Are these farmers mostly new customers, or were they already customers of your company?
- How do you see farms change after adopting precision agriculture?
    - How do you see farmers change after adopting precision agriculture?
    - Does farming change because of precision agriculture?
    - What is the future of farming in the use of precision agriculture?
- How do farmers learn to use precision agriculture?
    - Do you support this learning process?
    - (With advice, courses, other farmers?)
    - What are the biggest steps for farmers in learning to use precision agriculture?
- What knowledge do farmers need when using precision agriculture?
- Who are important in the support and use of precision agriculture on the farm?
- Do you have any further remarks on the use of precision agriculture?

Interview questions researchers

- Can you tell me about your work with precision agriculture?
- How do you see precision agriculture use in the Netherlands at the moment?
- Do you have contact with farmers using precision agriculture?
- What do you see as reasons for farmers to use precision agriculture?
    - How does precision agriculture develop after adoption, are other adaptation done?
    - If adaptations happen, how do you see this?
    - How do you see the current possibilities of precision agriculture technologies?
- I have heard from farmers that there are compatibility issues when starting to use precision agriculture, how do you see this?
- What is needed to make precision agriculture fit with farmers?
- What is important in the use of precision agriculture in your eyes?
- How do you see the future developments of precision agriculture?
- What is currently the biggest hindrance in using precision agriculture?
- Are the certain types of farmers using precision agriculture?
    - Why these farmers?
    - What is the role of the farm type in this?
- How do farms change through the use of precision agriculture?
- Does farming change after adopting precision agriculture?
- How do you see the future of farming?
- How do farmers learn to use precision agriculture?
    - Who are the actors involved in supporting this learning process?
    - What are the biggest steps in learning to use precision agriculture?
    - What are changes that need to be made to use precision agriculture?
    - How do you see the support in this process?
- Who do you see as important in the use of precision agriculture?
- Do you have further remarks on the use of precision agriculture?

Appendix 8: Details about the farmers in chapter 7

FARMER/ CONTRACTOR	FARMING SYSTEM	PRECISION AGRICULTURE SYSTEM
CF1, Male, 30-40 year old	140 ha of potatoes, beets, grain	GPS guidance systems, variable rate applications, crop sensors and yield monitors
CF2, Male, 30-40 year old	500-600 ha of potatoes, sugar beets, corn and grain	GPS guidance systems, variable rate applications, soil scanning, crop scanning and yield monitoring.
CF3, Male, 40-50 year old	200 ha of potatoes, onions, beets and grain	GPS guidance systems, variable rate applications, crop sensors and yield monitors
CF4, Male, 50-60 year old	300 ha of flower bulbs, most of the land on lease	GPS guidance systems, variable rate applications, crop sensors, soil scanners
CF5, Male 40-50 year old	Roughly 100ha of potatoes, onions and other high-quality crops	Variable rate applications of fertilizer and spraying, using drones and GPS guidance systems
CF6, Male, 50-60 year old	Mixed farming system with about 40 ha of potatoes	GPS guidance system, precision fertilizer system
CF7, male, 40-50 year old	110ha of potatoes, sugarbeets and grain	GPS guidance systems, variable rate application, crop sensors, soil scanner and yield mapping
CF8, male, 50-60 year old	Farmer-contractor with about 200 ha of land, growing potatoes, onions,	GPS guidance systems, yield monitors

	grain, beets and grass seed.	
CF9, male, 40-50 year old	90 ha organic farm with 10 different crops	GPS guidance systems
CF10, male, 30-40 year old	Farming on a collaborative farm of 800 ha growing potatoes, onions, beets and celery	GPS guidance systems, variable rate applications, crop sensors, soil scanners, yield monitors
CF11, male, 50-60 year old	Roughly 200ha of potatoes, onions, carrots	GPS guidance systems, weeding with optical sensors
CF12, male 30-40 year old	About 100 ha of grain, potatoes and sugar beets	GPS guidance system, variable rate applications, yield mapping and crop sensors
CF13, male 30-40 year old	Growing flowers and flower bulbs (100ha land, 1ha greenhouses) most of the land on lease	GPS guidance systems, soil scans, variable rate applications

Appendix 9: List of codes used for analysis in chapter 7

Codes used in the final analysis

Inductive Coding Set

- Adapting agricultural practice
- Adapting technology
  - Personal preference
  - Simplifying technology
  - Non-retrofitting adaptations
  - Retrofitting adaptations
- Adaptations in the broader industry
  - Support in the learning process
  - Use of agronomic advisors
  - Support of precision agriculture
- Agronomic-technological learning process
  - Tacit knowledge gains
  - Learning process
- Connectivity issues
- Impact of regulation
- Non-tech adoption
- Standardisation
- Under-utilising PA
  - Slow adoption
  - Post-adoption rejection

Deductive Coding Set

- Extending the farmer through technology
- Integration of farmer & technology
  - Farmers' knowledges
  - Using precision agriculture
  - Intuition of the farmer
- Situatedness
  - Connection to biophysical space
  - Grandfathers' knowledges
  - Place-based accounts

Appendix 10: interview questions in chapter 8

Interview questions – research on remote sensing for environmental policymaking

The focus of my research, and my main research question consists of two main elements. First is the question of how remote sensing technologies and environmental policymaking intersect and how remote sensing technologies affect what policies are possible. A second set of questions is focused on the technologies themselves, with questions on the uncertainties in the technology, the knowledge that is made available by these technologies and the limitations of the technology.

Of note is that this is a guiding document, depending on the interview certain questions might be left out or additional questions might be asked. Additionally, sub-questions are asked only if needed to clarify something. This hierarchy of questions and sub-questions is as follows:

Question

Sub-question

Further sub-questions

Clarifying notes in italics

Introductory questions

Q: Can you tell me about yourself? About your work and the technologies that you work with in relation to remote sensing?

Q: How did you enter this field? What got you to work with remote sensing technologies?

Q: How do you see the development of the field that you're working in? How has it developed over the last 5-10 years?

Q: Where do you see the technology going? What are potential uses and developments that you are excited by?

Technological capacities and limitations

Note: questions on specific cases – only asked when relevant.

Q: Can you tell me about the use of remote sensing in the CAP?

Q: How do you see the use of remote sensing for the CAP?

Q: Can you tell me about the development of these technologies in your country in relation to the CAP?

Q: How is the development and use of this technology going? Is this along expectations?

Q: How has this developed with the new CAP? Has this increased the role of remote sensing in monitoring?

Q: Are there risks associated with relying too heavily on remote sensing technology in policy-making?

Q: Do you think there are certain types of environmental problems that are better suited to being addressed through remote sensing technologies than others?

Q: How do you see the impact of this?

(For policy-making, stakeholders (farmers), the environment and for monitoring the CAP)

Q: Are there environmental parameters that you think should be monitored, but that are either out of the reach of current tech or not of interest to funders? If yes, which?

Q: How do you see the environmental issues that you are monitoring?

Q: How do you see the role of remote sensing in addressing these environmental challenges?

Q: How do you see uncertainties in remote sensing?

(as problems requiring solutions; inherent aspects of remote sensing; or as something else entirely)

Q: How do you see the impacts of these uncertainties?

Q: Is this considered in the uptake of these technologies? How do you see the approaches that are currently used to deal with these uncertainties?

Q: How do you see aspects that are unknowable with remote sensing

(potential examples are linked to biodiversity, soil biodiversity and certain soil characteristics)

Q: How does this affect the use of remote sensing for other actors (policy, farmers etc)

Q: How do you see the response to these aspects? Is this taken up by other actors?

Policy/government focus

Q: Have you been involved in exchanges of knowledge between researchers and policy-makers? What was the process like, and what challenges did you face?

(note: can be policy recommendations, attending policy events, writing reports for policy)

Q: What are important elements in this exchange? How is knowledge combined or integrated?

Q: How do you see the uptake of the technical aspects of remote sensing in policy-making (or in the CAP)?

Towards end-users

Q: How do farmers think about the use of this technology? How do they relate to this monitoring?

Q: Do you expect resistance to these technologies when they are used to monitor agri-environmental performance?

Q: Do you expect farmers to change practices because of remote sensing technologies?

Q: Do you expect behaviour that circumvents remote sensing technologies?

Q: How do you expect farmers' knowledge systems and ways of working to be impacted by remote sensing technologies?

Q: Do you see a surveillance aspect to these technologies, and why/why not?

Q: If so, how do you see the surveillance aspect of these technologies?