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DECISIONS TO ADAPT: TRADE-OFFS, MALADAPTATION AND TRANSFORMATIONS IN NORDIC AGRI-FOOD SYSTEMS

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ACADEMIC DISSERTATION
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ABSTRACT

This thesis is a study of climate change adaptation as a way of managing change. It deals with the human decision-making entailing uncertainty, risks and opportunities brought about by climate change and climate policies. The scope of the thesis is climate change adaptation as a human adjustment process in the context of Northern European agriculture.

Agricultural production of food in Northern Europe is under pressure. There are constant changes in societal structures, such as policies and economic markets, as well as climatic stressors. The climate impacts pose direct risks to production, such as increasing floods and droughts, as well as indirect pressures through, for example, the global demand for arable lands. This constantly changing and complex socio-environmental context of food production is expected to drive processes of adjustment in the agricultural sector. Recent assessments suggest that in most parts of Europe adaptation measures in the agricultural sector will increase significantly in the coming years.

Agricultural adaptation research is focused on describing the climate risks with respect to production and on the development of technical solutions. Agricultural and food production sciences are at the front line of technical development of adaptation measures for agri-food systems, such as new plant varieties, production environments and cultivation measures. There is also a growing body of literature on the systemic complexity of adaptation needs and options focused on climate impacts. Farm-scale adaptation is mainly studied in the development and management research fields among other applied research focused on developing countries, local case studies and agri-economic studies. The current literature suggests that farmers will implement the adaptation measures in order to secure their livelihoods and to sustain the productivity of agricultural soils and lands.

The perspective of agri-food system practitioners is, nevertheless, less represented in adaptation literature. This is also true of research on the societal drivers and outcomes of adaptation. That said, there is research suggesting that although adaptation is aimed at decreasing risks and vulnerability to climate change, the farm-scale adaptation measures may have unintended harmful impacts to different actors and resources. These are identified in yet few empirical studies to involve economic losses at farm scale, local environmental damage and short-term productivity decreases. This presents a gap in the research that should provide back-ground knowledge for governing the complex field of adaptation in agriculture and food production sectors. From the perspective of environmental and social sciences, the adaptation measures call for focused assessment in terms of their social drivers and socio-environmental outcomes in all regions globally.

This thesis sets out to address this gap and increase understanding on adaptation measures as an issue of decision-making within complex socio-environmental contexts and trade-offs. This thesis applies a qualitative empirical study with an interdisciplinary epistemological stand and methodological approach that draws on agri-food system practitioner perceptions. The focus is on crop farmers and on farm-scale adaptation. Furthermore, attention is paid to other professionals of the sector who deal with various agri-food systems, development and management, and in governance. The research is iteratively developing, starting with an analysis of adaptation measures and the drivers for their implementation at farm scale and the agricultural sector, followed by an analysis of the potential unintended harmful outcomes of these measures. Finally, the transformative adaptation measures that concern the food systems in the Nordic context are analysed.

Key findings of this thesis show that climate change adaptation measures in the Nordic agri-food systems are currently aimed at reducing risks and increasing long-term adaptive capacity when it serves the highly contextual and often subjective needs. These do not always reflect the public policy goals and often involve harmful outcomes with respect to other actors and the sustainable development goals. To advance sustainable implementation of adaptation measures in Nordic agriculture inevitably requires governance interventions that include actors from various fields of society.

TIIVISTELMÄ

Maatalouteen perustuva ruoantuotanto Pohjois-Euroopassa on ahtaalla. Tämä johtuu jatkuvista yhteiskunnallisissa rakenteissa tapahtuvista muutoksista ja ilmastonmuutoksen vaikutuksista. Ilmastonmuutoksen vaikutukset aiheuttavat välittömiä riskejä tuotannolle esimerkiksi tulvien ja kuivuuden muodossa ja ne näkyvät myös välillisesti esimerkiksi viljelymaan globaalin kysynnän kasvuna. Muuttuvien olosuhteiden on otaksuttu ajavan sopeutumiseen tähtäävää kehitystä maataloussektorilla. Odotuksena on, että maatalouden sopeutumistoimet lisääntyvät tulevina vuosina merkittävässä määrin suurimmassa osassa Eurooppaa.

Maatalouden sopeutumistutkimus on keskittynyt tuotantoon kohdistuviin ilmastoriskeihin ja teknisiin ratkaisuihin tuotannon turvaamiseksi. Vallitsevan tutkimuskirjallisuuden taustaoletuksena on, että viljelijät omaksuvat sopeutumistoimenpiteitä säilyttääkseen maatalousmaiden tuottavuuden ja turvatakseen elinkeinonsa. Maatalous-ruokajärjestelmien toimijoiden näkökulmat ovat kirjallisuudessa kuitenkin aliedustettuna, samoin kuin tutkimus sopeutumisen vaikutuksista ja yhteiskunnallisista ajureista. Sopeutumistoimet maatalous- ja ruokasektoreilla uhkaavat jäädä tehottomiksi, jollei näkökulmien moninaisuutta ja sopeutumiseen liittyviä erilaisia vaikutusketjuja tunnisteta nykyistä laajemmin.

Tämän väitöskirjan tarkoitus on lisätä ymmärrystä sopeutumistoimista päätöksenteon kysymyksinä kompleksisessa yhteiskunnallisten ja ympäristömuutosten kontekstissa. Väitöskirja on kvalitatiivinen empiirinen tutkimus pohjoismaisen peltokasviviljelyn sopeutumiskehityksestä, joka keskittyy viljelijöiden ja muiden maatalousalan ammattilaisten sopeutumiskäsityksiin. Lähestymistapaa aiheeseen viitoittaa tieteidenvälisyys. Tutkimus käsittelee ilmastonmuutokseen sopeutumista inhimillisenä mukautumiskehityksenä, johon sisältyy ilmastonmuutoksen ja -politiikan aikaansaamia epävarmuuksia, riskejä ja mahdollisuuksia.

Väitöskirjan tulokset osoittavat, että sopeutumistoimia kohdennetaan pohjoismaisissa maatalous-ruokajärjestelmissä etenkin riskien vähentämiseen ja pitkän aikavälin sopeutumiskyvyn lisäämiseen. Toimia edistetään, kun niistä on hyötyä myös muutoin kuin sopeutumiselle. Nykyisiin sopeutumistoimiin liittyy usein mahdollisia haitallisia seurauksia muille toimijoille ja kestävän kehityksen tavoitteille. Sopeutumistoimien edistäminen pohjoismaisessa maataloudessa kansallisten ja kansainvälisten politiikkatavoitteiden mukaisesti vaatii epäilemättä hallinnollista väliintuloa ja toimijoiden osallistamista yhteiskunnan eri aloilta.

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Language editing of this thesis was done by Marja Juhola to whom I want to express my gratitude for her excellent work. Her insightful comments helped me clarify the core conclusions and some of the theoretical assumptions in this thesis. As a disclaimer, it should be noted that she hasn't proof-read this section and thus the poor language here is all my fault.

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Janina Käyhkö
Vantaa, November 2020

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications and a synthesis of them:

I Juhola, Sirkku; Klein, Natacha; Käyhkö, Janina; and Tina-Simone Neset. "Climate change transformations in Nordic agriculture?" Journal of Rural Studies 51 (2017): 28-36.

II Neset, Tina-Simone; Wiréhn, Lotten; Klein, Natacha; Käyhkö, Janina; and Sirkku Juhola. "Maladaptation in Nordic agriculture." Climate Risk Management 23 (2019): 78-87.

III Käyhkö, Janina. "Climate risk perceptions and adaptation decision-making at Nordic farm scale–a typology of risk responses." International Journal of Agricultural Sustainability 17, no. 6 (2019): 431-444.

IV Käyhkö, Janina; Wiréhn, Lotten; Neset, Tina-Simone; and Sirkku Juhola. "Integrated framework for assessing transformative adaptation in agri-food systems." Environmental Science & Policy 114 (2020): 580-586.

The publications are referred to in this thesis as ‘papers’ followed by their roman numerals.

AUTHOR CONTRIBUTION IN THE PAPERS

	I	II	III	IV
Original idea	SJ, TSN	TSN, SJ	JK	JK
Study design	SJ, TSN	TSN, SJ	JK	JK, LW, TSN, SJ
Data collection	JK, NK	JK, LW, NK	JK	JK, LW, TSN
Analysis	SJ, TSN, JK, NK	SJ, TSN, JK, LW, NK	JK	JK, LW, TSN, SJ
Manuscript preparation	SJ, TSN, JK, NK	SJ, TSN, JK, LW, NK	JK	JK, LW, TSN, SJ

JK: Janina Käyhkö, SJ: Sirkku Juhola, TSN: Tina-Simone Neset, NK: Natacha Klein, LW: Lotten Wiréhn

I Original idea is by SJ and TSN who also developed the research design, framed the paper and supervised the research process. NK (in Sweden) and JK (in Finland) conducted the data collection. Data analysis was conducted by all authors with JK leading the Finnish data analysis. JK and NK participated in preparing the manuscript parts on methods, data and results with SJ leading the preparation.

II Original idea is by SJ and TSN who also developed the research design, framed the paper and supervised the research process. NK and LW (in Sweden), and JK (in Finland) conducted the data collection. Data analysis was conducted by all authors with JK leading the Finnish data analysis. JK, LW and NK participated in preparing the manuscript parts on methods, data and results with TSN leading the preparation.

III JK solely conducted the study.

IV Original idea is by JK and the research design was developed in collaboration with all the authors. JK conducted the Finnish workshops and participated in facilitating the Swedish workshops that were conducted by LW in collaboration with TSN. The analysis and the manuscript writing were conducted by all authors with JK taking the lead.

1 INTRODUCTION

European agriculture is experiencing changes in temperature, precipitation as well as weather and climate extremes that are expected to increase in the future and to involve new challenges (EEA/Blaz Kurnik, 2019; Ijaz et al., 2019; Olesen et al., 2011; Rötter et al., 2012). The challenges for agriculture in Southern Europe are anticipated to increase the production pressure in the Northern European regions. There regions have arable lands and are generally considered to benefit from the longer growing season resulting from climate change (EEA/Blaz Kurnik, 2019; Ijaz et al., 2019; Olesen et al., 2011; Rötter et al., 2012). While climate change creates such novel opportunities, it also creates new challenging conditions for agriculture through impacts such as increased water stress, flooding, decreasing water quality, soil fertility and ground instability (Eckersten et al., 2012; Iglesias et al., 2012). These climatic and environmental stressors are global environmental challenges that require changes in the agricultural sector in order to secure food production. Moreover, the agricultural sector is exposed to several non-climatic stressors, such as market fluctuations, national and international policies (Rehman et al., 2014; Smit & Skinner, 2002), in particular the Common Agricultural Policy (CAP) (Bindi & Olesen, 2011) in the European context, and the national subsidy systems (Uleberg et al., 2014). Together, the different stressors create a complex and constantly changing context for practicing agriculture in the EU.

Climate change adaptation is a human response to different climatic and climate-related stressors. It is an adjustment process in human systems that is implemented as adaptation measures. The adaptation measures consist of deliberate policies and consequential actions as well as emergent practices that are aimed at decreasing climate related risks and vulnerability, and at seizing potential opportunities from climate change (de Coninck et al., 2018; Noble et al., 2014). The need for adaptation in European agriculture was raised in the scientific literature already a decade ago, calling for measures such as effective extension services to support farm-scale adaptation, and foci on sustainable water management practices, as well as integrating adaptation to agricultural performance indicators (Bindi & Olesen, 2011; Falloon & Betts, 2010; Iglesias et al., 2012; Olesen et al., 2011; Reidsma et al., 2010).

The EU Adaptation Strategy is a strategic-level adaptation policy in the EU that guides the integration of climate change adaptation into key sectoral policies, such as the integration of agricultural adaptation to the European Common Agricultural Policy (CAP) (EEA/Blaz Kurnik, 2019). The policy framework around agricultural adaptation in the EU consists also of global agreements and other EU-level policies that relate to the climate impacts on the European agricultural sector. The key priorities and goals of current global agreements, most importantly, the 2030 Agenda for Sustainable

Development, Paris agreement and Sendai framework for disaster risk reduction are integrated into several EU policies (e.g. food and nutrition security, agriculture, and adaptation).

According to a recent assessment of the European Environmental Agency (EEA), the CAP reform in 2021 will introduce adaptation as a clear objective to the agricultural policies of member states and thus increase financing of adaptation measures in the sector (EEA/Blaz Kurnik, 2019). Moreover, EU research funding has been directed, for example, at developing tools for sustainable adaptation in European agriculture (e.g. AgriAdapt, 2019) and at integrating the costs of adaptation to CAP assessments (Ermolieva et al., 2019). Sustainable adaptation is a concept used in adaptation managament and planning to highlight the aim of integrating adaptation with the Agenda 2030 Sustainable Development Goals (SDG), such as ecologically sustainable agricultural production (Dube et al., 2018; Santhia et al., 2018).

The Paris agreement involves a requirement for national-level adaptation planning, monitoring and reporting from all the members in 2020 (Morgan et al., 2019). This basically means National Adaptation Strategies and Plans (NAS, NAP) in Europe, where these high-level governmental strategies often include sectoral assessments, such as those for agriculture. In their most recent report (EEA/Blaz Kurnik, 2019), the EEA assessed that most Member States are 'ready to go' on adaptation in agriculture from a policy perspective, meaning that they have addressed agriculture as a priority sector in their NAP or NAS and that climate change vulnerability and impact assessments (CCVI) for agriculture are prepared or on their way. Only few member states have, however, reached the implementation stage i.e. have defined specific adaptation measures for agriculture (EEA/Blaz Kurnik, 2019, 27-29).

In general, the literature on adaptation is dominated by systemic and quantifiable descriptions of climate risks and adaptation needs and options through foci on topics such as vulnerability of specific crops or agricultural production systems (Bär et al., 2015; Eza et al., 2015). Adaptation responses in such approaches are often considered *"objective, effective and consistent through time"* (Holman et al., 2019), i.e. they do not integrate the social and societal factors. Such factors can have a significant effect on the farmer's adaptation decision-making and actualization of the intended changes (Feola et al., 2015; Few et al., 2017). For instance, the quantification of adaptation in economic models traditionally sees adaptation as an unbound response at farm scale (that aims at profit maximation), excluding the role of contextual factors that can influence the motivation to take adaptation action (Gardezi & Arbuckle, 2019; Vanschoenwinkel et al., 2020).

The adaptation responses in agriculture are widely considered to consist of contextual balancing of opportunities and risks at the farm scale (Adger et al., 2018, 2009; Feola et al., 2015; van Valkengoed & Steg, 2019). Need for better understanding of the stakeholder perceptions on vulnerabilities, risks and the adaptation decision-making processes, is stressed by several scholars (Dessai

et al., 2004; Few et al., 2017; Gardezi & Arbuckle, 2019; Gillard et al., 2016; Máñez Costa et al., 2017; Slovic, 2000; Smit & Wandel, 2006).

Moreover, despite the fact that adaptation is intrinsically intended to decrease vulnerability to climate change, adaptation measures at farm scale may have unintended harmful impacts at different scales (temporal, spatial, societal) to the farmers themselves, to other actors and sectors, and to the common pool of resources (Juhola et al., 2016). Such outcomes have emerged as farm-scale economic losses, local environmental damage and short-term productivity decrease (Albizua et al., 2019; Antwi-Agyei et al., 2018; Dube et al., 2018; Guodaar et al., 2020). Trade-offs in the adaptation context generally refer to (i) such unintended harmful outcomes as described above, and (ii) to objectives or means of adaptation measures that exclude other objectives/means, such as those between economic and environmental goals (Denton et al., 2014). The potential trade-offs related to adaptation in agriculture and rural areas are mainly discussed in studies focused on the synergies with mitigation (Falloon & Betts, 2010; Kongsager et al., 2016; La Rovere et al., 2009; Smith et al., 2014) and the expected increased production demand in the Northern regions (Lehtonen, 2015; Olesen & Bindi, 2002). Trade-offs related to adaptation decision-making in Nordic agriculture have been recently identified as highly complex with the aspects considered ranging from the farm economy to issues of soil conditions, chemical demand, food security and biodiversity (Wiréhn et al., 2020).

The constant changes that the Nordic agricultural and farming systems need to adapt to are related to the specific climatic and non-climatic stressors of the region, as well as to the outcomes of adaptation. Adaptation in agriculture can be seen from various perspectives, for example, as a mainly technical (yet not simplistic) problem-solving focused on securing food production in changing climatic conditions, or as a question of change in public discourses on e.g. diets or rural development. At the empirical level, the question can be reduced to different types of adaptation responses and the related trade-offs. Grasping the complexity of the issue calls for a dialogue between and across different scientific disciplines and other domains. The gap in knowledge that this thesis addresses is particularly the lack of empirical evidence and the integrative understanding of the contextually-nested adaptation responses.

1.1 FOCUS AND AIM OF THIS THESIS

The design of this thesis is a case study of adaptation in Northern European crop production based agri-food systems that consists of crop farms. The scope of the study focuses on two aspects of adaptation with an interdisciplinary approach. These are (i) adaptation measures and their outcomes in agri-food systems, and (ii) farm-scale adaptation decision-making. This thesis sets out to integrate theoretical understanding and new empirical knowledge to

support adaptation research and adaptation governance for more sustainable adaptation practices and policies.

The study sites are in Sweden and Finland, and this puts the Nordic region as the geographical outline of this thesis, providing a generous context for studying adaptation measures, policies and actors, as the Nordic countries have globally been on the forefront of adaptation policy development through national and municipal adaptation strategies and plans. Despite this, the state of adaptation measure implementation in Nordic agri-food systems is not assessed widely nor in-depth regarding the needs and outcomes of the measures. Farmers' perceptions of vulnerability and farm-scale adaptation measures have not been studied empirically to a large extent in the Nordic context.

The aim of this thesis is to contribute to the understanding of agri-food system adaptation responses to climate change as well as to the current policies and the involved challenges. The research questions are:

(i) what features characterize adaptation measures and their outcomes in agri-food systems (I, II, IV)

(ii) what constitutes adaptation decision-making at farm scale (I, III, IV)

These are addressed in the four papers of this thesis with a focus on stakeholder perceptions of vulnerability, risk and adaptation (I, III), and the attributes of adaptation decision-making as well as objects and unintended outcomes of adaptation (II, IV) in the Nordic agricultural sector and agri-food systems. The crop farmers and other professionals of the sector who deal with various agri-food systems, are considered the key stakeholders in this thesis. The assessment that aims to respond to the first question draws on stakeholder consultation and literature review on what type of measures are applied or planned in the Nordic agri-food systems, as well as on the potential negative and unintended outcomes. To answer the second question, assessment foci is directed at the perceptions of climatic and non-climatic stressors as drivers of adaptation.

1.2 STRUCTURE OF THE THESIS

In this section I have covered the background for why adaptation in agri-food systems is a topic of interest and how it has been approached in research and through policies particularly in the last decade. In the next section, I present the theoretical background for how adaptation decision-making and the outcomes of adaptation are understood in state-of-the-art scientific literature that this thesis contributes to, and its key philosophical assumptions. In the third section, I introduce the theoretical background of the analytical approach and the operationalisation of the research questions (1 and 2) in this thesis i.e.

the analytical framework. Following this (section four), I present the key methodological assumptions of the thesis and introduce the methods used. Results are presented in section five in three parts, specifically, adaptation measures, decision-making and unintended outcomes of adaptation. Finally, in sections six and seven I first discuss and then conclude the findings of this thesis in relation to state-of-the-art scientific literature and their relevance to adaptation/decision-making in Nordic agri-food systems context and beyond.

2 STATE OF THE ART

To answer the overall research questions, this thesis focuses on two specific research topics: agri-food systems and adaptation measures. This section introduces the scientific literature on **climate change adaptation** as a human adjustment process at different levels of social organization, presenting the latest research on governance of adaptation (2.1), individual adaptation decision-making (2.2) and the outcomes of adaptation (2.3). In conclusion, this section presents how the thesis positions in relation to this literature and to the philosophy of science.

Agri-food systems as a concept is defined in accordance with farming system research tradition (see Darnhofer, Gibbon, & Dedieu, 2012) in this thesis with a comprehensive take on the interaction between the different system elements in a spatially-bound context that can range for instance from field scale to territorial or global scale (Lamine et al., 2012). As opposed to sectoral framing (agriculture as a sector), the spatial framing allows for a more comprehensive assessment of the risks through acknowledging actors from a wider spectrum involved with producing food through agricultural practices. The main agri-food system unit that this thesis focuses on is the farm. This thesis studies farm-scale as an operational context of agricultural adaptation with foci on the larger agricultural sector where it is nested (I, II), and as a single unit (III), as well as part of the broader Nordic agricultural food systems (IV).

Adaptation to climate change is implemented as **adaptation measures** at different levels of organization and decision-making in society. Due to the heterogenous group of actors and variety in measures, managing adaptation presents a complex issue for governance (Biesbroek et al., 2014; Head, 2014; Juhola, 2019). Adaptation measures in this thesis are framed through different levels of decision-making (collective - individual, regional, local) that have distinct motives and facilities/resources of adaptation (Chan et al., 2019; Thomas et al., 2019). Adaptation measures are associated with both negative and positive outcomes in agricultural production conditions and productivity, distribution of food, the occurrence of food security and safety, as well as with re-thinking human diets (e.g. Bindi & Olesen, 2011; Juhola & Neset, 2017; Kongsager et al., 2016; Loboguerrero et al., 2019; Smit & Skinner, 2002). Yet, there is a widely stressed gap in knowledge on adaptation decision-making and outcomes at the sectoral and systems level (e.g. Cradock-Henry et al., 2019; Keshavarz & Karami, 2014).

2.1 CLIMATE CHANGE ADAPTATION GOVERNANCE

In this thesis, governance of climate change adaptation is broadly understood to incorporate the different actors and mechanisms within society that are directed at management and adjustment processes of climatic and non-climatic stressors (Biesbroek et al., 2014). This relates to 'realist' philosophy of governance that considers adaptation governance as interaction between the different actors within the institutional context (Biesbroek et al., 2014). Institutional contexts for adaptation are in this thesis understood broadly through the theory of modern institutionalism, following Massey & Huitema (2016). These are seen to consist of such regulatory and cultural/social constraints and norms that guide human interaction, as commonly used in the adaptation literature (see e.g. Mandryk et al., 2015; Pelling et al., 2015; Smit & Skinner, 2002). Actors, in this perspective, refer to humans with agency in the institutional contexts of adaptation (Massey & Huitema, 2016).

Lamine et al. (2012) stress the increase in heterogeneity of agri-food system actors (formerly based in the rural and agricultural context) through emerging policy fields (such as climate), and urban actors, as well as civil society actors (e.g. community supported agriculture). These present both increased opportunities for sustainable agri-food systems, as well as novel challenges for governance. Adaptation is a novel and complex policy field that is not broadly institutionalised, i.e. the laws, regulations and norms, that guide adaptation *per se* are just emerging and understanding on the responsibilities related to implementation lacks clarity (Juhola, 2019). Authority in the adaptation policy field is dispersed (Juhola, 2019; Massey & Huitema, 2016), reflecting the current shift in environmental governance generally (Juhola, 2019), and adaptation has been characterized as a 'wicked' issue to govern (cf. Head, 2014). From this perspective, one of the most pressing issues in adaptation governance is to avoid the oversimplification of adaptation (Blythe et al., 2018; Gillard et al., 2016; Head, 2019).

Governance interventions, based on the 'realist' paradigm, aim to embrace the heterogenity and complexity of the field. To advance such interventions calls for an understanding of the different measures and actors, as well as the institutional structures of adaptation (Biesbroek et al., 2014; Bisaro et al., 2018). Scientific literature on adaptation provides an insufficient knowledge base on all these aspects, particularly on the stakeholder perceptions that guide the processes at sectoral and individual level.

2.2 INDIVIDUAL DECISION-MAKING ON ADAPTATION MEASURES

Individual adaptation decision-making is a matter of complex interactions between the individuals and their social-environmental context (Wilson et al.,

2020); i.e. how individuals decide on adaptation has impacts on their surrounding environments and communities, and *vice versa*.

The impacts of adaptation can be approached through a rough categorisation of adaptation measures: those that incrementally build on existing structures (systemic or societal), and those that create fundamental changes (transformations) in such structures (Few et al., 2017; Panda, 2018; Wilson et al., 2020). A common understanding of what distinguishes such incremental adaptation measures and transformative adaptation measures, however, has not yet been established (de Coninck et al., 2018; Panda, 2018). Termeer, Dewulf, & Biesbroek (2017) argue that the dichotomy can be restrictive to meaningful adaptation governance as it fails to capture the processual nature of adaptation that is not restricted to a single type of changes. An illustrative example of this is from a study in a Myanmarian region where transformative adaptation measures in the built environment (a flood protection dyke) resulted in an emergent transformative change in the livelihoods of the region (giving up on the flood-resilient farming strategy) (Otsuyama et al., 2019). A range of studies engaged with social aspect/s, such as public engagement (Schlosberg et al., 2017), networks (Dowd et al., 2014; Lamine et al., 2012) and perceptions of capacity (Eakin et al., 2016), have broadened the understanding of transformative potential of adaptation.

On the farm scale, adaptation responses are often based on complex and dynamic balancing of opportunities and risks that depend on subjective factors, such as perceived self-efficacy, and efficacy and costs of adaptation measures, values, knowledge, social identity etc. (Feola et al., 2015; Keshavarz & Karami, 2014; Le Dang et al., 2014a; van Valkengoed & Steg, 2019). Only a small number of studies focus on how farm-scale adaptation decision-making is actually linked to perceived adaptation needs and climate related risks (Findlater et al., 2018b), and capacities (Eakin et al., 2016). These studies show that individual adaptation decision-making at farm scale is influenced by the institutional constrains on the measures and is also a matter of cognitive features (Eakin et al., 2016; Findlater et al., 2018a).

When adaptation decisions are made in different socio-environmental and socio-economic contexts (individual, communal, sectoral, local, region, global), it is inevitable that they involve several types of trade-offs (Atteridge & Remling, 2018; Chelleri et al., 2016; Locatelli et al., 2015; Wilson et al., 2020) Moreover, studies on the outcomes of adaptation are generally under-represented in comparison to research on adaptation needs and measures regarding the impacts of climate change (Atteridge & Remling, 2018; Chan et al., 2019).

2.3 OUTCOMES OF ADAPTATION

Adaptation to climate change is by definition a positive intervention that aims at reducing risks. Implemented adaptation measures are commonly studied as

'successful adaptation', particularly in the early years of adaptation research, as discussed by a small number of researchers at the time (e.g. Adger et al 2005). The challenge with focusing on the successful and positive outcomes of adaptation is the involved bias that harmful outcomes are observed only when the perspective is broadened (and thus becomes inevitably more complex). The implementation of adaptation measures as the sole indicator of the success of adaptation should be considered with caution for two reason in particular. First, "adaptation is a process with varied and changing goals and risk context" (Morgan et al., 2019, 208), i.e. 'the success' is subjective (Adger et al 2005). Second, the potential harmful outcomes are yet rarely assessed in the implementation phase (Magnan et al., 2016).

In general, studies focusing particularly on the challenges of adaptation have emerged in the past decade with conceptualisations such as *maladaptation* (Barnett & O'Neill, 2010; Juhola et al., 2016; Magnan et al., 2016). The potentially negative aspects related to both transformative shifts and incremental adaptation, as well as trade-offs between the positive and negative outcomes of adaptation, are raised as a concern in the literature, while empirical studies on these are yet few, as pointed out in a number of recent studies (Dow et al., 2013; Feola, 2015; Ghahramani & Bowran, 2018; Juhola et al., 2016; Magnan et al., 2016; Schlosberg et al., 2017; Vermeulen et al., 2018).

Trade-offs related to adaptation are discussed in two ways (as described in section 1) and these both are considered in this thesis. On the one hand, the adaptation measures or decisions can shut out other options and aims, and, on the other hand, they can lead to unintended harmful outcomes, i.e. maladaptive outcomes. Maladaptation is acknowledged in the scientific literature and stressed by the IPCC, but not widely studied empirically nor *ex ante* (Juhola et al., 2016; Magnan et al., 2016). Juhola et al. (2016) therefore redefined the conceptualisation of maladaptation to a widely applicable framework that allows an *ex post* assessment of adaptation initiatives and that considers the harmful outcomes of adaptation by the affected actors: the practitioners implementing the adaptation measures, other practitioners or sectors, and the wider public/society broadly. Maladaptive outcomes of current practices that are implemented to increase adaptive capacity, such as intensification, extensification, water harvesting and irrigation, have been identified in the few empirical studies on the topic hitherto (Albizua et al., 2019; Antwi-Agyei et al., 2018; Chelleri et al., 2016; Dube et al., 2018; Guodaar et al., 2020).

Albizua, Corbera, and Pascual (2019), for example, have shown how the extensive irrigation policy to tackle drought-related challenges has shifted vulnerability in a Spanish region to the small-scale farmers. This is in line with results presented by Antwi-Agyei et al. (2018), which suggest that maladaptive outcomes will harm the most vulnerable agricultural actors and future generations in Northern Ghana. The risk of impacting on the environment is stressed in several studies related to agricultural adaptation strategies in

different regions (South and North) (Bindi & Olesen, 2011; Dube et al., 2018; Guodaar et al., 2020).

Moreover, a recent study on the maladaptation sense-making process of Nordic agricultural stakeholders shows that the adaptation outcomes are constantly negotiated with changing contexts and framings, and that maladaptation in Nordic agriculture can be understood, for example, as an economic, social or a moral issue (Neset et al., 2019a).

Current literature stresses that adaptation in agriculture is not only a complex socio-environmental management challenge but it involves highly contextual and complex negative aspects. This makes it a 'wicked' problem in itself that may cause harm to some while benefitting others (Head, 2019, 2014; Juhola, 2019; Neset et al., 2020). Research on the outcomes of adaptation is not yet widely represented in literature. While there is an increasing amount of scientific literature focused on addressing the complexity of adaptation needs and options through quantifiable and systemic approaches focused on the climate impacts, integrating the social-scientific knowledge to them is underrepresented, as suggested by recent studies (Adger et al., 2018; Holman et al., 2019; Jurgilevich et al., 2017). Research that address the human aspects of adaptation decision-making processes offers an important stand-point to address this gap (Cradock-Henry et al., 2019; Jorgenson et al., 2019; Wilson et al., 2020). Linking these approaches to empirical studies on adaptation outcomes is generally considered necessary (Atteridge & Remling, 2018; Locatelli et al., 2015; Vermeulen et al., 2018).

2.4 INTEGRATIVE APPROACH IN THIS THESIS

This thesis applies a systemic assessment of stakeholder perceptions to allow a more coherent assessment of the different types of adaptation measures and their outcomes. The epistemological grounds for this thesis are based on an interdisciplinary approach guided by the environmental social scientific research tradition that "joins structural and agency-focused analysis" (Scoones, 1999, 497). The interdisciplinarity in this thesis is thus rather conceptual (Huutoniemi et al., 2010). This thesis positions in the field of policy studies as it aims to synthesize knowledge on adaptation in agri-food systems and to inform the related policy development. In order to answer the research questions, this thesis draws on research from different disciplines and fields. Moreover, an interdisciplinary approach is considered possible based on the collaborative research process applied (Siedlok & Hibbert, 2017).

Epistemologically, this thesis roots in realism which shows as an interplay between the social theory main concepts of structure and agency. Realism in social sciences is generally based on the assumption that structure and action shape each other in a continuous loop. This understanding of social change can be applied on different scales of social structure, mainly spatial, temporal

and functional, in line with the 'structuration' concept by Giddens (1984). Perceptions of the actors, following this theory of 'structuration' (Giddens, 1984), are considered social representations of reality. Following Biesbroek et al., (2014) I consider agency to be bound within the institutional context of adaptation (structure) while the actors' perceptions that might or might not influence the structures have a qualitative value in increasing understanding of the areas where adaptation occurs.

This thesis focuses on addressing the gap in knowledge of actors' perceptions on vulnerabilities, adaptation needs and options, adaptation decision-making processes (Few et al., 2017; Gardezi & Arbuckle, 2019; Gillard et al., 2016; Wiréhn, 2018) and the potential trade-offs between the different spatial and sectoral level objectives of adaptation (de Coninck et al., 2018; Denton et al., 2014; Landauer et al., 2015). The literature presented in this section establishes the theoretical background for the analytical approach used to answer the overall research questions as well as those of the four papers. The thesis introduces an analytical framework (next section 3) that is applied as a qualitative heuristic to structure the empirical material (that draws on stakeholder perceptions) and its analysis.

3 ANALYTICAL FRAMEWORK

This thesis sets out to develop a framework that can be used to identify and assess perceived and structural vulnerability and risks of climate change, the adaptation measures to tackle those and the potential outcomes of the measures. To do so, this thesis utilises multiple theories (Table 1) that are presented in this section in relation to the research questions 1 and 2 (section 3.1 and 3.2, respectively).

This framework is based on a stakeholder-oriented assessment of adaptation that draws on the perceptions of the individuals and communities under investigation in this thesis (cf. Smit & Wandel, 2006). Concurrently, the framework systemically applies several typologies to analyse these stakeholder perceptions. Adaptation measures are recognised in this framework as the empirical demonstration of adaptation in society. Agri-food systems are regarded as the spatial context where decision-making on the measures is nested. Papers I and II focus on the agricultural sector, paper III on the farm scale and paper IV on the broader food systems. Outcomes of adaptation are considered with an actor-oriented approach from two directions: (i) the perceived aims (of the capable actors) and (ii) the unintended outcomes (to self or others).

The framework represents the theoretical operationalisation of the research questions and it is applied in the four papers as described in Table 1. In other words, the framework is developed to assist in responding to the research questions: what features characterise adaptation measures and their outcomes in the agri-food systems (RQ1), and what constitutes adaptation decision-making at farm scale (RQ2) (see Table 1 for overview).

Table 1. The research question and how they are operationalized in the papers of this thesis.

	Overall research questions	**Research questions** (papers)	**Analytical framework/ categories**
I	**RQ1** (adaptation measure types) **RQ2** (drivers of adaptation decision-making)	Are Nordic farmers taking transformative adaptation measures?	*Vulnerability* analysed as a function of a system's exposure, sensitivity and adaptive capacity (Brooks, 2003; Füssel and Klein, 2006; Smit & Wandel, 2006). *Aims* (reducing risk, increasing coping/adaptive capacity, catching opportunities) and *degree* (incremental, systemic, transformational) used in the analysis of the adaptation measures (Howden et al., 2010; Rickards &

			Howden, 2012; Smit et al., 2000; Smit & Skinner, 2002; Smit & Wandel, 2006).
II	**RQ1** (potential negative outcomes of adaptation)	What are the potential negative outcomes of adaptation measures in Nordic agriculture?	*Maladaptation* (rebound, shift, erode SDGs) (Juhola et al., 2016), the *features of successful adaptation* (Magnan et al., 2016), and the *degree* of the measures (incremental, systemic, transformational) (Howden et al., 2010) used in the analysis.
III	**RQ2** (farm-scale adaptation decision-making)	How do risk perceptions influence climate change adaptation at the Nordic farms?	The farm-scale *risk perception* driven *adaptation decision-making* analysed using the *protection motivation theory* (applied from Grothmann & Patt, 2005; Norman, Boer, & Seydel, 2005; Smit & Skinner, 2002).
IV	**RQ1** (transformative adaptation measures) **RQ2** (transformative adaptation decision-making)	What characterises transformative adaptation in the Nordic agri-food systems?	*Features of transformative adaptation* (target, mechanisms, object) (Few et al., 2017) integrated with the *adaptation activity spaces* concept (Pelling et al., 2015) in the analytical framework to assess adaptation decision-making as interaction between the systemic and social factors.

3.1 TYPOLOGY: ADAPTATION MEASURES AND OUTCOMES

In this thesis, adaptation in agri-food systems is considered to consist of the deliberate policies and the consequential actions/measures as well as the emergent practices that are aimed at decreasing climate related risks. These responses are considered to lead to changes in the implementing contexts and beyond.

A number of analytical typologies for adaptation measures in agriculture and agricultural management have emerged in the scientific literature in recent years (e.g. Iglesias & Garrote, 2015; Iglesias et al., 2012; Mandryk et al., 2015; Schaap et al., 2013). In this thesis, to capture adaptation measures and their outcomes, I have followed the typology developed by Few et al. (2017) to assess the features of transformative adaptation; the systemic definitions for degree of change by Rickards and Howden (2012) and Smit and Skinner (2002); and the redefined maladaptation concept developed by Juhola et al. (2016); as well as the successful adaptation framework by Magnan et al. (2016). Furthermore, I pay attention systematically to the temporal, societal

and spatial scales of the measures as suggested by several scholars (e.g. Few et al., 2017; Pelling et al., 2015).

The aim of adaptation in this thesis is understood as: (i) risk reduction, (ii) coping capacity building, (iii) adaptive capacity building and/or (iv) opportunity seeking (paper I), and approached with the questions "How is climate risk targeted?", "What are the mechanism of change" and "What is the object of adaptation?" (paper IV) (Few et al., 2017). The targeting of climate risk, following Few et al. (2017), is in paper IV analysed in relation to three categories (i) instrumental tackling of climate-related risks, (ii) progressive tackling of vulnerability, and (iii) radical targeting of the root causes of vulnerability. The categories also relate to the typology of aims presented in paper I. Instrumental targeting is similar to risk reduction and opportunity seeking, whereas progressive targeting of climate risks is related to building coping or adaptive capacities. These aims can overlap and develop from one to another, for example instrumental risk reduction or coping capacity building can develop into systemic progressive targeting of vulnerability. The radical targeting of the root causes of vulnerability relates to the transformative objects of change (Few et al., 2017).

Following Rickards and Howden (2012) and Wise et al. (2014), transformative adaptation is generally considered a societal response to climate change that often crosses spatial scales, and sectoral and jurisdictional boundaries. It eventually leads to transformations in the operating systems and beyond. The degree of change as a result of an implemented adaptation measure is analysed using the typology of Smit and Skinner (2002) on incremental, systemic and transformative change in the agri-food system context. The incremental adjustments to existing systems are the systemically lowest level of change whereas 'systemic change' refers to partially fundamental changes and 'transformative' to fundamental changes where a whole system is altered more than retained unchanged. Reversing this change is difficult or impossible (threshold effect) (Rickards & Howden, 2012; Wise et al., 2014). 'Transformational' was used in papers I and III to refer to the fundamental degree of changes in the agricultural adaptation practices (Rickards & Howden, 2012). Paper IV introduced 'transformative' with reference to Few et al. (2017) as a qualitative feature of the fundamental societal change process through adaptation. This thesis consistently uses 'transformative' to describe any fundamental degree of change/process and makes a distinction regarding the objective (practice/societal change) when it is relevant.

Few et al. (2017) describe four mechanisms of transformative change (innovation, reorganization, reorientation, expansion) that overarch the fundamental change process through adaptation. *Innovation* refers to novel adaptation measures or novel location for applying an existing measure, whereas *expansion* depicts applying an existing measure on a considerably greater scale or intensity (Few et al., 2017). *Reorganisation* as means of transformative adaptation, following Few et al. (2017, 3), refers to "major

change in the governance structures that frame adaptation" and *reorientation* to "reconfiguration of social values and social relations in adaptation.". Following Milestad, Dedieu, Darnhofer, & Bellon (2012), this thesis posits that farm-scale reorganisation can develop as a reactive response after disruption/disturbance or in a proactive way, for example through nurturing diversity that allows for more flexibility. The mechanisms can be overlapping and progressive. For instance, the early years of CAP involved detrimental environmental and social effects that resulted in the reorientation of public policies and redefinition (read reorganization) of the "role of different key agri-food governance mechanisms" (Lamine et al., 2012, 240).

The features of the expected outcomes of adaptation relate to the features of "successful adaptation" based on Magnan et al. (2016) (Paper II). Features of a successful adaptation measure are that (i) it does not increase green-house-gas emissions i.e. work against mitigation targets, (ii) it ensures economic and social equity, (iii) it increases the incentive to adapt, (iv) it avoids high-cost measures, and (v) builds flexibility into the measure (Magnan et al., 2016).

Furthermore, the adaptation outcomes in this thesis are evaluated with a focus on the unintended. The concept of maladaptation is applied and assessed in paper II according to the Juhola et al. (2016) typology based on the question "who is affected by the potential harmful outcome of adaptation?". In this typology, the maladaptive outcomes either *rebound* vulnerability back to the implementing actor/s, *shift* vulnerability to other actors or sectors, or *erode* the common pool of resources, i.e. sustainable development, and thus affect society more broadly.

The unintentional responses to climate change related risks are sometimes considered as (accidental) adaptation but they are not scoped in this thesis. These should not be confused with emergent adaptation (presented earlier), "hidden adaptation" (see e.g. Grüneis, Penker, & Höferl, 2016), or adaptation as part of regular farming practices (Asplund, 2016). Some studies examine maladaptation as disregarding adaptation, for example, by wishful thinking or denial (see e.g. Dang, Li, Nuberg, & Bruwer, 2014). This notion derives from the protection motivation framework (PMT) that was originally applied outside the climate change adaptation context, and where maladaptive coping is considered a negative option for adaptation intention. Thus, this or any of the other previous conceptualisations of maladaptation (e.g. Barnett & O'Neill, 2010) are not used in this thesis.

3.2 ADAPTATION DECISION-MAKING

In this thesis, the theoretical premise for assessing the adaptation decision-making processes is bound to the measure typologies presented in section 3.1. I focus on the aims, objects, targets, and intended degree of measures and, in particular, on the stakeholder perceptions that might not fit to these

categories. In this section, the features of the process are clarified regarding the perceived stressors and needs at farm-level adaptation decision-making. The perception of vulnerability is considered throughout this thesis as the key feature of perceived adaptation needs. **Vulnerability** is broadly understood as characteristic of human and ecological systems that are exposed to hazardous climatic and non-climatic events and trends (Oppenheimer et al., 2014) and as function of a system's exposure, sensitivity and adaptive capacity (Brooks, 2003; Füssel and Klein, 2006; Smit and Wandel, 2006). Non-climatic factors are generally considered to involve cultural, social, economic, political, and institutional aspects that affect adaptation behaviour (Smit & Skinner, 2002). In their empirical study focusing on risk perceptions, Dang et al. (2014) found similar types of system characteristic factors to influence the adaptation assessment, including the markets affecting the economic stability and prosperity at the farm and policies that might guide adaptation.

The protection motivation theory (PMT) suggests that the intention to implement adaptation measures essentially rises from the motivation to protect such assets that are perceived valuable and at risk (Grothmann & Patt, 2005; Norman et al., 2005). This is considered to raise an assessment of the efficiency and feasibility of the measures by the practitioner, here the farmer (ibid.). The intention to adapt rising from such motivation and favourable assessment is not yet a proof of behaviour change (i.e. taking the adaptation measure) and the logic model of risk perception driven protection motivation is applied in assessing the *premises* for adaptation decision-making at farm scale in paper III of this thesis. Farm-scale risk perceptions are assessed against the widely used definition by the Intergovernmental Panel on Climate Change (IPCC), where risks from climate change consist of three main elements: hazards arising from climate change, exposure to the hazards (impacts/outcomes), and vulnerability, and where the risks are considered to result of complex interactions between societies and communities, ecosystems and the hazards (Oppenheimer et al., 2014, 1050).

The stressors involved in transformative adaptation decision-making are assessed against the two types of transformative change processes that dominate the literature (Feola, 2015; Linnér & Wibeck, 2019; Pelling et al., 2015), often referred to as 'emergent' and 'deliberate'. Emerging transformations refer to such processes that are primarily not controlled, such as migration from drought hit areas (see e.g. Mortimore, 2010), whereas 'deliberate' refers to primarily controlled transformations. The emergent processes are somewhat progressive changes in adaptation measures or strategies, while deliberate shifts follow the proactive 'in order to' adapt logic (see e.g. Fedele et al., 2019; Feola, 2015). The latter are more common in the literature focused on the urban context, for instance, regarding proactive resettlement in response to sea level rise (see e.g. Gibbs, 2016), while this obviously concerns also agriculture in the coastal regions. Apart from such climate stress driven changes, Pelling, O'Brien, & Matyas (2015) underline that transformative adaptation can be aimed at tackling the structural causes of

vulnerability (social, cultural, economic) which in this thesis is referred to as non-climatic stressors.

The concept of activity spaces developed by (Pelling et al., 2015) is used to unravel the key non-climatic contextual factors of decision-making (paper IV). The seven activity spaces and exemplifying features (in brackets) introduced by Pelling et al. (2015) are individuals (values & identity), technology (material & organisational), livelihoods (production & labour processes), discourse (popular & policy), behaviour (practices & routines), environment (biotic & abiotic) and institutions (regulatory & cultural). The activity space concept considers the actors with power (i.e. agency) and the structural context of adaptation in an integrated way that involves interaction between the different elements. For example, the 'livelihood' activity space, is considered to consist of the production context (e.g. farm), and actors (e.g. farmer, labour) that hold power to make transformative changes (e.g. to the production processes) or by crossing with other activity spaces, such as 'behaviour' by transforming the practices.

To summarise, the analytical framework of this thesis builds on the theoretical background of social structures, systemic changes, and perceptions of risk and vulnerability in combination with an analytical application of the concepts of aims and degree of adaptation (Few et al., 2017; Rickards & Howden, 2012; Smit & Skinner, 2002), maladaptation (Juhola et al., 2016), and adaptation activity spaces (Pelling et al., 2015). This framework allows the author to approach the empirical material on adaptation in this thesis.

4 METHODOLOGY

Methodologically, this thesis is based on an integrative framework that sets out to address the contextually bound and empirically identifiable features of climate change adaptation in the agri-food system context. It is applied in the papers of this thesis through interviews, workshops and a literature review focusing on adaptation measures in the agricultural sector (I) and the drivers for their implementation at the farm-scale (I and III), the potential maladaptive outcomes related to these measures (II) and transformative adaptation in the broader Nordic agri-food system context (IV).

Stakeholders in this thesis represent actors with specialized knowledge and experience that are considered relevant to the research questions posed in this thesis, which deal with the complex challenges in decision-making related to global environmental changes, contextual vulnerabilities and mental models for action (Darnhofer et al., 2012; Findlater et al., 2018a; Welp et al., 2006). The empirical material of the thesis consists of stakeholder dialogues (see section 4.2.1) that are considered a representative take of the stakeholder perceptions on the qualities (features) of adaptation in the case sites (section 4.1). The stakeholder dialogues that were conducted as research interviews and game workshops (section 4.2). The material is analysed with a conceptually interdisciplinary take (Huutoniemi et al., 2010) and the collaborative research process between researchers from different scientific backgrounds (Siedlok & Hibbert, 2017). The analytical framework is developed and used as a heuristic to qualitatively structure the empirical material and analyse it with the means of content analysis (section 4.3) to answer the research questions (see Table 1, section 3).

The process of inquiry in this thesis has been iterative and the sub-questions as well as the methods of inquiry have been re-shaped as more knowledge has been gained. Reasoning in this thesis (see Table 2) is inductive with regards to the case approach and especially when drawing on stakeholder perceptions (I, III, IV)/ leading to new typologies (III). Yet, the reasoning is largely deductive as the analytical frameworks in II and IV are applied for thematic analyses.

Table 2. Thesis key concepts positioned by the two inquiry dimensions followed in this thesis (adapted from Larsen et al., 2012).

Deductive logic, identification based on existing models	**Inductive logic, iterative production of new hypothesis**
Measure types (I, IV)	Perceived vulnerability, adaptation needs and options (I)
Maladaptation types (II)	Perceived risks (III)
Adaptation decision-making features (III, IV)	Risk responses (III)
Adaptation activity spaces (IV)	Transformative changes (IV)
Stakeholder types (all)	

4.1 CASE DESCRIPTION

The case sites were chosen because they represent Northern European regions where climate change adaptation in crop production based agriculture has socio-economic relevance. The two regions share both similarities and feature differences to provide a wider perspective on adaptation in Nordic agriculture that represents the northernmost agricultural region in Europe and globally.

The two case sites of this thesis, Uusimaa (Finland) and Östergötland (Sweden), are important crop production regions in the Nordic countries that produce for the food industry and domestic consumption, and export in nationally significant amounts. Rural areas in the Nordic countries generally dominate the geography while the majority of the population is centered in the urban areas[1]. Uusimaa consists of the Finnish capital region and the rural areas in the region are mostly close to urban areas, and some core rural areas with the rural congregates, and only a small proportion of remote rural areas that are located in the archipelago (SYKE, 2014). Uusimaa region is thus more urban than Finnish regions generally. Östergötland is a typical Swedish region as it is mostly semi-rural while some of its southern municipalities are more rural than urban (Tillväxtverket, 2014). Agriculture in Östergötland is more 'professional' than in Uusimaa i.e. it employs a larger proportion of the population and the average farm size is significantly larger (see table 3). Östergötland has a general plan for managing climate change adaptation (Bratt, 2014). It includes general tasks to advance agricultural adaptation knowledge in the regions and a mapping of climate change related risks in the

[1] The distinction between rural and urban area is not straigthforward and usually different scales are used to describe the level of 'urbanity' or 'rurality' of a region. Finland and Sweden use three main classes of rural areas: a) close to urban areas, b) core rural areas and b) sparsely populated rural areas (SYKE, 2014; Tillväxtverket, 2014)

region[2]. In Uusimaa region, the adaptation plans are focused on the capital region and urban settlements, and the agricultural adaptation is guided nationally by the Ministry of Agriculture and Forestry.

The long-term trend is that farm sizes are growing while the number of farms along with population in the Nordic rural areas is declining[3]. Agricultural production rates, on the other hand, are rising along with the increased availability of more efficient farming technologies and intensification in Nordic agriculture. Climate change is widely presented as an exhilarator for productivity due to the beneficial changes in some of the traditionally limiting conditions for crop production in the Nordic region i.e. the short warm season. The increased heat summation (temperature increase) and longer frost-free period that is expected to result in more profitable crops and higher crop yields (Peltonen-Sainio et al., 2018) is a particularly relevant scenario in the study sites that are situated in the southern parts of Sweden and Finland. Along with the increase in production and characteristic vulnerabilities in these regions, the challenges with harmful biological organisms, soil quality depletion, erosion and water management issues (Bindi & Olesen, 2011; Jørgensen & Termansen, 2016; Uleberg et al., 2014; Wiréhn, 2018; Wiréhn et al., 2020) are expected to become more prominent. The long coastlines with the Baltic Sea (Uusimaa 1200 km, Östergötland 738km) expose coastal arable lands in the regions to sea level rise. The dominant soil types (clayey soils) in the regions are sensitive to flooding, drought and lack of periodical frost.

[2]https://www.lansstyrelsen.se/ostergotland/miljo-och-vatten/energi-och-klimat/klimatanpassning.html;https://extgeoportal.lansstyrelsen.se/standard/?appid=cd1bcd002e3b43a8af80406739436776

[3] While agriculture is becoming more 'business like', it is still a heavily subsidised sector in the Nordic countries that employs only 2-3% of the workforce. In addition to the EU rural development funding and the production subsidies, the national governments provide financial support for young farmers with an aim to keeping the sector alive. (Antman et al., 2015).

Table 3. Fact sheet: Uusimaa and Östergötland regional, agricultural and climatic vulnerability factors based on the most recent available sources (in April 2020) (ELY, 2012; Kottek et al., 2006; Maanmittauslaitos, 2020; Official Statistics of Finland (OSF), 2020; Peltonen-Sainio et al., 2017; Statens Jordbruksverk, 2016; Thomas Brinkhoff/ City Population, 2020).

	Uusimaa region	**Östergötland region**
Location	South of Finland	South-East of Sweden
Inhabitants	1 644 107	461 583
Habitats/ km²	180	43
Total land area (km²)	9 097	10 559
Arable land (km²)	1 812	2 012
Forested land (km²)	6 004	6 660
Municipalities	26	13
Climate (Köppen-Geiger classification)	Boreal, precipitation all year round, warm summer	Warm temperate, precipitation all year round, warm summer
Employees in agriculture	7 010	9 900
Average farm size (Ha)	50	347
The main crops (excluding fodder)	Spring wheat, barley and oats	Winter wheat, potato, spring barley
Dominating soil types	Clayey soils, clayey silt soils	Clayey soils, sandy soils

Potential measures to reduce vulnerability and increase adaptive capacity in the Nordic agricultural and farming system are identified in a recent literature review (Wiréhn, 2018) and other studies (Bindi & Olesen, 2011; Huttunen et al., 2015; Jørgensen & Termansen, 2016; Puupponen et al., 2015; Uleberg et al., 2014; Wiréhn et al., 2020). These discuss farm-based adaptation measures that are focused on *capitalizing* on the new crop varieties, intensification and northward expansion of production; and *managing the challenges* of drought, excess precipitation, extreme weather events and increased pest invasions by taking areas out of production, changing crops, adjusting existing systems and practices or implementing new ones, such as irrigation and drainage systems (Bindi & Olesen, 2011; Jørgensen & Termansen, 2016; Uleberg et al., 2014; Wiréhn, 2018). Policy-driven adaptation is mainly focused on plant breeding and drainage improvement (Wiréhn, 2018), while adaptation as an implicitly integrated part of sectoral policies might involve other adaptive capacity building measures, such as incentives for soil quality improvement (Huttunen et al., 2015).

Adaptation policies in the Nordic countries are currently on governmental strategic agendas (National Adaptation Plans and Strategies i.e. NAP and NAS). They are applied in various ways, mainly with sectoral and regional foci (EEA/Blaz Kurnik, 2019, 28). In Finland, the mid-term assessment of the NAP in 2019 has provided information on the adaptation measures in agriculture (Mäkinen et al., 2019). In Sweden the climate change vulnerability and impact

(CCVI) assessment for agriculture is in preparation (EEA/Blaz Kurnik, 2019, 28). Massey and Huitema (2016) have assessed the adaptation policy development in Finland to be primarily pluralistic, i.e. several actors are involved in the process. In Sweden, the process is assessed to be led top-down (Massey & Huitema, 2016). This means that the actors are mainly from the scientific community and governmental organizations/institutes.

Both countries have sectoral adaptation plans that provide general guidelines for adaptation in agriculture and the food sector (Livsmedelsverket, 2018; Markensten, 2019; MMM, 2014). Different types of recommendations and information sources for various actors in the agri-food systems are provided by different government agencies (Livsmedelsverket, 2018; MMM, 2017, 2014). The rural development programme in Finland, for example, is considered one of the key policy tools for adaptation in Finnish agriculture (Mäkinen et al., 2019).

The materials and methods of this thesis (Table 4) address different elements of the cases (regions, stakeholders, material collection type).

Table 4. Materials and methods in the papers.

	Material	**Case study area; stakeholders**	**Methods**
I	*Stakeholder interviews* focusing on the perceptions of vulnerability and the adaptation measures	Östergötland (Sweden) and Uusimaa (Finland); farmers and extension officers	*Content analysis:* coding analytical and grounded themes/sub-/categories that were organized and patterns and relationships were identified (Berg, 2009; Creswell, 2014).
II	*Stakeholder interviews, literature review* (Khan et al., 2003) focusing on the potential negative outcomes of adaptation measures	Östergötland (Sweden) and Uusimaa (Finland); farmers and extension officers *Literature review:* Nordic countries	*Thematic analysis* (Kvale & Brinkmann, 2009) deductively identifying the analytical themes.
III	*Stakeholder interviews* focusing on the perceptions of risk and elements of adaptation decision-making	Uusimaa (Finland); farmers and extension officers	*Content analysis:* coding and organising analytical themes and identifying an explanatory typology (Yin, 2014; Halperin & Heath, 2012).
IV	*Game workshops* focusing on transformative adaptation measures and decision-making	Östergötland (Sweden) and Uusimaa (Finland); farmers extension officers, representatives of agricultural organizations/ education/ agencies	*Content analysis:* deductively identifying the analytical and grounded themes (Eskola & Suoranta, 2001).

4.2 EMPIRICAL MATERIAL COLLECTION AND SERIOUS GAME DEVELOPMENT

4.2.1 STAKEHOLDER DIALOGUES

Stakeholder participation in this thesis is mainly cooperative and consultative i.e. the researchers control the research agenda and process (in cooperation with stakeholders), and analyse the stakeholder knowledge and perceptions (received by consulting the stakeholders) (Gibbon, 2012; Welp et al., 2006). Following Welp et al. (2006), the interaction with the stakeholders on different occasions is an important interface between science and society. The stakeholder consultations i.e. the research interviews and game workshops, but also the dialogues held outside the controlled research environment played a role in identifying research questions, developing and evaluating the game as a method and creating a sense of ownership of the research (Welp et al., 2006).

The requirement of a careful stakeholder analysis is duly stressed by André et al. (2012) to study and advance adaptation processes in a sustainable way. In this thesis, the stakeholder selection draws on literature focusing on farm-scale adaptive capacity and motivation suggesting that the expertise, experiences and perceptions of farmers, extension officers, public authorities working with adaptation, particularly regionally, need to be incorporated in systemic agricultural adaptation research and planning (Himanen et al., 2016; Mitter et al., 2018; Ross et al., 2015). Furthermore, a variety of farm types within the study scope (crop farming) was considered as a selection criteria following Reidsma et al. (2010) who highlight the necessity to study agricultural adaptation at different organizational levels as these represent such different preconditions for adaptation, as well as to pay attention to farm-specific features that define the contextual vulnerabilities on each farm.

The theory-driven sample is complemented with a snowball sampling (Warren et al 2002), which can be used to identify groups that are 'hidden' from the research community or lay people (Atkinson & Flint, 2001). The agri-food systems actors that have knowledge and/or experience of adaptation are considered in this thesis to represent such a group since adaptation is not yet a mainstream practice in the agri-food systems and there are few actors who formally work with this issue. The criterion for all stakeholders was to be involved in professional crop production and experience or interest in adaptation. Following (Reidsma et al., 2010), the sampling of the stakeholders aimed to respect the age, gender and production orientation (organic/conventional) balance in the study sites.

The stakeholders were contacted personally by e-mail or phone based on contact information obtained from public sources (internet) and from other stakeholders (snowball sampling). The first contact involved an informed consent (Kvale, 2011a) i.e. introduced the research aims, affiliations, and funding, and the voluntary nature of participation and their right to withdraw

from the study at any time, as well as the possibility for a travel expenses reimbursement. Further details were discussed in the follow-up communications that aimed at building trust with the participants. Gaining the trust of the stakeholders can be understood as an aspect that increases their acceptance towards the researchers, and openness and honesty in the research situation (Evers & Van Staa, 2012).

Most of the stakeholders reached were willing to participate in the research as long as a suitable time was found. Only a few declined, stating lack of time as the reason. A suitably representative group of stakeholders was eventually reached with consensus by all the involved researchers. The material was considered saturated when the participants started repeating similar discussions. The saturation point was evaluated in consensus with the researchers. The collaborative work regarding the practical research tasks was complemented with joint discussions that were held regularly after the first interview rounds and game workshops.

4.2.2 INTERVIEWS

To begin the inquiry, the empirical material for this thesis was collected by means of semi-structured stakeholder interviews (see Table 5) with open-ended questions. This data collection method and mode allows exploring the novel topic with flexibility regarding the discussed topics and the depth of dialogues in the interview situations as the respondents can discuss the issues raised by the researchers more freely, as well as to elaborate on their own points of interest and experiences regarding adaptation (Denscombe, 2010; Hirsjärvi & Hurme, 2015). Two test interviews were performed (one in each country) to test that the operationalization of the interview guide worked for gathering information on experiences, expectations and perspectives on adaptation. The complete interview guide can be found as an appendix in paper II.

The interviews were arranged at a suitable location and time for the interviewees. The interviews started with a brief introduction of the research project and the course of the interview, after which assent to the use of the audio-recorded material for research purposes was acquired.

Interview recordings were subsequently transcribed in a convention describing only talk and simple annotations of laughter, pauses and emphasis. This convention was appraised sufficient because the analysis of this thesis draws mainly on *what* the interviewees say (content analysis) (Hirsjärvi & Hurme, 2015) (see 4.2.4).

As climate change is a topic that can cause psychological responses that are generally perceived adverse, such as emotional stress and anxiety (Reser et al., 2011), extra time for discussion after the interviews/workshops was included and the possibility for the participants to contact the researchers afterwards was provided. These procedures were based on the understanding that providing accurate information on the risks, ways to take action and the

available resources on the problems and solutions can be helpful for dealing with the adverse psychological responses (Reser et al., 2011). Some of the participants indeed expressed worry, even 'anxiety' (direct quote). In these situations, time was spent on applying the planned procedure to ease the stress. For the most part, the discussions after the interviews dealt with climate change and agriculture, and the farms of the respondents in a relaxed manner. Sometimes notes were taken to raise some interesting points for the analysis.

The interview material was analysed in papers I and III, and in paper II it was analysed concertedly with the literature review (see 4.2.3).

4.2.3 LITERATURE REVIEW

The second round of material collection consisted of a literature review on the Nordic agricultural adaptation measures and their potential maladaptive outcomes. This part of the inquiry was lead and performed by Lotten Wirehn who conducted the initial search based on key-words and titles of publications dated between 2000 – 2017 which resulted in approx. 160 publications. Of these, after a second reading, 60 were found relevant to agriculture, climate related impacts and/or adaptation, and one or several of the Nordic countries (Sweden, Finland, Norway, Denmark). The original paper on the findings of the review presents adaptation challenges, opportunities and needs in Nordic agriculture (Wiréhn, 2018). The author of this thesis provided supplementary material on exclusively Finnish literature for the extension of the review in paper II. The search was performed using Google Scholar and it provided 6 publications to contribute to the total of 60 publications assessed in the review, of which 24 made reference to potential maladaptation in Nordic agriculture[4]. A comprehensive list of reviewed papers can be found in the Supplementary material of Paper II.

4.2.4 THE M-GAME AND GAME WORKSHOPS

The results based on the stakeholder interviews and the literature review in papers I and II were used in building a serious game for the purpose of studying adaptation decision-making and for initiating a dialogue with the target group - the Nordic agricultural stakeholders. Integrating serious gaming in studies of decision-making in complex socio-ecological systems is an emerging methodological approach that involves opportunities for more dynamic stakeholder participation and engagement (see e.g. Reibelt et al., 2017; Rumore, Schenk, & Susskind, 2016; Washington-Ottombre et al., 2010).

[4] The initial search included the following string (Agricult* OR Crop* OR farming) AND Climate AND (risk OR hazard OR stress OR impact OR vulnerability OR effect) AND (adaptation OR action OR response) AND (Nordic OR Scandinavia OR Norway OR Sweden OR Denmark OR Finland) which was translated in Finnish by the author and applied in Google Scholar search (Neset et al., 2019b).

The research purpose of the M-game[5] (see Fig. 1) was to create a decision-making situation that reflects aspects of Nordic farm-scale adaptation and maladaptation. M-game is designed as a single player online 'card game' that introduces the four main climate change related challenges for Nordic agriculture (increased temperature/drought, increased precipitation, increased risk of pests and weeds; longer growing season) and a variety of adaptation measures to tackle them that all have several potential maladaptive outcomes. The game is available in three languages (English, Swedish, Finnish). The players are instructed to take the role of a Nordic farmer. The task in the game is to tackle the challenges in a preferred manner while inducing as little harm as possible to the farmer, others and the common pool (based on Juhola et al., 2016). Players are given a starting budget to purchase the measures. After each choice, the M-score, which represents the potential harmfulness of the measure, is made visible. The relative values of the costs (4 scales, from expensive to low cost) and the harmfulness (3 scales, least harmful being the impact on farmer and common pool impact being most harmful) were assessed by the researchers.

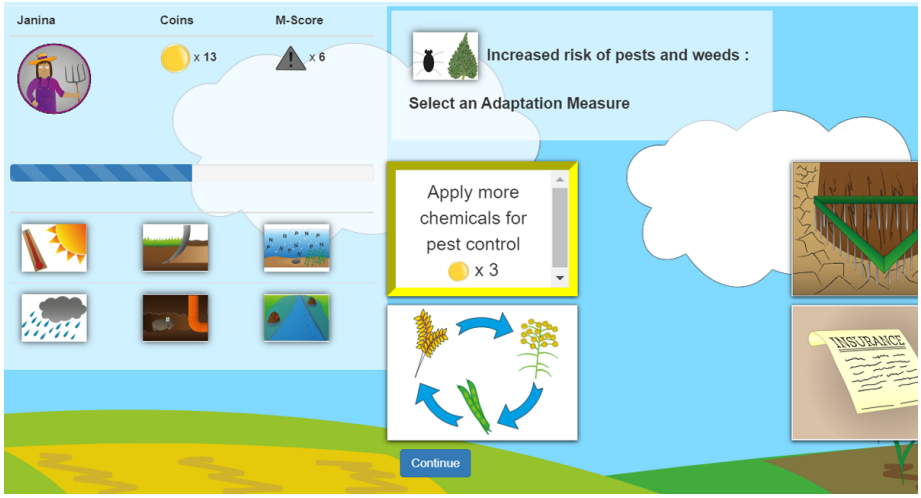

Figure 1. Screenshot from the game phase where players are choosing a measure to address increased risk of pest and weed infestations. Key game features: measure cards with illustrative pictures and text explanation in the back, the M-score and budget up-date (upper left of the screen), up-date on the decision-paths that are selected (left-hand side of the screen).

The third round of material collection was executed in the game workshops (see Table 5), where the serious game was used as a tool for initiating dialogue. Transformative measures were not included in the game, as no maladaptive outcomes were identified related to the previously identified transformative

[5] http://maladaptationgame.info/

measures in Nordic agriculture. The research questions in paper IV were thus operationalized in the game workshop interview guide. The interview guide is available as an Online Resource in Wiréhn et al. (2020). Similar to the interviews, two test sessions (one in Finland, one in Sweden) were held prior to the actual workshops and provided valuable material on developing the workshops regarding instructions on playing.

The workshops were held in small groups of two (i.e. in pairs) to provide more perspectives (the quantitative incentive) as well as to achieve more illuminating material through reflecting on the views of other participants and gaining more sense of involvement and trust in speaking their minds (qualitative incentive) (Denscombe, 2010). The pairs were thus mainly selected with 'homogenous' background regarding their expertise to create more room for this type of collegial discussions and not focus on explaining their standing points.

Each game was moderated by one or two researchers and one additional researcher was present in some sessions to make observations. The workshops began with an introduction to the research and the game, followed by a set of preliminary interview questions in a semi-structured manner. The gaming session followed. During the gaming, the researchers asked complementary questions and replied to direct questions from the stakeholders. In the three cases where the stakeholders were playing the game alone (not in pairs), the researchers participated more in order to assist in the description of the decision-making process. At the end of the game, final questions were asked and the workshop was wrapped up.

Table 5. Details of interviews and workshops. See Table 2 in Paper I for details on the interviewed stakeholders, and Supplementary Material A in Paper IV for a detailed listing of participants in the gaming workshops.

	Interviews	**Workshops**
Total amount	23	20 (37 stakeholders, of which 19 farmers)
Stakeholders/ representive organisation	4 County Officers 4 Agricultural advisors 3 Farmers Union 12 Farmers (2 organic, 10 conventional)	11 Students 5 Teachers, educational specialists 3 Agricultural adaptation researchers 3 Agricultural extension service 4 National agri-/adaptation governance 4 Regional/municipal agri-administration 4 Farmers union 2 Activists 1 AgriTech company
Time	Spring/summer 2014	Autumn 2018
Interviewers, moderators, observers	Natacha Klein (Swe), author of this thesis (Fin)	Lotten Wiréhn and Tina-Simone Neset (Swe), author of this thesis (Fin, Swe)
Duration	Approx. 45 min. to 1 hour	

Location	Work or study place of the stakeholders or the hosting Universities' facilities (University of Helsinki and Linköping University)
Language	Mother tongue of the stakeholders (Finnish or Swedish)
Recording	Audio-recorded with two recorders
Transcriptions	Simple convention; transcript authors: Natacha Klein (Swe interviews), author of this thesis (Fin interviews), Rasmus Sihvonen (workshops)

4.3 METHODS FOR ANALYZING THE EMPIRICAL MATERIAL

The general method for analyzing the interview and workshop transcripts in this thesis is a qualitative content analysis which stays on the level of *what* the interviewees say (Hirsjärvi & Hurme, 2015), while stress is also placed on how the respondents describe such themes that are considered to indicate the perceptions. Qualitative content analysis is often used to analyse interview material with the assistance of both deductive theoretical perspectives on the study topic and inductive logic to particularly identify the perceptions of the stakeholder/actors (Berg & Lune, 2011). The material from all interviews was analysed in this way as one text piece, and the material from the workshops as another set of material. These two sets of material were coded and categorized by the predetermined codes derived from the analytical frameworks (III, IV) or by the analytical categories (I, II), and inductively by the frequently occurring themes, opinions and keywords; and contradictions, patterns and thematic connections in the material (Halperin & Heath, 2012). This involved identification of relevant explicit expressions of e.g. measures ("ploughing subsoil is used to decrease vulnerability to drought and flooding") and implicit expressions of perceptions (e.g. "neighbors thought I'm crazy").

The coding and categorizing process was analytical in all papers, and the grounded themes complemented the analysis (Eskola & Suoranta, 2001; Halperin & Heath, 2012). In paper II, a thematic analysis (Kvale, 2011b) of both the literature review material and the transcripts was applied to deductively identify the predetermined analytical themes. In paper I, the analysis focused on identifying patterns and relationships between the theoretical categories and the grounded themes and subthemes similar to the paper IV. The categorization in paper III is based on the analytical technique of explanation building used for "explaining how" climate risk perceptions and adaptation policies affect farm-scale adaptation.

The supplementary material in III and IV includes the thematic coding maps. The coding map of paper III is narrowed to represent the analytical process for that paper and Finnish material only, however, it illustrates how the analysis in papers I and II was applied on the complete material. Managing the material of paper IV was assisted by the computer programs *Atlas.ti* (for

Finnish material) and *N-Vivo* (for Swedish material) (see e.g. Eskola & Suoranta, 2001).

To summarize, the methods are presented in Figure 2.

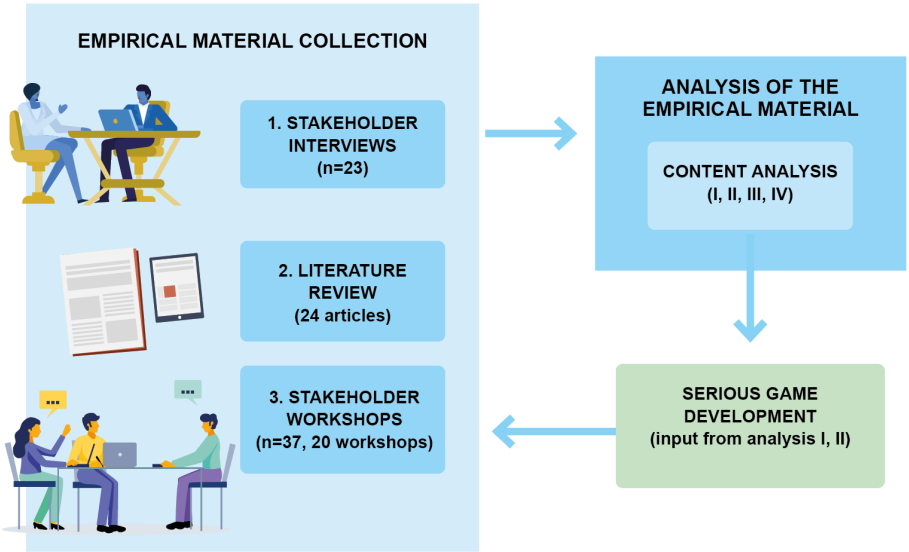

Figure 2. Flow-chart of the material collection and analysis (figures in the chart designed by stories/Freepik).

4.4 LIMITATIONS OF METHODOLOGY

This thesis is a qualitative empirical study with its mainly empirical material, qualitative methods and analysis. The main challenge in qualitative research is generally the intertwined nature of the analysis and the evaluation of credibility (Eskola & Suoranta, 2001). The biases of the researcher can affect the study in many ways. This needs special attention in qualitative single author papers where the theoretical robustness of the paper and the skills of researcher has a more important role than in multi-researcher studies (Eskola & Suoranta, 2001). In this thesis, the interpretations in one paper (III) are by the single author whereas in other papers, there are several authors to increase the researcher/investigator triangulation. This and two of the other dominantly used types of triangulation, theory and data triangulation, (Yin, 2013) are applied in this thesis.

The collaborative research process applied in this thesis (Siedlok & Hibbert, 2017) is used to enforce the triangulation throughout the different phases of the study. The sound theoretical background and operationalization are also the key to avoiding biases in the interpretations of the material and in

the analysis (particularly stressed in III). In this thesis, the integrated approach on theory and methods is based on the understanding that the material and theory triangulation enforces the credibility of the results, particularly in the case study strategy where it builds reliability and validity of the material as evidence (Eskola & Suoranta, 2001; Yin, 2013). Given this, the effort put on securing the aspects of credibility, internal validity and reliability of the material and methods could nevertheless be improved by, for example, more variable sampling and more engagement with the stakeholders to build trust and to gain a better view of the key aspects of the case (Evers & Van Staa, 2012).

While the sample in this thesis can be argued to be small (60 stakeholders), it is nevertheless considered sufficient for the qualitative analysis of the material that allows for presenting a rich picture in response to the research questions. The quality of this study is partly based on the representativeness of the material (and transferability of the results, see 6.3). Moreover, the iterative inquiry, applied together with a conceptual interdisciplinary take (Huutoniemi et al., 2010), shows novelty value in the methodology (as well as results regarding new hypotheses, see section 6).

The semi-structured interview method in both the individual stakeholder interviews and as part of the game-workshops can be justified as an economic way of gaining concrete statements of the study issues, while allowing certain freedom in the discussions (Flick, 2014). The individual interviews proceeded often in a way that required very little interruption from the interviewer as the participants described their experiences and perspectives in a narrative-like way that included most of the issues in the interview guide. The workshop situations were more clearly dialogues. This resulted in material that is rich in the specific statements that were sought for in the content analysis. The typical limitation of these two methods in combination (semi-structured interviews and content analysis) can be considered to relate to their general nature that puts a lot of stress on the skills of the researcher (Eskola & Suoranta, 2001; Flick, 2014). While these methods might be the jack-of-all-trades in social scientific inquiry, the researchers conducting the interviews/workshops must be skilled in reading the interviewees and the development of the dialogue as well as managing the interview situation while following the interview guide and identifying relevant grounded issues (ibid.).

While the results of papers I and II are integrated into the game which communicates them to the player implicitly, the communicative purpose of the game was not to inform the players about the spectrum of measures, outcomes and challenges, but to initiate a dialogue on the complex concepts of adaptation and maladaptation generally. Other studies have developed further informative games on adaptation for assisting in decision-making for practitioners and policy-makers (see e.g. AdaptiveFutures; AgriAdapt; IMPREX). These have, nevertheless, not focused on maladaptation, nor in synthesized knowledge-building.

5 RESULTS

The main findings of this thesis are presented in three sections drawing on the results presented in the four papers. The findings show (i) what type of adaptation measures are considered by the stakeholders in the Nordic agri-food systems (section 5.1), (ii) what constitutes decision-making on the measures at the farm-scale (section 5.2), (iii) what potential unintended outcomes the measures have and how such outcomes are related to farm-scale adaptation decision-making (section 5.3). The key findings of each paper are summarized in Table 6.

Table 6. Key findings of the thesis papers.

	Key findings
I	Results of this study show what type of adaptation measures are planned or implemented at the Nordic farm scale. The key findings are that Nordic farmers are taking initial steps towards decreasing the perceived agri-food systems' vulnerabilities and that the idea of larger scale adaptation measures is recognised while rarely aimed for. The fluctuating policies and markets are a higher priority for farmers to adapt to than the climate impacts.
II	This study identifies the potential maladaptive outcomes linked to adaptation measures that are planned or implemented at the Nordic farm scale. The key findings support the results of earlier studies that mere implementation of adaptation measures and targeting the desired outcomes does not guarantee successful adaptation since there can be maladaptive outcomes for different actors and in further reaching temporal and spatial scales.
III	The results of this study show the type of risk perceptions related to the adaptation decision-making at Nordic farm scale. The key findings are that Nordic farm-scale adaptation mainly reflects emerging processes that are directed at securing the farm economy. The study presents a novel typology of adaptation responses that reflects earlier findings on farm-scale risk aversive and risk-seeking (opportunity-seeking) behavior, and a new approach related to 'innovation farmers' in the adaptation context representing experimental behavior.
IV	The results of this study show how transformations can develop through different adaptation mechanisms that target climate risks through either changing the current practices or tackling structural vulnerability. The key findings are that transformative adaptation in Nordic agri-food systems works in two ways and that both ways might involve severe negative trade-offs as well as several opportunities for various objects related to food production/supply, land use, and biodiversity, and to various actors. The study presents a novel typology of transformative adaptation processes that reflects previous findings on (i) societal climate change responses that lead to fundamental changes in the agri-food systems, and (ii) on farm-scale adaptation that might lead to transformative changes in other domains.

5.1 ADAPTATION MEASURES IN THE NORDIC AGRI-FOOD SYSTEMS

Drawing on findings from paper I and IV, this section presents results regarding the types of adaptation measures that are planned or implemented in Nordic agriculture and food systems. This section responds to the overall research question 1 on what characterizes the agri-food system adaptation measures and their intended outcomes.

Farmers and extension officers assess that most pressing climatic stressors for Nordic agriculture are increased precipitation and temperature, intensified climate variability and winds, and the longer growing season. They are considered to have various indirect effects that are particularly challenging for the protection of water quality, water management at farm scale, field work management, farm economy and crop protection (against increased pest, disease, fungi invasions).

The stakeholders describe the farm scale in particular as sensitive to weather variation and exposed to increased precipitation and temperature, which is considered to increase along with climate change. The measures considered consist of increasing farm economy robustness and field scale water management including drainage and irrigation plans.

Certain growing phases (e.g. harvesting) and important crops are particularly sensitive to climate impacts, such as long periods of excess water on the fields (e.g. barley and broad bean) and to intensive winds (wheat). Technical measures beyond farm scale, such as research and development work on new crops and crop varieties, is thus recognised as important. However, it is seen as too distant temporally to be considered a real option for current adaptation. With an actor-oriented perspective, these types of technical measures are furthermore restricted to actors with access to specific resources (economic or research resources). The findings suggest that measures for capitalizing on climate change in Nordic agriculture are yet few as they represent such transformative changes that are often considered too risky at the farm scale. Some of the stakeholders describe a lack of a broader vision and shattered actor network of Uusimaa agriculture sector as a vulnerability-increasing factor and therefore stress the need for long-term strategic planning together with different stakeholders.

The temporal scale of the measures ranges between rather reactive 'on the spot' measures to progressive long-term transformations. The stakeholders describe measures that are taken in response to weather and climate variations as part of normal farming measures but that are also recognised as measures that might become more frequently necessary in the future. These consist mainly of incremental measures that are directed primarily at reducing the risks or increasing coping capacity. They are mostly described as tactical measures in the rather short term, such as adjustments in sowing times or changes of crops. In general, most prominent farm-scale measures are the longer-term adaptive capacity building measures.

Adaptive capacity building measures are foremost directed at systems scale changes in the agrological and environmental management systems, such as taking up crop rotation, biogas production or irrigation systems. The transformational measures identified in the first round of inquiry (interviews) are directed at a shift of the production to another location or shift of the production orientation i.e. the goal of action consists of changes in the production structure or sector. These are measures that target the underlying causes of vulnerability within the agri-food system context in terms of the analytical framework in paper IV.

The results of paper IV show that measures beyond the agri-food systems could be used to target the underlying causes of vulnerability although these do not explicitly appear on the adaptation agendas of the Nordic agri-food system actors. Implications of general discontent with the current structures are, however, often raised which implies an incentive for measures such as progressive reorganization and expansion of local agri-food system actor networks, or radical reorientation of the discourse on food or agriculture. The temporal scale of these transformative measures is often described as dependent on factors that might either emerge abruptly (e.g. an extreme event that causes a change in perceptions) or progressively (e.g. through generation shift) or on a rather abstract level (e.g. "somewhere in the future").

To illustrate the range of adaptation measures in Nordic agriculture, I synthesize the typologies used in papers I and IV and apply them to a single climatic challenge (increased precipitation) in Table 7. The contextual nature of the responses is prominent even in such a narrow exemplification. For instance, the riverbank buffer zones and wetlands are an agro-environmental policy measure for the protection of water quality in Finland. They also decrease vulnerability for farmers in the event of increased precipitation and subsequential flooding. Furthermore, they could be categorised as 'climate change capitalization' measures. Buffer zone as a new type of 'product' at a farm represents a potentially transformational change in the farm-scale practices. At farm scale, it is primarily applied to reduce the potential economic risks in the event of flooding (when the riverside crop yield would be lost). Creating wetlands is a measure that requires more investment from the farmer and it is expected to pay for itself in the longer run and is thus considered an adaptive capacity building measure. Similarly to buffer zones, it can be a completely novel product of a certain field/plot (ecosystem service) and thus transformational with respect to the adaptation practice, or it can be considered a new way to manage water on a certain field/plot (replacement of an old water management system e.g. drainage) and thus systemic. Moreover, ecosystem services reflect a potential progressive social change where society pays farmers for preserving such valuable common goods as river water quality. The highly localized agri-food systems illustrate a potential way to target the underlying causes of vulnerability that in the radical vision involves detachment from the global food systems and economies.

Table 7. Synthesizing typology on the adaptation measures in the Nordic agri-food systems with illustrative examples on responses that relate to the challenge of excess water (precipitation). (Adapted from papers I and IV; (Few et al., 2017; Rickards & Howden, 2012).

Aim of the measures	**Example**	**Degree of change**
Risk reduction (climate risk targeted instrumentally)	Change crop in the spring (to less vulnerable)	Incremental
	Change to no-tillage practice (to reduce top-soil run-off)	Systemic (change in field-scale nutrient management)
	Introduce buffer zones as new ecosystem services (to reduce the economic risk)	Transformational (change in farming practice)
Increased coping capacity	Subsoil improvement with plough ('subsoiling') the vulnerable fields (to increase coping with excess water and drought)	Incremental
Increased adaptive capacity	Maintenance of sub-soil drainage	Incremental
	Build wetlands (water management)	Systemic
	Build wetlands (new ecosystem service)	Transformational (change of goal)
Climate change capitalization	Drainage water usage for irrigation	Incremental
	Ecosystems services	Systemic/transformational
Social change (vulnerability targeted progressively)	Ecosystem services	Transformative (social change)
Social change (vulnerability targeted radically)	Localized agri-food systems	Transformative (social change)

At actor level, these measures are focused on the farmer who is often the decision-maker on whether or not to take the adaptation measure, and what type of measure to take up, and whether to co-operate. With the government/ EU subsidized measures, such as some of the ecosystem services, the state as a provider of the economic subsidy plays a major role in enabling the potentially costly measures. With farm-scale measures that require specific tools or machinery, such as no-tillage, subsoiling, sub-drainage and wetlands, the farmers are often dependent on the expert advice and practical work of contractors or advisors. Neighbouring farms and farmer colleagues from e.g. production organisations are important for gaining knowledge of new measures and sharing it. Similarly, regarding the measures that aim for

societal change, the local actor networks are considered important in enabling such adaptation efforts.

5.2 ADAPTATION DECISION-MAKING

This section draws on the findings on non-climatic stressors, risk perceptions (paper III) and on the transformative adaptation activity spaces (IV) as it sets to answer the overall research question 2, 'what constitutes adaptation decision-making at farm-scale'. The impacts of market and policies on the decision-making in agri-food systems are seen as the main non-climatic stressors.

The stakeholders often view changes in global agri-food markets and in agricultural policies as unexpected, and this increases the general uncertainty around production. While adaptation is not always recognised or considered a separate field of governance by the stakeholders, an analogue between it and the environmental policies in agriculture is often drawn. That is, climate policy frameworks at national and EU levels are streamlined to sectoral policies both at the national and EU level (CAP). Moreover, stakeholders recognise other policy instruments that may involve synergies with adaptation, as described regarding the agro-environmental water protection measures in the previous section (5.1). Furthermore, mitigation policies are frequently raised by the stakeholders in terms of expected changes that require adaptation, such as animal production decline, changes in forestry and land use, and energy transition. In this perspective, adaptation is seen rather as a liability related to the mitigation policies and not as a response that aims for decreased vulnerability to climate change *per se*.

Dealing with policies and legislations is generally considered one of the most prominent disincentives for adaptation at farm scale. Nevertheless, the subsidized environmental measures also work as an incentive for farmers to cultivate new plants that have a positive effect on soil quality and this has encouraged farmers to try new types of plants.

Both the non-climatic and the climatic stressors and the related indirect impacts that challenge the Nordic agriculture, as presented previously (section 5.1), are highly contextual. The following excerpt exemplifies how the perceived vulnerability directs the choice of the measure.

> *I believe that this trend of having periods of cloudburst versus drought will increase and the same as with drainage, we must upgrade the systems and I have even thought of building a dam down here but I thought that the price scared me a little bit too much.*
>
> *(Farmer, Paper I)*

Adaptation at farm scale is not a simple response to a certain impact, such as excess precipitation, since the subjective/contextual factors play an

important role in how vulnerability is perceived. This can result in objectively irrational choices. The findings suggest that social relationships, experience, and perceived expertise are involved with the perceived self-efficacy in managing adaptation and the efficacy of the measures. For example, several stakeholders described how their relationship with the landowner sets certain limits to adaptation measures. The risk of losing the rent contract on the fields (which are generally very short, approx. 5 years in Finland) prevents them from taking field-scale adaptive capacity building measures that pay back in the long-term.

The results in paper III show that the intentions to apply adaptation measures on the Nordic farm scale can be divided into three main types of responses to the climatic and non-climatic stressors (careful, opportunity-seeking and experimental). These response types demonstrate logic models in the decision-making situation that can overlap and change over time. The careful (risk aversive) approach primarily aims at reducing risks with minimum costs or sticking to old routines, while the opportunity-seeking approach is focused on increasing profit in terms of adaptation. The opportunity-seeking risk response involves measures for capitalizing on climate change directly or indirectly through vulnerability reduction measures in a profitable way that may also involve risks. The experimental risk response type considers climate change as the new normal which calls for novel solutions and actively participates in finding them, for example, through innovative mechanisms which are regarded as a feature of transformative adaptation.

The results in paper IV show that there are complex interactions between different actors with various intentions, capabilities and tools for transformative adaptation measures in agri-food systems. The findings suggest that transformative adaptation in Nordic agri-food systems can derive from the perceived inadequacy of the current measures to secure livelihoods, as well as from various changes in the public discourse, attempts to avoid environmental tipping points, the development of equally accessible technologies, and the behavioral changes. As these findings move away slightly from the main framing of this thesis, an illustrative synthesis of the results of the transformational shift of production orientation from animal husbandry to crop farming is presented (Fig. 3).

The example draws on the stakeholder dialogues on pressures at farm scale to give up animal husbandry as an adaptation measure directed at risk reduction. As the foci of this thesis is on crop farming, the challenges in animal husbandry are presented only cursorily (as a potential driver for change).

Nordic animal farms experience challenges posed by climatic stressors. These reduce animal drinking water and forage availability, and increase vector-transmitted diseases and heat-related health problems for animal farming (AgriAdapt, 2019). The economic risks include potential production losses, decreased subsidies, and the lowered product demand and prices. The

example (see Fig. 3) reflects the general findings of this thesis, i.e. that the main activity space of farm-scale measures is 'livelihood' i.e. how the farmer views the necessary adaptation measures in terms of their livelihood. The environment as an activity space for transformative adaptation is often considered a limiting factor to most harmful practices subsequent to certain environmental tipping-points. These may shift the priorities through institutional power (restrictions, incentives). Public discourse as an adaptation activity space in this example involves the emergence of public discussion on the negative climate impacts of animal husbandry and animal-based diets (and the positive impacts of crop-based agriculture and plant-based diets). This constrains the producers to change their production orientation. Similarly, the public institutional support for crop-based agriculture could become more voluminous and less supportive of animal husbandry practices that have the largest climatic impact.

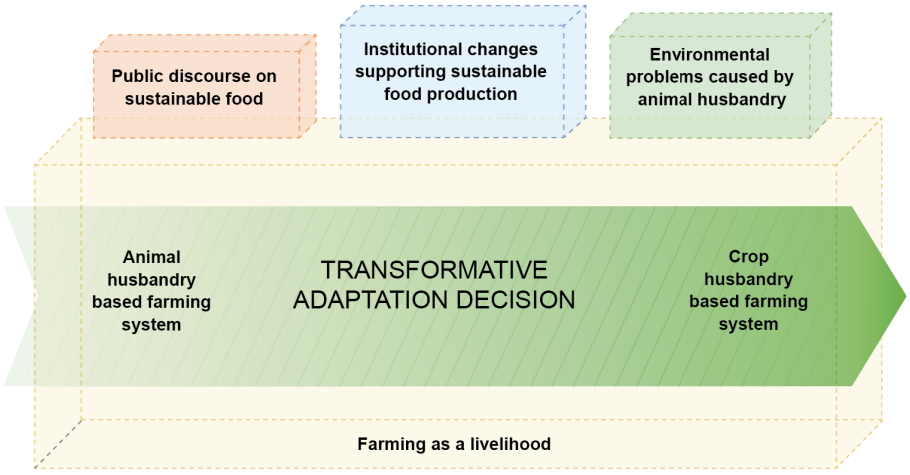

Figure 3. An illustrative example of adaptation decision-making constrains involved in the transformative change process from animal husbandry to crop farming based system applying the 'adaptation activity spaces' concept presented by Few et al., (2017).

5.3 UNINTENDED NEGATIVE OUTCOMES

This section responds to the overall research question 1 on the subject of the potential negative outcomes of adaptation measures in agri-food system context (paper II). This section also contributes to research question 2 with respect to what adaptation decision-making *does not* consists of, drawing on papers III and IV. Empirical evidence of maladaptation is based on the

stakeholder consultations as well as a literature review[6] on the potential risks and single observations or case descriptions. The results show that maladaptation is relevant to all types of adaptation measures and decision-making.

The most prominent maladaptive outcomes discussed by the stakeholders are the increased costs or economic losses that are often unintended but not unexpected, such as investment in new machinery or other equipment, pesticides, or new fields. Implementation of new measures or new crops can present novel management challenges and risks for the farmer (Himanen et al., 2016) and novel technical solutions can furthermore increase energy costs and cause a buy-in to the technology (Williams et al., 2010). These types of maladaptive outcomes that rebound the vulnerability of the implementing actor (mainly the farmer) are primarily not harmful to others. Many of the identified rebound effects nevertheless also partially shift vulnerability to others. For example, the increased beneficial climatic conditions and introduction of new crops, such as maize and (other) energy crops, can increase the risk of pest invasions and alien invasive species (Ministry of Agriculture and Forestry, 2014) which, in turn, can result in increased need for pest control that typically involves increased heavy machinery work on the fields. On the one hand, increased use of chemical pesticides as pest management strategy can lead to increased costs for the farmer, as well as shift the vulnerability to other farmers through increased risk of pests developing immunity to pesticides, and a risk to the consumers by decreased quality of food (Kvalvik et al., 2011; Wivstad, 2010). Tillage as the mechanic pest control strategy widely applied in organic farming, on the other hand, can increase the risk of nutrient run off and soil erosion. Indeed, many of the identified measures that involved increased heavy machinery work on the fields (chemical pest control, tillage, subsoil improvement with plough) can result in packed soil that damages the production conditions. This is harmful for the farmer and the landowner (Jordbruksverket, 2013; Uleberg et al., 2014).

Maladaptation that involves shift of vulnerability to other actors and sectors is particularly prominent in terms of conflicts in resource use and management practices. These and conflicts related to other infrastructure are furthermore raised in literature as potential challenges for local policies and communal organisations (Sairinen et al., 2010). The expected seasonal increase in the need for irrigation in the study sites can result in conflicts between different users, including the civil infrastructure (Bastviken et al., 2015; Länsstyrelsen Skåne, 2014; Noreen et al., 2017). Managing groundwater, irrigation, floodwaters and drainage in general, as well as pest and weed management, are all practices that are discussed by the stakeholders and mentioned in the literature to involve potential risks of shift of vulnerabilities to others (ibid.; Stenrød et al., 2016; Wivstad, 2010). For

[6] References to the reviewed literature are used in this section to highlight the results that draw from that material.

example, stakeholders raised the issue of chemical pest management strategy. One farm can make organic pest management impossible at a neighboring farm, particularly as a result of intensified winds that can increase challenges with timely chemical pest management in the study sites.

The common pool maladaptive outcomes identified in this thesis are related to many of the above-mentioned outcomes that involve a shift in vulnerability. They also have negative impacts on the environment (e.g. nutrient leakages, pesticide spills) or natural resources (e.g. arable land depletion), and involve issues of social inequity both in the Nordic society and globally (i.e. transboundary impacts). Soil quality issues are generally related to soil compaction, erosion and loss of soil organic matter. For example, participants frequently mentioned that arable lands are a globally scarce resource and that measures which result in decreased soil quality are thus harmful for society more broadly. Soil organic matter depletion is furthermore related to decreased nutrient retention and increased greenhouse gas emissions from the soil (e.g. Corsi et al., 2012; Qin et al., 2016).

Most of the common and novel water management practices (irrigation, drainage, subsoil improvement with plough, wetlands, etc.) are considered by the stakeholders to involve potential risk of nutrient leakages, which is supported by the literature (Aura et al., 2006; Fogelfors et al., 2009; Jeppesen et al., 2011). Nutrient leakage is also related to the increased use of fertilisers and fertiliser-intensive crops (Fogelfors et al., 2009; Leip et al., 2008) as a strategy to take advantage of the enhanced production conditions or to cope with nutrient leakage in the first place (Eckersten et al., 2012). Furthermore, transboundary impacts are related to measures that increase the demand for fertilizer production. This can contribute to the depletion of finite resources, such as phosphorus (Neset & Cordell, 2012), and the emissions from their production and transportation.

With all these measures that are common in agriculture and involve potential maladaptive outcomes, the stakeholders highlight that it is not always the measure *per se*, but how it is applied in the novel climatic context that can lead to potentially harmful outcomes. Successful application of adaptation measures, such as no-tillage, subsoil improvement with plough and crop-rotation, in particular, are seen to require skills that might take years to learn in practice. During this learning process, maladaptive outcomes may occur. For example, many of the measures involve antagonistic effects for mitigation through an increased need for driving on fields which produces green-house gas emissions directly (and through soil depletion, see above).

The findings on agri-food maladaptation decision-making show that unintended, as well as intended, outcomes are highly contextual. For instance, a rebound effect from the farmer's perspective, such as soil quality loss, can be considered a shift in vulnerability to the coming generations who are challenged by a lack of arable lands.

The findings on risk perceptions and adaptation decision-making at farm scale (paper III) show that the identified risk response types (careful,

opportunity-seeking, experimental) relate to different types of processes with harmful unintended outcomes. The careful approach may involve unwillingness to take measures that involve novel risks to the farm, such as economic investments, and thus result in inadequate adaptation measures. The opportunity-seeking approach may involve a focus on short-term profits e.g. with new crops that results in trade-offs with elements of long-term adaptive capacity building, such as soil quality. Opportunity-seeking approaches may involve what is described by some stakeholders as "subsidy driven" decision-making that is criticized for stepping away from what is considered good farming skills and practices (maintain good soil quality, provide food). Some farmers claim that, in order to maintain the economic viability of their farm, they are bound to utilize subsidies and, accordingly, implement such farming measures that do not represent good farming skills or practices. Last, the maladaptive outcomes related to the experimental approach on climate related risks involve the potential of unexpected failure and harmful outcomes of the experimental/ innovative measures.

The adaptation pathway model that was applied in paper II to categorise the identified maladaptive outcomes is used in Fig. 4 to exemplify how maladaptation can occur within the Nordic farm-based adaptation context. The figure illustrates the complexity involved in the three different measures that are all relevant at the Nordic farm scale and often discussed by the stakeholders. Example (a) shows how a simple reactive measure to reduce risks caused by heavy rain can involve weighting of outcomes to the soil structure, farm economy, machinery, and pest and weed resilience in the following season. While a farmer would implement this measure with the intention of minimising the overall harmful outcomes, certain trade-offs need to be accepted and, furthermore, some unexpected outcomes can occur. Example (b) illustrates the systemic changes in excess water management, which is generally considered to increase adaptive capacity of the farm. These changes can result in negative outcomes to the farm economy, neighbouring farms and the environment. The vulnerability shifting features of the measure and the potential environmental degradation related to it are not often considered in agri-food systems. The example (c) shows how the transformative measure of giving up animal husbandry is considered to involve mainly harmful outcomes to the farmer. These are acknowledged at the farm scale and strategies to tackle them are usually prepared, while uncertainty related to these involves an element of unexpectedness.

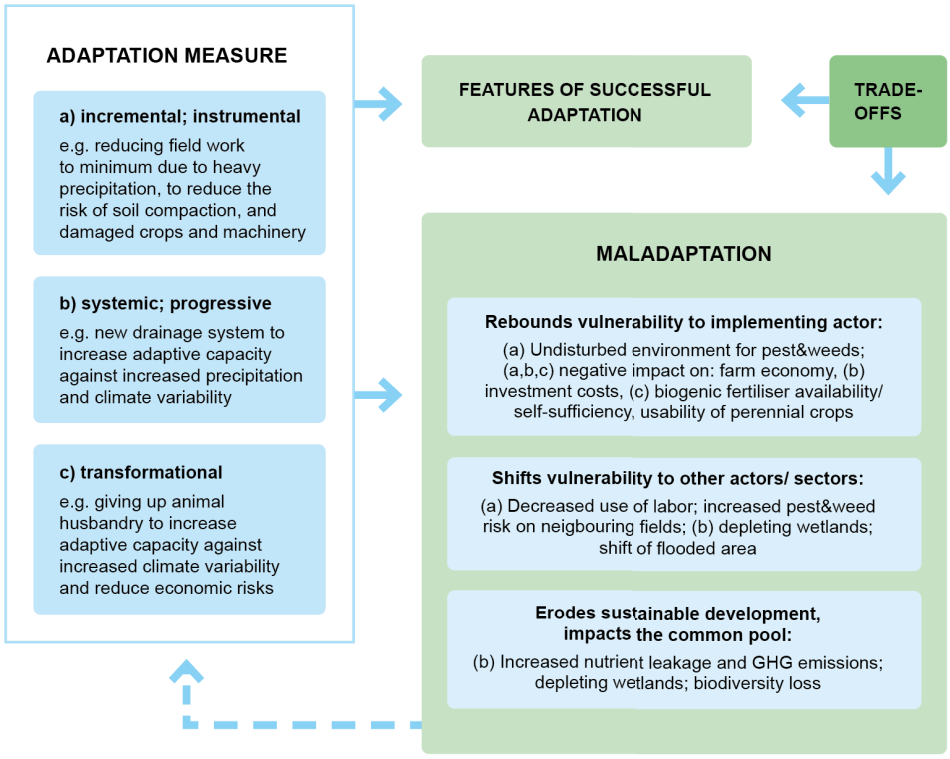

Figure 4. Maladaptation involved with farm-scale adaptation measures based on the frameworks of adaptation aims by Rickards and Howden (2012) and by Few et al. (2017); the maladaptation conceptualization by Juhola et al. (2016) and the successful adaptation indicators by Magnan et al. (2016).

6 DISCUSSION

This thesis sets out to contribute to the understanding of adaptation-related trade-offs. It supports earlier theories and empirical findings to broaden the understanding of individual adaptation decision-making within socio-environmental contexts. The findings of this thesis show how climate change adaptation is addressed in farm management and what type of adaptation outcomes are expected in the agri-food systems. The results of farm-scale adaptation measures, decision-making and maladaptation in the Nordic context address the knowledge gap on the complex relations between the adaptation needs, options and outcomes in the agricultural sector.

6.1 ADAPTATION MEASURES AND THEIR OUTCOMES IN THE AGRI-FOOD SYSTEMS

In response to the research question 1 of this thesis, 'what characterizes adaptation measures and their outcomes in agri-food systems', the results show a wide range of farm-scale adaptation measures with different aims and degrees related to different agri-food systems and society more broadly. The results bring an empirical contribution to support previous findings on agri-food system measures in the Northern European context (Bindi & Olesen, 2011; Jørgensen & Termansen, 2016; Uleberg et al., 2014; Wiréhn, 2018; Wiréhn et al., 2020) and other agricultural regions globally that feature similar socio-economic production conditions (mainly Australia) (Dowd et al., 2014; Howden et al., 2010; Jakku et al., 2016; Rickards & Howden, 2012). While the results reflect previous findings of agri-food system measures and potential outcomes, they present a novel synthesis on adaptation in the Nordic agricultural sector. The results introduce the stakeholder knowledge and draws together the current literature on maladaptive outcomes in Nordic context. Moreover, the novel application of several typologies links the measures more systemically to the potential outcomes (aims, degree of change, maladaptation).

The findings of this thesis are in line with previous empirical studies in agri-food system contexts (Albizua et al., 2019; Antwi-Agyei et al., 2018; Chelleri et al., 2016; Dube et al., 2018; Guodaar et al., 2020) and the theoretical understanding that mere implementation of the measures and targeting the desired outcomes does not qualify as successful adaptation, suggesting that the potential maladaptive outcomes are an important characteristic feature of adaptation measures (Adger et al., 2005; Juhola et al., 2016; Magnan et al., 2016; Morgan et al., 2019).

The results show that some trade-offs related to adaptation measures involve negative impacts on the environment, other sectors and actors. This

implies a conflict with sustainable development goals set out in the policy framework for adaptation in the agricultural sector in the EU (EEA/Blaz Kurnik, 2019) related to the Sustainable Development Goals set in the Agenda 2030, such as reducing hunger, supporting small-scale farmers and ecologically sustainable agricultural production, which are supposed to be streamlined with adaptation.

The theoretical take on assessing the features of potential transformative adaptation, i.e. mechanisms, objects and aims of change (Few et al., 2017) from the stakeholder perspective, shows two types of potential transformation processes that contribute to the gap in empirical studies on transformative adaptation in agricultural systems (Panda, 2018). On the one hand, transformative changes in society as a result of climate change can fundamentally shape the context of agri-food production, leading to transformative changes in production (Otsuyama et al., 2019). On the other hand, adaptation implemented at farm scale with the intention to target climate risks through either changing the current practices or tackling structural vulnerability can lead to further reaching transformative changes. Both processes involve negative trade-offs, as well as opportunities in food production and supply and biodiversity in the Nordic context.

The recently published 'sustainable adaptation' guidelines and manual for European agriculture (AgriAdapt, 2019) suggests that the Northern European agricultural region (a climate risk zone consisting of Finland, Sweden and the Baltic region) benefits most from extensification of the farming systems. This is also identified in this thesis as a potential progressive transformative adaptation in the Nordic context.

There is also a vast collection of studies promoting 'eco-technologies' and ecosystem-based approaches in adaptation (Few et al., 2017; Jones et al., 2012) that are in line with the principles of 'sustainable adaptation' that stresses the integration of adaptation management and planning with the sustainable development goals (Dube et al., 2018; Santhia et al., 2018). This is similar to how the intensification of agriculture is streamlined with the goals set for ecological sustainability in the 'ecological intensification' concept (see e.g. Koppelmäki et al., 2019). The application of such measures shows several opportunities, whilst the potential trade-offs related to the increased use of inputs, decreased food production and greenhouse gas emissions (see Koppelmäki et al., 2019; Purola et al., 2018) call for further research to advance their wider application and, arguably, for policy support.

From another perspective, the rising trend of intensification, currently supported by economic markets, can be seen as a response to the general uncertainty about the economic viability affected by climate change (see e.g. Bindi & Olesen, 2011; Jørgen E. Olesen & Bindi, 2002). It should be noted that the few historical analogies that can be drawn on transformative adaptation in the land-use sector and in agriculture particularly involve maladaptive outcomes of intensification due to top-down decision-making that excludes the local people (see Parsons & Nalau 2016). Furthermore, the contemporary

challenges related to intensification, most importantly the significant environmental distress and social inequity, should be acknowledged (Bindi and Olesen, 2011; Olesen & Bindi, 2002).

6.2 ADAPTATION DECISION-MAKING AT FARM SCALE

In response to research question 2 of this thesis, 'what constitutes adaptation decision-making at farm scale', the results show that farm-scale adaptation relates to different types of risk responses, supporting earlier studies which showed that adaptation decision-making at farm-scale is highly contextual and dynamic (Le Dang et al., 2014a; Singh et al., 2016; Takahashi et al., 2016). Key findings support previous studies that there are numerous and complex societal factors that affect the farmer's adaptation decision-making and actualisation of the aimed changes (Feola et al., 2015; Few et al., 2017). Results of transformative adaptation show that adaptation decision-making on measures that may lead to transformative changes is related to the socio-environmental context of adaptation in a highly complex way. This finding is in line with recent studies (e.g. Wilson et al., 2020).

Whilst the adaptation policy field is developing (see e.g. Aguiar et al., 2018; Juhola, 2019; Massey & Huitema, 2016), agricultural adaptation policies that were in place during the time of material collection of this study were few and not directed at farm scale on the study sites. The results of this thesis show that farmers recognise risks to farm and agriculture related to climate change, and that they are capable of adapting to various climatic conditions despite the lack of guiding policies while, in many ways, the measures are limited and inconsistent. In their recent study, Puupponen et al. (2015) draw similar conclusions regarding the adaptive capacity of Finnish farmers and point out that this might undermine the acceptability of adaptation policies among farmers. Although adaptation is often described as a rational and consistent deliberative process (Biesbroek et al., 2015; Gillard et al., 2016; Holman et al., 2019), this thesis shows that Nordic agricultural adaptation is based on rather emergent decisions at farms. These decisions are made with the options 'at hand' to support the general farm management and securing the farm economy.

Farmers, on one hand, are often valued as experts in adapting to varying weather conditions, which is seen one of the core skills of their profession. On the other hand, the capacities of individuals are not necessarily an indicator of adaptation action (see e.g. Wamsler & Brink, 2015), and the skills of farmers do not necessarily translate into adaptation measures at farm scale (Findlater et al., 2018a). The findings of this thesis, as shown by previous studies, point towards inconsistencies between the adaptation needs and the actions due to, for example, perceptions of the role of policies, markets, temporal scale of measures, and the success of these measures (Abid et al., 2016; Arbuckle et al.,

2015; Gebrehiwot and Van Der Veen, 2015; Keshavarz and Karami, 2014; Mase et al., 2017; Puupponen et al., 2015; Takahashi et al., 2016).

The findings confirm that, in the Nordic region, challenges rising from policies and financial markets are more likely to drive farmers to adaptation measures than climatic stressors as suggested in previous studies (Asplund, 2016; Himanen et al., 2016; Kvalvik et al., 2011; Puupponen et al., 2015; Smit and Skinner, 2002). The results show that the stakeholders' view of climate impacts is similar to the general scientific understanding of them. However, climatic stressors are considered either so distant that they do not raise intentions to adapt, or they are perceived somewhat manageable with familiar measures that more or less exclude transformative measures. In line with previous studies, the findings suggest that the employment of transformative adaptation measures in the agri-food systems (e.g. change production orientation) by private actors would require different type of institutional support than what is sufficient for incremental adaptation measures (e.g. climate service to support adjusting field management measures) (Jakku et al., 2016; Park et al., 2012).

Nordic stakeholders prefer measures that serve other purposes than climate change adaptation at the farm management frequently labelled as 'no regret' measures (see e.g, George et al., 2019). The necessary measures and information to support adaptation in the Nordic context are not always equally available or applicable to all farms due to the contextual and socio-economic factors (Jørgensen and Termansen, 2016). The accessibility issue due to socio-economic factors has been previously raised with respect to lower income regions of the world (Brown et al., 2018; Comoé et al., 2014; Le Dang et al., 2014b).

The findings on risk response types relates to what recent studies suggest (Findlater et al., 2018b; Neset et al., 2019a) about the use of several different framings i.e. mental models of adaptation at farm scale. Here, these mental models reflect three main types of responses to adaptation, i.e. careful that aims to avoid risk, opportunity-seeking that may embrace risks, and experimental that approaches the risk in a rather neutral way and focuses on finding new ways to manage them. On the one hand, the results show emergent and primarily incremental adaptation measures that respond to the market and policy fluctuations, not climatic stressors. This is similar to what Findlater et al. (2018) present on the survival framing of adaptation at farm scale, suggesting that such framings may remain unnoticed in the studies that dominate the field, such as economic models. On the other hand, this thesis identifies discontent over the current structures and practices that create vulnerability, as well as innovation potential to tackle the perceived challenges.

6.3 FUTURE CONSIDERATIONS

This thesis has focused on examining particular processes in specific cases. The focus of further studies should be the inclusion of a broader empirical and geographical scope. Furthermore, the key limitations of this thesis and topics and approaches not included in this study could be considered in future studies.

This thesis contributes to the understanding of a topic that is yet little studied. A gap in empirical studies was impassable and a collection of novel empirical material was thus considered as a necessity. The material collection was conducted based on proxies/indicators for what was considered to represent the nature of adaptation measures and decision-making, i.e. approaches to weather variation, extremes and risks generally. The maladaptive outcomes, for example, were identified mainly from implicit descriptions related to possible negative effects of adaptation. This is due to the fact that most adaptation policies and measures are still at a planning stage or only recently implemented. More importantly, adaptation assessment is at its infancy and the monitoring and evaluation frameworks are currently being developed in the EU. Assessment reports based on quantifiable indicators will provide relevant study material for future attempts to complement stakeholder testimonies, as used in this thesis.

Perceptions of the Swedish-Finnish participants, the farmers and other experts were not compared in this thesis, but treated as equal statements of the complex reality of adaptation in Nordic agri-food systems. Studies with a different focus can be useful in identifying and assessing, for example, obstacles of adaptation (e.g. Eitzinger et al., 2018).

This study has captured aspects of processes that may be incorporated into further studies on agri-food system adaptation and transformation with other types of approaches. Scenario-thinking is generally considered to fit future-oriented climate change adaptation governance research that takes into consideration the 'wicked' nature of adaptation governance field (Rickards et al., 2014). Following the systemic application of mental models in risk management by Parviainen, Lehikoinen, Kuikka, and Haapasaari (2019), mapping the dynamic adaptation decision-making context with different stakeholders to assess the field of adaptation governance in vital sectors could also be considered in future studies. Similar calls for tools for studying the complex transformative adaptation decision-making context have been made (Cradock-Henry et al., 2019).

Parsons and Nalau (2016) suggest historical foci on transformative changes in order to understand the current climate-related change processes and stress the need to understand how vulnerability shapes the process and what risks are related to the irreversible changes. While keeping an eye on the risk of anachronism, the historical analogy approach was found useful in the material collection of this thesis at an anecdotal level. It could provide a novel perspective to the adaptation related trade-offs. Parsons and Nalau (2016)

suggest place-specific historical analyses to understand the long-term causes of vulnerability. Moreover, Adamson, Hannaford, and Rohland (2018) stress the need for 'second order observation' on adaptation research from the perspective of historians to ensure that the adaptation policy recommendations are not mere representations of historical power structures. To avoid the redistribution of vulnerability in the governance of adaptation processes altogether, there is a need for research that, in particular, addresses the already marginalised and vulnerable (Atteridge & Remling, 2018). This could include the use of (systemic) participatory approaches that embrace the heterogeneity of actors (Schlosberg et al., 2017). Such approaches have been used to understand the adaptation needs (Ross et al., 2015) and provide novel knowledge to inform adaptation decision-making (Olazabal et al., 2018). Research on the role of farm workers in adaptation planning and decision-making is mainly focused on low-income countries while recent studies have raised the importance of the issue in relation to the socio-economic impacts in high-income regions (e.g. Greene, 2018).

The findings of this thesis show that maladaptation is recognised to an extent, whilst it is not considered a topical concern in the Nordic agri-food systems where adaptation has only recently started to gain recognition. The results provide limited examples of the most complex adaptation processes that involve maladaptive outcomes. A recent assessment of the trade-offs in Nordic agricultural adaptation by Wiréhn et al. (2020) contributes to this gap by showing numerous examples of complex and systemic interactions that relate to different socio-ecological aspects – most importantly to water management, soil structure, and farm economy – and how the complexity of adaptation decision-making increases with the number of aspects involved. The analytical framework for assessing, comparing and mapping trade-off structures in agri-food systems presented in Wiréhn et al. (2020) could be used in further studies with specific foci on the most complex and severe maladaptation, for instance, related to chemical pest control. Chemical pest control is one of the most obvious and accessible adaptation measures to farmers, as this thesis and recent studies show (e.g. Ramborun et al., 2020), while it involves several maladaptive outcomes and is a particularly persistent technology (Cowan & Gunby, 1996).

The scope of this thesis was narrowed to identify adaptation measures and maladaptive outcomes in the Nordic context and thus excluded the global scale that was addressed in the workshops. Related to these, recent studies have raised, for example, such important issues as the sectoral EU-level maladaptation (Papadimitriou et al., 2019), and issues related to transboundary adaptation measures globally (Benzie et al., 2018; Olmstead, 2014), as well as the sectoral trade-offs in Europe (Papadimitriou et al., 2019), and the comprehensive sustainability assessment of the Nordic agri-food systems (Tälle et al., 2019).

The stakeholder-oriented approach integrated with a novel analytical application of several theoretical/conceptual frameworks in this thesis enabled a grasp of the complex reality of adaptation processes in the case sites. The findings are in line with recent studies (Cradock-Henry et al., 2019) with regards to the systemic approaches on thematising the perceived stressors. This contribute to the understanding of the decision-making constraints and expectations at the adaptation practitioner level in a way that responds to the need to integrate social scientific knowledge to systemic assessment of adaptation (Adger et al., 2018; Holman et al., 2019; Jurgilevich et al., 2017).

The analytical frameworks applied in the papers may be applicable in studying maladaptation (II), risk perceptions (III), and transformative adaptation (IV) within other domains also. The conceptual framework of maladaptation applied in this thesis (paper II) allows an actor-oriented assessment of the adaptation measures and outcomes. The application of the maladaptation framework shows how this type of assessment opens up opportunities to study and understand trade-offs, for instance, between the different policy goals and actors. Findings of this thesis show that the processes of transformative adaptation can be approached with the integrated assessment of the interactions within and between the different activity spaces where adaptation measures are implemented by actors with varying intentions, aims, and tools.

However, such an integrative approach is challenging as it balances between the epistemological and ontological pluralism that, in the worst case, hinders the understanding of the study topic and disables sound policy support (Biesbroek et al., 2015; Feola, 2015). The challenge of adaptation as a 'wicked' problem calls for focused attention from researchers on adaptive and reflexive governance (Hurlbert & Gupta, 2016; Juhola, 2019).

Top-down state-led adaptation governance in agriculture (through formal institutional mechanisms, such as CAP, NAP) in the study sites leans on the scientifically relevant national guidelines and common global commitments. The knowledge this thesis provides to support adaptation decision-making is directed at the development of governance approaches and the findings generally inform these actors of the perceptions of professionals of the sector, providing an objective bottom-up 'stream'. In particular, the novel findings can support decision-makers in identifying and assessing the complexity of farm-scale risk perceptions in comparison to the often-simplified risk characterizations, such as probabilistic risk theories.

7 CONCLUSIONS

This thesis sets out to increase understanding of climate change adaptation-related trade-offs and adaptation decision-making within complex socio-environmental contexts. The results contribute to literature on farm-scale climate change adaptation and adaptation outcomes within the Nordic agricultural sector.

The context of agriculture and food production is complex due to constant societal and environmental changes. The gravity of climate change related risks to global agricultural and food production emphasizes the need for transformative adaptation measures in Northern European agri-food systems. Findings of this thesis show that such transformative measures in the Nordic agri-food systems are possible whilst currently not aimed for at the farm scale.

The results show that Nordic farmers are willing to apply adaptation measures, when they also serve other purposes than climate change adaptation at the farm. These are frequently referred to as 'no regret' measures. Furthermore, results show that farm-scale responses to climate-related risks reflect distinct behavioural patterns that correlate with subjective and contextual features of vulnerability and adaptive capacity. These findings suggest that the advancement of adaptation measure implementation in Nordic agriculture in line with the national adaptation policies requires that the policy implementers pay attention to the farm-scale perceptions of adaptation needs and options. To advance transformative measures, these findings suggest a need for governance interventions.

Moreover, the results clearly show that all types of agri-food system adaption measures involve trade-offs and can lead to unintentional maladaptive outcomes. These may be disadvantageous to the implementing actors, others or the common pool of resources. Such outcomes are not acknowledged nor addressed in farm-scale adaptation decision-making. This suggests a need for re-evaluation of the concept 'no-regret' measure and similar. More importantly, these findings indicate that to advance adaptation in line with the Agenda 2030 Sustainable Development Goals and to ensure sustainable climate change adaptation in Nordic agriculture, practitioners and policy-makers need to understand and address the trade-offs and potential maladaptive outcomes of the planned measures, preferably proactively.

Climate change adaptation offers a chance to change practices to enable transformations towards sustainability. However, it involves risks that are not currently integrated in adaptation planning and management. Findings support previous theories on the 'wicked' nature of adaptation as a governance issue. Static and general top-down prescriptions do not fit to the complex reality of adaptation in agriculture that involve a heterogenous group of actors. This highlights a need to complement the current top-down state-led adaptation measures in agriculture with bottom-up measures by different

agri-food system actors and social-scientific research. This thesis supports the previously recognised need to advance science-policy-practice dialogues to facilitate concerted efforts towards sustainable adaption in agriculture, in line with national and international policy goals.

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