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Integrated framework for identifying transformative adaptation in agri-food systems

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Abstract

Climate change adaptation measures and practices may induce fundamental changes i.e. transformations in socio-ecological systems. Adaptation that intentionally aims for transformation is often intended to increase benefits and synergies with other broader societal development goals such as sustainability. Adaptation measures also have possible unintended negative effects that, in the case of system transformations, may be difficult to reverse. This study seeks to identify characteristic features of the adaptation processes that may result in agri-food system transformations. We introduce an integrated framework to identify these features and 'adaptation activity spaces', and apply this framework to the Nordic context, analysing stakeholder interviews that integrated serious gaming. The results show how transformations may result from adaptation measures targeted towards climate risks with an objective of changing either current practices or surrounding supportive structures. This study addresses reasons why transformative adaptation is not occurring in Nordic agri-food systems and presents novel information that may contribute to policymaking and further research needs on transformations in relation to adaptation decision-making.

Keywords: climate change adaptation; agriculture; transformation; adaptation measures

1 Introduction

Transformations towards sustainable agricultural and food systems (agri-food systems) is one of the most important challenges of our times (Campanhola and Pandey, 2019a, 2019b). Securing food production under climate change is expected to require societal responses involving fundamental changes in agri-food systems (Anwar et al., 2013; El Bilali, 2019). As a deliberate societal response to climate change, adaptation has been described as an opportunity to shift towards more sustainable practices in agri-food systems (e.g. Fedele et al., 2019; Loboguerrero et al., 2018), along with reconstructing harmful power relations that create or sustain vulnerability (Gillard et al., 2016). The Intergovernmental Panel on Climate Change (IPCC) and the United Nations' Food and Agricultural Organisation (FAO) both emphasize the need for deliberate transformative systemic changes integrated with the sustainable development goals in instances when incremental adaptation is insufficient (Campanhola and Pandey, 2019a, 2019b; de Coninck et al., 2018). Such transformative adaptation refers to fundamental changes in, for example, production systems or societal structures, as opposed to incremental changes in existing structures (Few et al., 2017; Panda, 2018; Wilson et al., 2020).

Overall, transformation has more often been applied as a metaphor than as a rigorously defined analytical concept (Feola, 2015) and "transformative adaptation is rarely considered in adaptation projects, plans or policies to reduce the impacts of climate change" (Fedele et al., 2019, 117). Theoretical *ex ante* studies have described and prescribed needs and opportunities of transformative adaption in agri-food systems (see e.g. Few et al., 2017; Rickards and Howden, 2012), whereas empirical studies show little evidence of transformations occurring, and even less evidence that these ensure better outcomes (Panda, 2018; Salomaa and Juhola, 2020; Vermeulen et al., 2018). Trade-offs and negative externalities regarding food security, social justice (e.g. Feola, 2015; Schlosberg, Collins, and Niemeyer, 2017), and the environment (e.g. Ghahramani and Bowran, 2018; Vermeulen et al., 2018) are identified in studies of current and anticipated shifts, along with historical analogies (e.g. Kates, 2000; Parsons and Nalau, 2016). However, a number of studies that employ social aspect/s of adaptation, 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 adaptation. These studies bring forth the heterogeneity of agri-food system actors that may have interest in and/or capacity to implement transformative adaptation, and thus present new points of departure for empirical assessments, as well as to identify additional knowledge gaps.

An understanding of transformative adaptation decision-making processes is essential for identifying any potential outcomes and considering compatible policies (Blythe et al., 2018; Gillard et al., 2016; Wilson et al., 2020). Several recent studies argue for interdisciplinary and pluralistic approaches in studies on transformation, to complement the currently dominant focus on systems based technical problem-solving with social science (Blythe et al., 2018; Feola, 2015; Gillard et al., 2016; Thompson and Scoones, 2009). Some have suggested 'activity spaces' to conceptualize the dynamic decision-making context for transformative adaptation in socio-ecological systems (e.g. Gillard et al., 2016; Pelling et al., 2015). The activity space concept considers the actors and the structural context of adaptation in an integrated way. Additionally, we call for a closer look at transformative adaptation measures and their outcomes and how these are considered in adaptation decision-making. While adaptation decision-making is frequently deliberate, we argue that an identification of adaptation measures that involve transformative features may strengthen the analytical value for the concept of 'transformation' in adaptation studies. Moreover, such identification could contribute to increased understanding of the related benefits for socio-ecological systems, along with unexpected negative outcomes that may be difficult or impossible to revert.

In this study, we assess features of transformative adaptation in adaptation measures (Few et al., 2017) in relation to an analysis of adaptation activity spaces (Pelling et al., 2015) within agri-food systems. To accomplish this, we present and apply an integrated analytical framework. The research questions are i) what characterizes transformative adaptation in agri-food systems and ii) what are the adaptation activity spaces for agri-food system transformations? To answer these questions, we conduct and analyse pair-wise stakeholder interviews and discussions, supported by serious gaming, with 37 participants from Sweden and Finland with experience and expertise in agri-food systems, agricultural adaptation, or both.

2 Analytical framework

Transformative responses to global environmental changes (Feola, 2015), including transformative climate change adaptation decision-making (Park et al., 2012; Wilson et al., 2020), are complex and dynamic processes that involve an interplay between systemic elements and involved actors. Such processes comprise individual and collective adaptation decision-making -influenced social factors (e.g. social norms, institutional support) and socio-psychological factors (e.g. capacity perceptions) (Eakin et al., 2016; Wilson et al., 2020) embedded in various societal contexts. Degrees of transformations could theoretically (Few et al., 2017; Pelling et al., 2015) be achieved by means of adaptation in various ways. This study focuses on adaptation decision-making at both the farm scale (Feola et al., 2015; van Valkengoed and Steg, 2019) and at other collective levels of decision-making (Biesbroek et al., 2015; Lyle, 2015) within the systemic context of agri-food production (Juhola and Neset, 2017; Thompson and Scoones, 2009).

'Transformative adaptation' is employed as an overarching concept to describe adaptation responses that may result in fundamental systemic changes, i.e. policies and measures or practices aimed at reducing risks related to climate change vulnerability and/or taking advantage of climatic changes (de Coninck et al., 2018; Few et al., 2017). This definition incorporates both deliberate and emergent transformative changes resulting from adaptation responses, as Few et al. (2017) emphasize that while characteristic features of the potential outcomes of an adaptation measure on different scales (temporal, spatial, social) can be assessed, *ex ante* identification of an adaptation response as transformative is hardly possible. Temporal scales of transformations refer to the expected pace (e.g. abrupt or progressive) and the span (e.g. present - near term – long term) of change processes (Few et al., 2017; Rickards and Howden, 2012). Spatial scales of transformations in agri-food systems are used to define the extent of change, ranging from the field plot or farm to the global scale (e.g. Rickards and Howden, 2012) to rural or watershed area (see e.g. Lyle, 2015). Social scales of transformation focus on who the intended beneficiaries are (those who implement the measure, others, or both) (Wilson et al., 2020) and who the potential unintended impacts affect (Juhola et al., 2016).

We present an analytical framework that integrates the typology of transformative adaptation features (Few et al. (2017) and the concept of 'activity spaces' by Pelling et al. (2015) (Figure 1). The transformative change in the agri-food system is indicated with a colour change in the box illustrating the agri-food system before (light tone) and after (dark tone) the transformations and the arrow from the 'trigger' to 'transformation' and beyond the agri-food system. Three grey pointed rectangles illustrate the features of transformative adaptation, the dashed arrow represents indirect targeting of root causes through changes in practice. The dashed box illustrates the adaptation activity spaces that construct the frames for adaptation decision-making. (adapted from Few et al., 2017; Pelling et al., 2015).

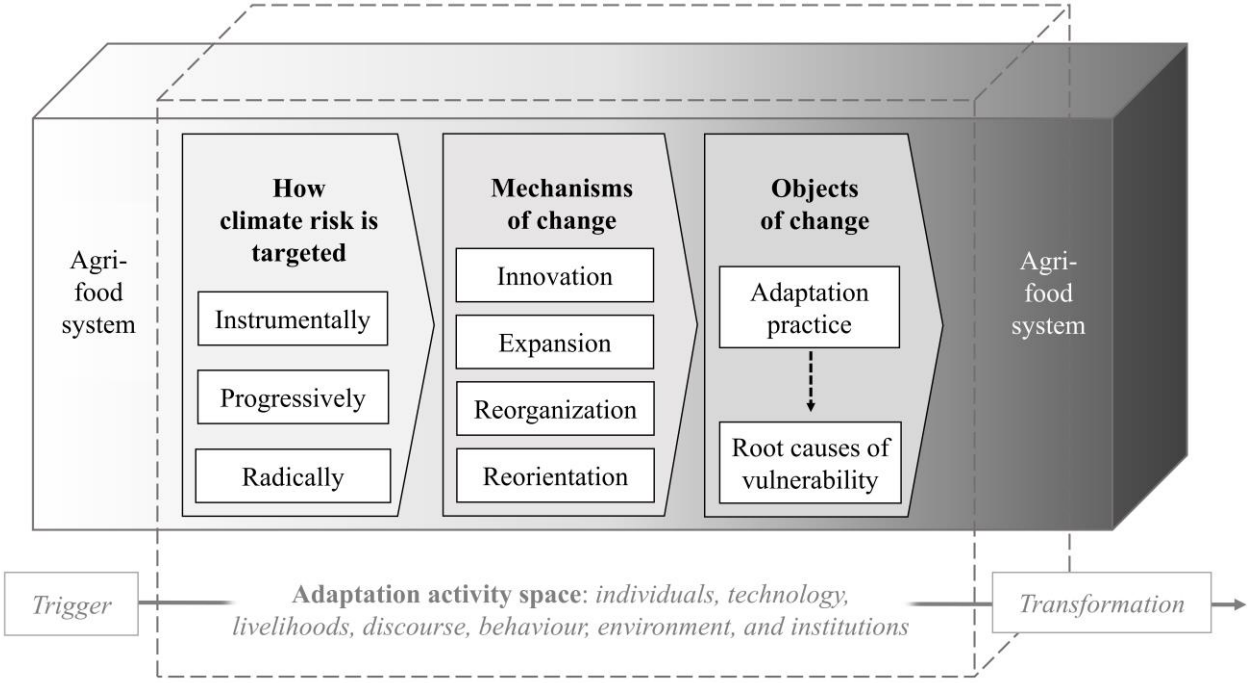

Figure 1. Analytical framework to assess transformative adaptation in the agri-food system.

The typology provides an approach to understanding the three distinctive features of transformative adaptation: 1) how climate risk is targeted, 2) what the mechanism of change is, and 3) what the primary object of the adaptation response is (Few et al., 2017). The typology is neither comprehensive nor a linear representation of transformative adaptation but calls for particular attention to the temporal, spatial, and social dimensions along with the triggers of the assessed process of change.

First, adaptation measures are considered to follow one of the three alternative strategies for targeting climate risks: *instrumental* tackling of the risks, *progressive* targeting of vulnerability, or *radical* tackling of the underlying causes of vulnerability. Progressive and radical strategies for addressing vulnerability may emerge/be implemented indirectly (e.g. through agri-environmental policies or social movements), whereas instrumental targeting of climate risk refers to measures primarily implemented as a direct response to a specific environmental change and/or related risk (Few et al., 2017). Second, four potentially overlapping mechanisms of change in transformative adaptation are considered to overarch these types of measures: *innovation* (novel adaptation measures or novel location for applying an existing measure), *expansion* (applying an existing measure on a considerably greater scale or intensity), *reorganization* ("major change in the governance structures that frame adaptation"), and *reorientation* ("reconfiguration of social values and social relations in adaptation.") (Few et al., 2017, 3). Third, the primary object of change is considered in relation to the degree of change either within the context of (i) the adaptation measure/practice or (ii) the root causes of vulnerability that denotes structural social/ socio-economic inequality (Few et al., 2017).

The concept of "activity spaces" is introduced as a conceptual tool to address the social dimension of adaptation decision-making processes that lead to transformation (Pelling et al., 2015). Activity spaces are considered dynamic windows of opportunity (Gillard et al., 2016) for transformation created by the actors with power to shape their content and interactions (Pelling et al., 2015). Pelling et al. (2015) introduce seven coexisting and interacting activity spaces (with exemplifying features in brackets): individuals (values, identity), technology (material, organizational), livelihoods (production and labour processes), discourse (popular, policy), behaviour (practices, routines), environment (biotic, abiotic), and institutions (regulatory, cultural). For example, the production context and the actors with the power to make transformative changes, such as the farm and farmer, respectively, are understood as the 'livelihood' activity space. The power to cross activity spaces may be manifested as what Eakin et al. (2016, 812) have described as the farmer's capacity to shape

their choices through "political mobilization, inter-sectoral collaboration and collective action, and ultimately institutional reform".

In agriculture, transformative change to target climate risks often occurs in two distinctive ways: shifting the location of production (e.g. inland or to less drought-prone areas) or changing the focus of production at the farm scale (Rickards and Howden, 2012). Such measures, reflecting the mechanisms of innovation and expansion, are mainly located in the activity spaces of technology, livelihood, and the environment (Few et al., 2017; Pelling et al., 2015). Reorganization of governance structures framing the adaptation and reorientation of actors are mechanisms of political or personal change directed at the root causes of vulnerability (Few et al., 2017) and thus locate the change to informal and formal institutions or to individuals, behaviour, and discourse (Pelling et al., 2015).

Processes towards transformation may be initiated in a single activity space (Pelling et al., 2015) if the climate risk is targeted instrumentally (Few et al., 2017). Instrumental targeting of climate risk may emerge especially as changes in technology or environment through direct measures, such as a shift to irrigation-based production as a response to increased droughts, but also in regulatory institutions through secondary means (e.g. policies) to address climate risks (Few et al., 2017). Such transformations in agri-food systems may be described, for example, with historical reference to the 'green-revolution', i.e. the widespread shift to intensified agricultural practices to secure food production that, nevertheless, involved increased vulnerability in several ways (see e.g. Brooks and Loevinsohn, 2011). Progressive targeting of vulnerability is another type of approach to transformative adaptation, which for example Chung Tiam Fook (2017) demonstrate in their study of social learning processes at the community level that lead to informal institutional reorientation. Outcomes of deliberate adaptation measures initiated within a single activity space may result in emerging transformations in other activity spaces. Informal institutions, such as communities and networks, have the power to reorganize a local food supply and distribution, which also has implications for territorial-scale transformations (Lamine et al., 2012). Moreover, radical targeting of societal change as adaptation is not restricted to the implementation context (e.g. farm) (Few et al., 2017) and the outcomes may expand to other scales crossing several activity spaces. Frequently, it is the dynamic interaction between various activity spaces that enables the change in a comprehensive way (Pelling et al., 2015).

We propose that this integrated framework can be used to understand the characteristics (and processes) of potential transformative changes through adaptation in agri-food systems. The three features of transformative adaptation (targets, mechanisms, objects) are identified in an empirical context, along with the adaptation activity spaces. Furthermore, attention is given to the temporal and spatial scales of the assessed processes of change (Few et al., 2017; Pelling et al., 2015).

3 Materials & methods

European Nordic countries (Finland and Sweden) are the case regions of this study, and are considered to have relatively strong socio-economic conditions for adaptation (Dunford et al., 2014). However, cross-border impacts along with high-end and long-term scenarios are currently not considered in Nordic national adaptation strategies (Jurgilevich et al., 2019; Papadimitriou et al., 2019). Gaps in knowledge and in the implementation of adaptation have been identified in several sectors (Johannsdottir, 2014; Wiréhn, 2018). Agriculture and food production are especially challenging in terms of competing land-use purposes and policy goals that may question contemporary agri-food production (see e.g. Schmidt, 2019). Previous studies have identified adaptation measures (Juhola et al., 2017) and trade-offs (Wiréhn et al., 2020) that involve potential transformative changes in Nordic agriculture.

To assess adaptation decision-making and measures involved in transformative changes, the perspectives and experiences of Nordic agri-food production actors were examined in this study through stakeholder interviews. Thirty-seven Swedish and Finnish stakeholder participants were interviewed in pairs for the purpose of evoking dialogues in which they disclosed their reasonings rather than in single interviews or larger groups (Eskola and Suoranta, 2001, 95–99). Participants were selected to represent a diverse spectrum of viewpoints and expertise related to climate change adaptation in the Nordic agri-food system (see Supplementary material

B). The interviews began with more overarching questions concerned with the subject of climate adaptation and agriculture (see Supplementary material A) and continued with discussions supported by serious gaming, including follow-up questions and specific questions related to transformation. The 'Maladaptation Game', which was played during the interview, is an on-line game designed for studying perspectives on maladaptation in agricultural decision-making in Nordic agriculture (Neset et al., 2020). As the game does not address transformation *per se*, questions specifically targeting the theme of transformation were integrated into the interview guide. Drawing on recent studies of climate change-related serious games and visualization tools (see e.g. Flood et al., 2018; Glaas et al., 2017; Reckien and Eisenack, 2013; Reibelt et al., 2017; Wu and Lee, 2015), we argue that introducing a serious game may support stakeholder discussions during the interview and provide additional topics to the dialogue. In this study, the primary reason for including the game was to induce discussion between participants on adaptation measures and their potential negative consequences.

The interviews lasted approximately 60 minutes and were held at the participants' work or study place. The interviews followed a semi-structured interview guide and were audio-recorded. The recordings were transcribed verbatim, and the transcripts were deductively coded in accordance with the analytical framework and flexibly open-coded to identify frequently emerging themes considered relevant to the study topic (Eskola. and Suoranta, 2001, 175–82) (see Supplementary Material B for the coding map). The transcripts were treated as one text, i.e. the codes were not linked to the collected demographic/background information of the participants. The computer assistance programmes *Atlas.ti* and *N-Vivo* were used for managing the codes (see e.g. Eskola and Suoranta, 2001).

4 Results

4.1 Transformative adaptation measures in agri-food systems

4.1.1 Mechanisms of change

The mechanisms of change, i.e. how transformative change occurs in agri-food systems, were discussed with emphasis on reorganization, reorientation, and a variety of combinations of these and the mechanisms of expansion and innovation. These discussions mainly reflected the activity spaces of *technology*, i.e. the practical organization of the transformation and *livelihood* at the farm and regional scales by farmers.

The activity spaces of *livelihood*, *individual*, or *behaviour* were particularly prominent in cases where a farmer could carry through with the transformative change. Generally, participants discussed that transformative adaptation at farms increasingly relies on the farmer's expertise to handle change, while science and policy fail to provide sufficient information and guidance. While farmers were generally intrigued by the complexity of their work, the decision to give up farming altogether as an adaptation measure (reorientation), for example, could relate to a change in motivation when uncertainty becomes unbearable for an *individual*.

Discussions of reorganization as a transformative adaptation mechanism at the farm scale focused on shifts to organic production, as well as towards protein plant self-sufficiency e.g. using hemp. Furthermore, organic production was argued to potentially expand from the farm to the regional scale when conventional farmers observe how it builds robustness against changing conditions and brings new enthusiasm to their work, as observed in some agricultural regions in Finland. For example, reorganizing fertilization from chemical based to continuous vegetation cover/ green manure based may be an optimal field-scale adaptation measure while also contributing to mitigation, which is often acknowledged on the farm scale. Participants also frequently discussed that innovations expand through peer examples at the farm scale and further in the agricultural region when successful applications of new measures are recognized. Participants argued that *environmental* pressures, such as intensified winds and droughts, drive innovations in self-sufficient energy production to respond to the risk of electricity cuts and new ways to store water respectively. Participants also raised the reorganization of agriculture on a global scale to ensure a just transformation of the food system, describing the role of the Nordic region as potentially significant because of its comparatively better production conditions in a global perspective.

4.1.2 Objects of change and their targeting

We identified discussions on transformative change through adaptation focusing mainly on farm-scale activities or on broader societal discussions related to agri-food systems as 'objects of change'. While instrumental targeting of climate risk and the progressive tackling of vulnerability dominated the discussions, the radical tackling of the underlying causes of vulnerability was also raised on a more abstract level. The temporal scale of transformation was demonstrated in these discussions as target outcomes of current practices, policy developments, and future visions.

The recent reorganization of crop loss compensation in Finland from the public to the private sector was addressed in the discussions as an instrumental measure targeted restrictively to economic risk management. Similarly, reorienting production indoors (led lights, vertical farms, etc.) is a farm/field-scale risk response, which was argued to be technically feasible and already implemented to a certain extent. Costly instrumental measures were expected to evolve reactively, e.g. new subsidies and large-scale investments for drainage and irrigation systems after extreme wet and dry years, respectively.

The described progressive changes to target vulnerability involved value-related and temporally further-reaching discussions. Future generations were considered to be born into the reality of climate change and thus respond to it differently. Education on the value of agri-food systems more broadly was also observed to potentially support progressive targeting of vulnerability created by a lack of resources. Social learning and community-scale activities could change the local and regional *discourses* on what is or is not perceived as viable transformative adaptation. Successful experiences of neighbouring farms that were brought up during the discussions, e.g. pilot programmes with research institutes, garden-classroom cooperation with local schools, and a new administrative policy for run-off water control, were perceived to affect the *discourses* concerning the type of changes considered possible, who is part of the agri-food system, and how transformative adaptation processes may develop.

The discussed objects of societal transformations reflect a radical approach. Participants argued, for example, that transformations as a consequence of adaptation responses to climate risks are not possible without structural changes in the capitalist system. Perspectives concerning measures for radical changes were sometimes conflicting. On one hand, radical responses were considered to potentially rise from a value-changing crisis. On the other hand, controlled transformations were considered critical to prevent increased inequality, agro-ecological degradation, and productivity drops, along with potential maladaptive outcomes:

> "Soil packing can have a broader impact through increased need for imported food. If we destroy the [agricultural] soils --- then we export our negative effects, as well as the positive, such as biodiversity" (interview S4)

Respondents often emphasized that transformative adaptation should be considered a part of the broader transformation to climate-smart and sustainable agri-food systems that is ultimately driven by *environmental* preconditions. Within this context, critical environmental changes (climate change, biodiversity loss, pollution) were discussed as *environmental preconditions* while recognizing their human origin and society's role in mitigating them.

4.2 Adaptation spaces for agri-food system transformations

The discussed *institutional activity spaces* for transformative adaptation considered the cross-sectoral effects of policies along with markets that are not directed at adaptation *per se* but yet hold power to open or close gates for transformative adaptation in agri-food systems. For example, while afforestation of (less-productive) agricultural lands is not supported by public policies, it was discussed as an adaptation measure that is becoming more prominent through synergies with mitigation policies and national bio-economy strategies that indirectly create market incentives for it. Large-scale intensification of currently diverse Nordic agriculture was discussed as transformative adaptation development, mainly driven by the fluctuating but robust global agri-food market. As the prevailing intensification trend involves expansion of farm sizes and a decreasing

number of farms, the context for agricultural adaptation in Finland and Sweden changes, as traditional and farm-based knowledge on coping with changes becomes scarce.

Transformative adaptation, which was described as driven by changes outside the farm-scale, exemplified the sense of a lack of ownership of the change process. *Technology* for enabling future transformations, such as new cultivars, was often discussed as not being in the grasps of practitioners but conditional to favourable market/policy conditions. Discussions relating to processes outside the farm scale involved the role of the broader network around agri-food production considering consumers/citizens and the retail sector, emphasizing the costs of adaptation and how the risks of climate change should be spread more equally across the food system, as they were now described as mainly burdening farmers. This perspective stresses long-term thinking, support for small-scale farms, downscaling of animal husbandry, and acknowledging the values of biodiversity and self-sufficiency, which are all individual measures for increasing the robustness of agricultural productivity as a whole through a boundary-crossing reorganization of agri-food systems management.

The necessity for cross-sectoral governance of adaptation was frequently discussed with a focus of securing food production, which relates to increased interaction between several food system actors and activity spaces. While the food self-sufficiency rate in Sweden and Finland was considered fairly high, the required inputs, such as fertilizer and seed corn storages, are insufficient. A common Nordic seed corn storage was discussed as a possible regional-scale measure that would technically require a fairly simple reorganization of risk governance. For example, efficient use of animal manure for fertilization requires well-functioning logistics and processing facilities. The model of localized agri-food systems was brought up in these discussions highlighting nutrient and energy self-sufficiency in enhancing the adaptive capacity and resilience of both local production and food security.

The rising interest in plant-based diets and the consequential demand decrease for animal products is a transformative change that was considered to broadly affect current agri-food systems. When giving up animal husbandry was discussed as a transformative adaptation measure, the synergies with the supportive *public discourse* and mitigation efforts, along with expected policy responses were recognized as influential external factors in farm-scale decision-making. Changing *livelihood* to crop husbandry was also discussed as an option with animal husbandry practitioners in the case of *environmental* and *institutional* changes that may increase difficulties for pastoralism, fodder production, and/or animal drinking water provisioning. Participants argued that intensive animal production, which in itself represents an adaptation challenge, also has other *environmental* impacts. For example, it requires a rather continuous flow of inputs to function, which makes it particularly vulnerable to increased weather variation and extreme events.

5 Discussion and conclusions

Acknowledging the pressing need to find alternative ways to sustainably produce food has led to several initial studies on transformative adaptation in agri-food systems (Panda, 2018; Vermeulen et al., 2018). In this study, we capture elements of potentially transformative adaptation in the Nordic agri-food system and discuss reasons why transformations are not taking place. We assess the social dimensions of transformative adaptation processes through the analytical lens of activity spaces (Pelling et al., 2015), pointing towards potential negative outcomes for different actors and objects. As a complement to a problem-solving and systems-based take on transformative adaptation, this study demonstrates, in line with previous studies (Blythe et al., 2018; Gillard et al., 2016), that there are complexities and dynamics in the relations between different actors and contexts of action.

Results of this study show that the dynamics within and between the different activity spaces cause a large variation in the willingness and capabilities for farm-scale transformative adaptation activity and that the socio-ecological consequences of adaptation measures are rarely considered a priority. The transformative changes within the farm management context were often expected to be driven by examples from other actors or through policies and markets, and to be reached gradually. Our results support previous findings concerning

the importance of social learning, community engagement and the capacity to act in relation to societal norms in applying transformative measures that target the root causes of vulnerability and inevitably relate to questions of power (Chung Tiam Fook, 2017; Dowd et al., 2014; Schlosberg et al., 2017).

The integrated analytical framework enables the identification and assessment of the dynamic and contextual decision-making on transformative adaptation measures in socio-ecological contexts such as agri-food systems. Our results indicate that, as identified in earlier studies (e.g. Park et al., 2012), transformative changes through adaptation responses are often related to drivers other than climate risk. They involve changes that (i) have different effects at various temporal and spatial dimensions and (ii) involve trade-offs (and related negative externalities) with various actors and objects. Thus, the simplification of the complex and dynamic reality of adaptation, which often crosses several activity spaces, may lead to problematic governance prescriptions as a result of "institutional incompatibility" as suggested by Gillard et al., (2016). Several recent studies (e.g. Blythe et al., 2018; Feola, 2015; Gillard et al., 2016) raise this as a challenge with approaches that are more or less bound to the existing structures, such as transition management and resilience. We also identified these incompatibilities with measures that involve trade-offs between various activity spaces and scales. For example, a short-term instrumental measure at the field scale may lead to increased vulnerability of the whole production/environment in the longer term (e.g. excess field measures that destroy soil quality) and shift vulnerability to other actors. This study suggests that the trade-offs, including counteracting rebound effects to mitigation, are not always evident to or considered relevant by the implementing actors. Moreover, the results indicate that maladaptive outcomes resulting from transformative adaptation often are more complex than maladaptive outcomes resulting from incremental adaptation. These findings, in line with the results of recent studies, stress the need to shift the focus from a purely technical problem-solving and systems-based approach to transformation towards the societal aspects of adaptation decision-making (Blythe et al., 2018; Gillard et al., 2016) and to distinguish social drivers for incremental and transformative adaptation processes (e.g. Wilson et al., 2020). Public adaptation policies are considered to benefit more from integrative, inclusive, and participatory approaches that engage with social aspects, broaden the understanding of transformative adaptation potential, and embrace actor heterogeneity (Schlosberg et al., 2017).

The transformative adaptation measures identified in our study were primarily focused at the regional level. The global scale of adaptation trade-offs became obvious in our results, reflecting the transboundary climate risks and required adaptation measures, as stressed recently by e.g. Benzie et al. (2018). The results show that although adaptation measures in Nordic agri-food systems are implemented primarily at the farm level, the drivers and outcomes are spatially much more widely spread out. Thus, the adaptation policy agenda should also aim to find ways to guide adaptation across sectoral and spatial boundaries. Similar calls have been made in a sustainability assessment of Nordic agri-food systems that address multiple socio-ecological scales (temporal, spatial, social) and dimensions (Tälle et al., 2019). This claim is also backed up by a recent study identifying significant regional and sectoral trade-offs between adaptation strategies, such as intensification in agriculture, and sustainable development indicators such as food security (Papadimitriou et al., 2019).

Climate change adaptation in the Nordic agri-food sector is commonly discussed in relation to private practitioners' work, while there are limited discussions on policies to support incremental changes such as farm-scale risk management (Wiréhn, 2018). The implemented and planned adaptation measures are accordingly mainly incremental, while recent studies (Juhola et al., 2017) have identified certain transformative adaptation measures aimed at farm-scale changes. While transformative adaptation approaches are considered to involve opportunities, this study highlights the importance of understanding the complex and contextual nature of adaptation measures and how they may cause transformative changes in society that in addition to the intended opportunities also could involve harmful outcomes with potentially considerable impact on society and nature. This conceptual approach, we argue, provides more rigour to the analytical applicability of 'transformation' in adaptation studies and policies which recent studies (Fedele et al., 2019; Feola, 2015) suggest as currently lacking.

In conclusion, our assessment of transformative adaptation broadens the understanding of potential transformations in agriculture and informs related practical and policy decision-making, increasing

preparedness for climate change and securing livelihoods and food supply in the Nordic region. In line with the strand of literature that calls for systemic integration of social science and systems approaches in order to study and understand transformative adaptation processes (e.g. Feola, 2015; Gillard et al., 2016; Wilson et al., 2020), this study emphasizes the role of heterogeneity of actors linked to transformative adaptation spaces. This study suggests further interdisciplinary research on these trade-offs and development of participatory adaptation policies that are not limited to incremental adaptation as a precautionary practice. This should be done also to identify the involved actors and their perceptions.

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Supplementary material A: Interviews and participants

List of interviews (F= Finland, S= Sweden) included in the study, with the number of participants and descriptions of the participants' professions/ fields of expertise. A detailed description of the process is provided at the end of the table including a description of the serious game that was used in the interviews.

	Interview	**Participants: profession/ field of expertise**
	F1	a) Farmers union representative, practicing farmer b) Farmers union representative
	F2	a) Doctoral student in agro-technology b) Applied agricultural sciences lecturer, practicing farm manager
	F3	a) Regional administration representative (subsidies and monitoring in agriculture) b) Regional administration representative (subsidies and monitoring in agriculture), practicing farmer
	F4	a) Expert of environmental protection in agriculture at municipal administration and projects, practicing farmer b) Expert of environmental protection in agriculture at municipal projects
	F5	a) Applied agricultural sciences student, practicing farmer b) Applied agricultural sciences student, practicing farmer
	F6	a) Applied agricultural sciences teacher, practicing farmer b) Applied agricultural sciences teacher, agrology education developer, practicing farmer
	F7	a) Expert in agricultural adaptation research and communication b) Expert in agricultural adaptation research and communication
	F8	a) Agricultural adaptation governance representative b) Agricultural adaptation researcher
	F9	a) Agricultural and food activist, practicing farmer b) Agricultural and food activist
	F10	a) Agricultural extension service development
	S1	a) Master student in Sustainability Studies b) Master student in Sustainability Studies
	S2	a) National agency representative working with agricultural adaptation b) National agency representative working with agricultural adaptation
	S3	a) Agricultural knowledge broker, practicing farmer b) Extension officer, practicing farmer
	S4	a) Vocational school teacher (agriculture), practicing farmer b) Vocational school teacher (agriculture), practicing farmer
	S5	a) Vocational school student (agriculture), practicing farmer b) Vocational school student (agriculture), practicing farmer
	S6	a) Vocational school student (agriculture), practicing farmer b) Vocational school student (agriculture)
	S7	a) Vocational school student (agriculture), practicing farmer b) Vocational school student (agriculture)
	S8	a) Farmers union representative b) Farmers union representative
	S9	a) Representative from the Swedish Board of Agriculture
	S10	b) Representative from an AgriTech company
Total	*20 interviews*	*37 stakeholders*

Stakeholder selection: The initial stakeholder selection was conducted and subsequently complemented with snowball sampling to identify groups that are 'hidden' from the research community (Atkinson and Flint, 2001). This was done in accordance with methodological literature suggesting that the expertise, experiences, and perceptions of farmers, extension

officers, and public authorities working with adaptation, particularly regionally, need to be incorporated into systemic agricultural adaptation research and planning (Himanen et al., 2016; Mitter et al., 2018; Ross et al., 2015). Adaptation is currently not a mainstream practice in agri-food systems and few actors formally work with this issue. Following Reidsma et al. (2010), the sampling of the stakeholders aimed to include a balanced distribution of age, gender, and production orientation (organic/conventional).

Interview conditions and process: Each interview involved one or two researchers and one additional researcher was present during some sessions to make observations. The interviews were categorized into three sections: (i) introduction (ii) game-supported dialogues, (iii) final interview questions. Section (i) started with an introduction to the research and the game, followed by the following set of introductory interview questions: *What do you think about climate change impacts for agriculture in Sweden/Finland? How should Swedish/Finnish agriculture adapt to climate change, what is necessary? Who do you think is responsible for adaptating? What do you think of adaptation per se, what type of possibilities and challenges do you foresee?* In section (ii), the participants jointly played the Maladaptation game, and discussed their considerations and choices, while the researchers asked the following complementary questions: *What is your reasoning now? Why? How do you reason when you choose between adaptation measures/ maladaptive outcomes that you accept?* The researchers also replied to direct questions from the participants. In section (iii), the following final set of questions were asked: *If we zoom out and think about the larger system and possible profound changes i.e. transformations to agriculture in the climate change context, what potential actions (e.g. on farms) could lead to such changes and what implications could such changes have on agriculture. Can you think of any unintended consequences that have not yet come up, related to these types of measures?* The interviews were conducted in the mother tongue of the stakeholders (Finnish or Swedish) and lasted approximately 1 hour each.

The Maladaptation Game: The game is designed as a single-player online 'card game' that introduces 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 these issues. Each adaptation measure has several potential maladaptive outcomes. The elements of the game are research-based (see Asplund et al., 2019; Neset et al., 2020).
Participants played the game in pairs on a laptop as part of the interviews and were instructed to take the role of a Nordic farmer. Their task was 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)). The Maladaptation Game is available in open access and in three languages (English, Swedish, Finnish): http://maladaptationgame.info/.

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592 ***Supplementary material B: Coding map***

<table>
<tr><td colspan="2">Analytical framework</td><td colspan="2">Operationalization</td><td></td></tr>
<tr><td>Thematic analysis</td><td>Analytical themes</td><td></td><td>Codes</td><td>Grounded themes[1]</td></tr>
<tr><td rowspan="3">Typology of transformative adaptation features (Few et al., 2017)</td><td>MECHANISMS OF CHANGE
Thematic categories: innovation, expansion, reorganization, reorientation</td><td>Analytical question: What is the mechanism of change?</td><td>indirect/direct, actors</td><td rowspan="4">Historical analogies

Uncertainty</td></tr>
<tr><td>TARGETING CLIMATE RISK
Thematic categories: instrumental, progressive, radical</td><td>Analytical question: How is climate risk targeted?</td><td>indirect/direct, actors, risk/ vulnerability/ opportunity</td></tr>
<tr><td>OBJECT OF CHANGE
Thematic categories: adaptation practice itself, broader development aspects through adaptation</td><td>Analytical question: What is the primary object of the adaptation response?</td><td>agri-food system, adaptation practice, society, social progress</td></tr>
<tr><td rowspan="4">‘Activity space’ concept (Pelling et al., 2015)</td><td>INDIVIDUAL
Balance of self and society. May require rejection of prescribed identities. Value of learning communally and through practice. Liberation pedagogy. Transformative learning.</td><td rowspan="4">Interview questions on a) responsibility of adaptation and the likelihood of transformative changes through agricultural adaptation; b) adaptation decision-making

Follow-up questions (FUQ) on how the potential transformations could occur and</td><td>values, identity</td></tr>
<tr><td>TECHNOLOGY
Engineered structures, new seed varieties, watershed-management tools, early-warning systems, social media. Transformation of science. Organizational transformation at the farm level (inclusions of marginal interests).</td><td>material, organizational</td></tr>
<tr><td>LIVELIHOOD
"The skill sets and entitlements that shape individual and household asset profiles". A key interaction for adaptation is between livelihood sustainability and ecosystem stability.</td><td>production, labour, skills, household, asset</td></tr>
<tr><td>DISCOURSE</td><td>popular, policy</td></tr>
</table>

[1] Frequently emerging themes that were considered relevant to the study topic.

	"Conceptual models that place boundaries on the material interventions considered legitimate and possible in adaptation". Including broader issues of global sustainability, including the stabilization of greenhouse gas emissions. Change in socio-political systems that support technological choices.	**consequences they could involve.** *Analytical questions*: What are the frames for action that is considered transformative adaptation (based on the interrogation typology)? FUQ (analytical): Are the identified actions related to single or multiple activity spaces? FUQ (analytical): Are there interrelations between the multiple activity spaces?		
	BEHAVIOUR Adaptive capacity is reproduced through everyday activity. Transformative adaptation is likely to be observed less through fundamental changes in behaviour and more through changes in the social contexts in which they emerge.		practices, routines	
	ENVIRONMENT Human "interventions can transform local biological and physical processes, impacting the resilience of social-ecological systems, just as non-linear changes in climate systems and weather extremes can influence such systems." Large-scale physical adaptation interventions.		biotic, abiotic	
	INSTITUTIONS "Regulate and facilitate social behavior, reproduce power asymmetries and police its reproduction" Formal or informal. Shadow networks and informal institutions; experimentation threatening existent institutional forms.		regulatory, cultural, informal, formal	
Transformative change (Few et al., 2017; Pelling et al., 2015)	TEMPORAL SCALE, SPATIAL SCALE, TRIGGERS	*Analytical questions*: What is the temporal scale/ spatial scale/ trigger of the identified change?	pace, span, fundamental, irreversible, all-inclusive, local/ regional/ global, rural/urban, risk/ vulnerability/ opportunity	

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