A framework to map agroecological initiatives illustrated with the case of Conservation Agriculture in Denmark

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Period 2-5 (2022-2023)

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ABSTRACT. Agroecology is key to respond to the global crises we are facing today. Agroecological transition can be enhanced through the collaboration of agroecological initiatives with scientists in reflexive arrangements. An in-depth understanding of the agroecological initiative is essential for a reflexive arrangement to have an impact. This can be achieved through mapping. We developed an analytical framework based on three pillars to map the context, the actors, and the barriers and levers for the development of agroecological initiatives and applied it to the Danish Conservation Agriculture Network. The outcomes are threefold: context information in the six dimensions biophysical environment, knowledge, society, policy and governance, economy and farming system, key actors identified through social network analysis and key barriers and levers identified through applying network metrics on a cognitive map of barriers and levers. Connecting the outcomes of the three pillars of the framework applying a multi-level perspective shed light on the main themes of the Danish Conservation Agriculture Network and its position in agroecological transition. We found a new role of consultancy to be emerging, where consultants facilitate horizontal knowledge structures and construct networks and thereby enhance technological and network anchoring processes. Institutional anchoring remains difficult due to contested knowledge. Our mapping framework generates in-depth insights into the functioning of agroecological initiatives, points out strengths and major issues to take on and provides the results in a consistent structure, making it possible to compare and learn across initiatives. Thereby it supports reflexive arrangements to advance agroecological initiatives in their development.

Keywords: Agroecology; Cognitive mapping; Conservation Agriculture; Multi-level perspective; Reflexive arrangements; Social network analysis

INTRODUCTION

A transition in agriculture is urgent to face current crises, such as climate change or biodiversity loss. Agroecology is by many seen as a key element of such transition (FAO 2018). Agroecology intertwines science, social movement and agricultural practice (Gallardo-López et al. 2018, Rivera-Ferre 2018). Méndez et al. (2017) defined agroecology as "an approach that seeks to integrate ecological science with other academic disciplines and knowledge systems to guide research and actions towards the sustainable transformation of our current agrifood system." The holistic approach of agroecology to food systems is visible in the diversity of agroecological principles, which include agronomic, social, environmental and economic aspects (FAO 2018, HLPE 2019). Agroecology comprises many different farming practices such as agroforestry or conservation practices (Castella et al. 2022).

A frequently used model to conceptualize agroecological transitions is the multi-level perspective (Magrini et al. 2019). The multi-level perspective is built on three interacting levels: landscape, regime and niche. The socio-technical regime represents the current rules and comprises technical, network and institutional components (Elzen et al. 2012, Darnhofer 2015). The regime is embedded in the socio-technical landscape, which represents its exogenous environment that changes only slowly over time (Geels and Schot 2010). Niches are defined as protected spaces for the development of innovations and are often created strategically (Smith 2006). Anchoring refers to the connection of an innovation, for example a new farming practice, with the regime or with a niche (Elzen et al. 2012). The multi-level perspective defines transition as a shift in the socio-technical regime which happens through interaction of processes at all three levels (Geels and Schot 2007a). Key to the initiation of transition are interactions between niche and regime, manifested in anchoring processes (Diaz et al. 2013).

The agroecological transition is composed of many individual transition pathways of agroecological (AE) initiatives (Polita and Madureira 2021). Zooming in, these transition pathways develop around anchoring of agroecological practices (Elzen et al. 2012, Castella et al. 2022). AE initiatives are multi-actor networks aiming to enhance agroecological transition through scaling-out and scaling-up certain

agroecological practices. The adoption of agroecological practices is location specific and tailored to the ecological conditions and the cultural knowledge of a place, which results in a high diversity amongst AE initiatives (Teixeira et al. 2018, Castella et al. 2022).

To advance AE initiatives in their development, transdisciplinary knowledge development has an important role to play (Levidow et al. 2014, López-García et al. 2021). The temporary collaboration of scientists and non-scientists with the goal of facilitating learning and promoting structural change has been called a reflexive arrangement. Reflexive arrangements question what is taken for granted and aim to co-create new knowledge that is translated into joint action (Koole 2020). There is a wide range of reflexive arrangements. Examples are Participatory Action Research (Guzmán et al. 2013), Co-Innovation (Rossing et al. 2021) or Agroecosystem Living Labs (McPhee et al. 2021). This research is part of the Horizon Europe project Agroecology-TRANSECT (AE-T), at the heart of which are reflexive arrangements with AE initiatives.

When collaborating with AE initiatives, reflexive arrangements are situated in the specific context of the initiative (Guzmán et al. 2013, Méndez et al. 2017, McPhee et al. 2021, Rossing et al. 2021). Therefore, an in-depth understanding of the initiative is essential for a reflexive arrangement to have an impact. This can be achieved through mapping. We understand mapping as a systematic approach to collect and analyse information about the evolution and the current state of an AE initiative to gain an in-depth understanding of its functioning and determine its strengths and its major issues. Mapping furthers reflexive arrangements with AE initiatives by generating new insights through an in-depth analysis, supporting the initiatives' self-reflection and making it possible to compare and learn across initiatives.

Literature on agroecological transition highlights three elements to be crucial for mapping AE initiatives: (i) the context, (ii) the actors, and, (iii) the barriers and levers for the development of the AE initiative. (i) AE initiatives are embedded in their local context (Méndez et al. 2017). Understanding the context when collaborating in reflexive arrangements was shown to enhance their effectiveness (Klerkx et al. 2017). Additionally, understanding the context provides a base for further analysis and performance assessment (Petersen et al. 2020, Mottet et al. 2020a). (ii) Actor networks have been shown to play an important role in transitions (Elzen et al. 2012, Magrini et al. 2019). Social networks enhance agroecological transition in two ways. First, different actors contribute with complementary resources and knowledge to a social learning process, which results in the development of feasible practices. Second, scaling of agroecology is enhanced through horizontal networks of peers resulting in an increased adoption of practices (out-scaling) as well as through vertical networks fostering change at an institutional level (up-scaling) (Gaitán-Cremaschi et al. 2022). (iii) Barriers and levers for the development of AE initiatives are key for their success. In research about agroecological transition, factors which enable or block the adoption of agroecological practices are frequently analysed (e.g. adoption of agroecological farming practices (Schoonhoven and Runhaar 2018, Ryschawy et al. 2021), crop diversification (Morel et al. 2020), adoption of cultivars (Vanloqueren and Baret 2008)).

Approaches related to mapping in literature are related to sustainability assessment of farming systems, participatory system innovation, network analysis, living labs and trajectory analysis. Sustainability of agricultural systems is often assessed with quantitative approaches such as MESMIS (López-Ridaura et al. 2002, Cândido et al. 2015) and TAPE (Mottet et al. 2020b), which include the characterisation of the system as a first step. Agroecology Europe analysed the current state of Agroecology in different European countries and assessed AE initiatives (Agroecology Europe 2020). Participatory approaches designed to enhance innovation systems such as RAAKS (Engel 1997), RMA (van Mierlo and Regeer 2010) and RIO (Bos et al. 2009, Elzen and Bos 2019) provide tools to analyse systems, including actors, barriers and levers. Approaches to map systems are Cognitive Maps (Vanwindekens et al. 2013) and Social Network Analysis (Rocker et al. 2022), where networks are constructed and analysed with network metrics. Holmén et al. (2022) developed an analytical framework for sustainable transition labs, which structured qualitative data to compare transition labs. Systemic barriers to crop diversification were identified and categorized by Morel et al. (2020) using mixed methods. Whereas the previously mentioned approaches focussed on the current state, other approaches addressed the evolution of niche

initiatives such as Outcome Trajectory Evaluation (Douthwaite and Hoffecker 2017), Outcome Harvesting (Britt and Wilson-Grau 2012, Blundo-Canto et al. 2017), Critical Incident Technique (Gremler 2004), Chaînes opératoires (Coupaye 2015) and Social sequence and relational chain analysis (Polge and Pagès 2022), which highlight barriers, levers and actors. More details are provided in Appendix A.

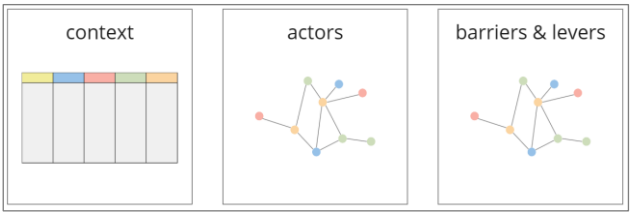
Although there is a large body of methods and methodologies that are useful to provide insights in AE initiatives, a systematic approach to gain an in-depth understanding of AE initiatives is missing. We address this gap by developing an analytical framework to map AE initiatives to answer the following questions: (1) What is the context the initiative is embedded in? (2) Which actors are related to the initiative, how are they related to each other, and which actors are key? (3) What are the barriers and levers for the development of the initiative and which are key?

In the following section, I present the analytical framework to map AE initiatives based on the three pillars context, actors, and barriers and levers. After that, I apply the framework to an AE initiative, namely the Danish Conservation Agriculture Network, which is part of AE-T. The results are presented according to the pillars of the framework. In the discussion, the outcomes of the three pillars are interlinked and placed in the context of agroecological transition using the multi-level perspective. The contribution and limitations of the framework are discussed, before wrapping up with main conclusions.

ANALYTICAL FRAMEWORK TO MAP AGROECOLOGICAL INITIATIVES

In the following section, we present a framework which provides a systematic approach to map AE initiatives. It consists of three pillars: context, actors, and barriers and levers (Figure 1). A broad range of existing approaches was reviewed to find suitable elements for this framework (see Appendix B). To find existing approaches, the search terms actor*, agroecolog*, analys*, assess*, evaluat*, framework, innovati*, “innovation system*”, “living lab”, method* and trajectory were used in different combinations, followed by backward and forward sampling of relevant references.

Figure 1 The three pillars of the analytical framework to map agroecological initiatives



Context

AE initiatives are embedded in their specific context (Barrios et al. 2020). The context of an AE initiative is therefore the starting point for the mapping framework. We developed a semi-qualitative framework (Table 1) to structure the context information, inspired by Holmén et al. (2022). The framework consists of six Dimensions which are based on the framework for assessing food systems by Nesheim et al. (2015) and adapted considering other frameworks related to socio-technical innovation systems (Geels and Schot 2007b, Ghosh et al. 2022) and socio-environmental systems (Millenium Ecosystem Assessment n.d.) including food systems (shiftN 2023) and farming systems (Schoonhoven and Runhaar 2018, Escobar et al. 2019, Agroecology Europe 2020, Mottet et al. 2020). Based on a literature review each Dimension was subdivided into Elements, which specify relevant qualitative or quantitative aspects. The Elements are further specified with examples of what they include. The first pillar ensures the relevance of the outcomes of the second and third pillar by enabling a context-related analysis of the actors, and barriers and levers.

Actor network

Social networks are crucial for agroecological transition (Anderson et al. 2019a). The capacity of a social network to innovate is determined by its structure and the position of individual actors (Gaitán-Cremaschi et al. 2022). Studying relations between actors across different field of action gives insight into strengths and weaknesses of the network and highlights possible levers of change through reorientation of relationships (Rocker et al. 2022). Therefore, we capture the social network of an AE initiative and categorize the actors according to their field of action.

To analyse the actor network, we used social network analysis (SNA). SNA is a quantitative approach to measure the structure of social networks. It provides

Table 1 Specification of the Context pillar of the AE initiative mapping framework in terms of the six Dimensions and their Elements, which are specified with examples.

Dimension	Element	Examples
Biophysical environment (Nesheim et al. 2015, Escobar et al. 2019, Agroecology Europe 2020, Mottet et al. 2020b, shiftN 2023, Millenium Ecosystem Assessment n.d.)	**Climate** (Moraine et al. 2016, Alvarez et al. 2018, Schoonhoven and Runhaar 2018, Mottet et al. 2020b)	Climate (Alvarez et al. 2018), average annual temperature (Alvarez et al. 2018), annual precipitation (Alvarez et al. 2018, Mottet et al. 2020), impact climate change (Mottet et al. 2020b)
	Landscape (Moraine et al. 2016)	Slope (Mottet et al. 2020b), land use (Mottet et al. 2020b, Ryschawy et al. 2021), soil type (Nesheim et al. 2015)
Knowledge (Geels and Schot 2007a, Nesheim et al. 2015, Schoonhoven and Runhaar 2018, Mottet et al. 2020b, Ghosh et al. 2022, shiftN 2023)	**Research** (Nesheim et al. 2015, Schoonhoven and Runhaar 2018, Millenium Ecosystem Assessment n.d.)	Universities and research centres (Knierim et al. 2015)
	Education & Learning (Schoonhoven and Runhaar 2018, Mottet et al. 2020b)	Agricultural education (Mozzato et al. 2018, Fieldsend et al. 2021), available courses
	Information	Types of knowledge exchange (e.g. peer to peer, advisory services) (Moraine et al. 2016, Mozzato et al. 2018, Schoonhoven and Runhaar 2018, Anderson et al. 2019b, Agroecology Europe 2020, Fieldsend et al. 2021)
Society (Geels and Schot 2007a, Schoonhoven and Runhaar 2018, Escobar et al. 2019, Mottet et al. 2020b, Ghosh et al. 2022, shiftN 2023, Millenium Ecosystem Assessment n.d.)	**Farmer community** (Schoonhoven and Runhaar 2018, Hazard et al. 2022)	Types of communities related to agriculture (e.g. farmer groups) (Schoonhoven and Runhaar 2018), types of activities
	Consumer preferences (Moraine et al. 2016)	Diet (Nesheim et al. 2015, Alvarez et al. 2018), demand for AE products (Moraine et al. 2016, Schoonhoven and Runhaar 2018, Agroecology Europe 2020, Blanch-Ramirez et al. 2022)
	Wealth (Nesheim et al. 2015)	Human development index (Mottet et al. 2020b), GDP (Mottet et al. 2020b), Gini Coefficient, poverty rate
Policy & Governance (Geels and Schot 2007a, Nesheim et al. 2015, Schoonhoven and Runhaar 2018, Agroecology Europe 2020, Ghosh et al. 2022, shiftN 2023, Millenium Ecosystem Assessment n.d.)	**Policies** (Nesheim et al. 2015, Schoonhoven and Runhaar 2018, Mottet et al. 2020b, Millenium Ecosystem Assessment n.d.)	National or local policies (e.g. concerning natural resource management, nutrition, food safety, labour, agricultural production, risk management, emissions), subsidies, taxes
	Social movements (Nesheim et al. 2015, Schoonhoven and Runhaar 2018)	NGOs and other political actors
Economy (Geels and Schot 2007a, Nesheim et al. 2015, Schoonhoven and Runhaar 2018, Escobar et al. 2019, Agroecology Europe 2020, Mottet et al. 2020b, Ghosh et al. 2022, shiftN 2023, Millenium Ecosystem Assessment n.d.)	**Agricultural sector**	Economic importance of farming (Moraine et al. 2016), globalisation
	Markets & Supply chain	Typical market structure and supply chains: length, intermediaries (Nesheim et al. 2015, Moraine et al. 2016, Mottet et al. 2020b), local markets (Moraine et al. 2016), labels and contracts (Alvarez et al. 2018, Schoonhoven and Runhaar 2018, Mottet et al. 2020b)
	Financial system	Capital, funding, investment possibilities (Schoonhoven and Runhaar 2018)
Farming system (Moraine et al. 2016, Schoonhoven and Runhaar 2018)	**Infrastructure**	Farm infrastructure (Alvarez et al. 2018, Schoonhoven and Runhaar 2018, Mottet et al. 2020b), roads, infrastructure related to value chain (Mozzato et al. 2018)
	Farmers & Employees	Age and gender of farmers (Schoonhoven and Runhaar 2018), agricultural labour (e.g. wage, availability, migration)
	Farm structure & Ownership	Farm size (Alvarez et al. 2018, Schoonhoven and Runhaar 2018, Mottet et al. 2020b), ownership of farm
	Agricultural production	Common crops, livestock, diversity of farms, sustainable farming practices (Alvarez et al. 2018, Schoonhoven and Runhaar 2018, Mottet et al. 2020b)

metrics to measure network characteristics, which indicate network dynamics and the role and importance of actors (Pachoud et al. 2019). SNA thereby provides a basis for qualitative research to investigate deeper patterns of relationships and their conditions and consequences (Rocker et al. 2022). We use SNA to identify the key actors related to the AE initiative.

Network of barriers and levers

Barriers and levers for the development of AE initiatives are tied to the initiatives' progress towards agroecology transition. Barriers hinder or block agroecological transition. Innovation studies see barriers hindering innovation as system failures. They slow down the innovation system and block actors in their learning (van Mierlo et al. 2013). System failures may occur in different features of the innovation system such as physical infrastructure, knowledge infrastructure, and market structure (Klein Woolthuis et al. 2005, Klerkx et al. 2012). Inspired by that, we developed a set of categories to classify the identified barriers and levers according to the field of action they relate to.

Levers relate to leverage points, which are described as places in a system where small interventions cause a big change from a system thinking perspective (Meadows 1999, Fischer and Riechers 2019). Donella Meadows (1999) distinguished between shallow levers, which are easy to mobilize but limited in their effect, and deep levers, which are difficult to mobilize but have profound repercussions.

Barriers and levers for the development of AE initiatives can arise within an initiative or external to it (Schoonhoven and Runhaar 2018). The identification of key barriers allows to shed light on the most important points to intervene to advance the development of the AE initiative. The key levers highlight the achievements of an initiative and are especially interesting for similar initiatives to take inspiration from.

Barriers and levers are analysed using social cognitive maps. Cognitive mapping captures the perception of individual actors of an investigated system in a network. Combining individual cognitive maps results in a social cognitive map. The same network metrics as in SNA can be used to investigate the structure of the network and gain insight into the role and importance of individual barriers and levers (Vanwindekens et al. 2014).

MATERIALS AND METHODS

This section describes how the analytical framework to map AE initiatives was applied to the case of the Danish Conservation Agriculture Network. The procedure consisted of three steps: First, a literature review and a review of preliminary material to understand the context and prepare the interviews. Second, interviewing key actors, and third, constructing, analysing and interpreting the actor network and the network of barriers and levers.

Case study: Conservation Agriculture Network Denmark

The framework to map AE initiatives was developed as part of the research project Agroecology-TRANSECT (AE-T). At the heart of AE-T was the collaboration between scientists and 11 AE initiatives called Innovation Hubs (IHs). The IHs were based in different European countries, comprised different farming systems, different socio-economic landscapes, and different constellations of actors, and existed for several years before joining AE-T. One of the IHs was the Conservation Agriculture Network around the consultancy company Agrovi in Zealand, Denmark.

Conservation agriculture is an integrated crop and soil management strategy based on three principles: First, aim for minimum mechanical soil disturbance, meaning reduced or no tillage. Second, have permanent soil cover through crops, cover crops, or crop residues. And third, diversify species through a variation of crop sequences and a diverse crop rotation (FAO 2022). CA is considered as an agroecological way of farming and is related to agroecological intensification (Garbach et al. 2017).

Due to its potential to protect or enhance ecosystem services while sustaining high yields, CA is considered as a promising compromise between conventional and organic farming and gaining more attention (Chabert and Sarthou 2020). In CA, inversion tillage to control weeds is usually replaced by herbicide (glyphosate) application, which increases herbicide input compared to ploughed systems and makes CA dependent on the availability of glyphosate (Melander et al. 2013). Despite its herbicide use, positive effects of CA on environmental services such as soil structure, soil fertility, control of erosion and water runoff, pest control and conservation of biodiversity and habitats have been reported (Scopel et al. 2013, Garbach et al. 2017, Chabert and Sarthou

2020). A positive impact of CA on soil organic carbon (SOC) stocks in the upper soil layers has been shown, whereas controversial results have been reported on its impact on overall carbon sequestration (Chenu et al. 2019, Chabert and Sarthou 2020). Earlier enthusiasm about its potential to increase carbon sequestration has recently been questioned and disproved through the investigation of deeper soil levels (Wacker et al. 2022).

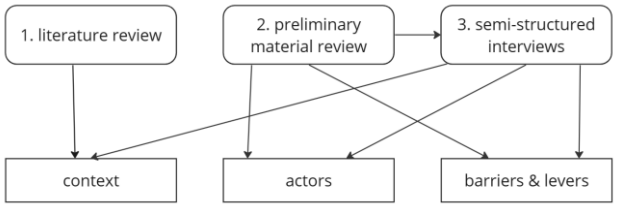
Irrespective of the overall effect on soil carbon, the efficacy of CA to provide environmental services is highly dependent on the specific site and is influenced by the local biophysical and socio-economic conditions (Giller et al. 2009). In Europe, the adoption of CA is low compared to other parts of the world and mostly driven by economic considerations (Lahmar 2010). By suppressing tillage, European farmers can considerably decrease crop production expenses for fuel, labour and machinery (Melander et al. 2013, Scopel et al. 2013).

The main objective of the Danish IH was to foster the adoption and expansion of conservation agriculture through participatory collaboration and the stimulation of a social and political CA movement (Description of Work of AE-T (unpublished) n.d.). The core of the Danish IH comprised the plant production unit of the consultancy company Agrovi, scientists from Roskilde University and farmers who were part of knowledge-exchange groups. The farmers shared a particular interest in CA and applied principles of CA on their farm. Most of the farmers reduced soil disturbance by not ploughing but practiced harrowing or similar tillage methods. Roskilde University (RUC) is a university with a strong in interdisciplinary and transdisciplinary approach. The collaboration of Agrovi and Roskilde University originated in earlier projects and was reinforced through the formation of a reflexive arrangement in AE-T. Agrovi engaged in the promotion of CA with a range of activities. Crucial was their provision and facilitation of knowledge-exchange groups for farmers and the organisation of their yearly Healthy Soil conference, an event which attracted more than 100 farmers.

Data collection

The data collection consisted of three steps: a literature review, a review of case study material, and semi-structured interviews (Figure 2).

Figure 2 Overview of data collection methods



First, a literature review of scientific articles and websites was conducted, to create a context description according to the different categories of the context framework for the Danish IH.

Second, the interviews were prepared. All material about the IH available by the AE-T project until February 2023 was analysed, in order to create a preliminary map of actors and a timeline of significant events in the evolution of the IH. The material included an interview of my colleague with the two IH facilitators about the evolution of the IH at the first Co-Innovation Workshop of AE-T, the Action Plan and Learning History developed by the IH within the project and a power point presentation to present the IH to AE-T. Additionally, websites of projects and actors mentioned in relation to the IH were visited.

Third, semi-structured interviews were conducted to collect data about the actors and their relationships, the barriers and levers for the development of the IH, and additional information about the context of the IH. A semi-structured interview guide was developed (see Appendix D) and tested with the Belgian IH in terms of understandability, procedure, time required and completeness.

The interviews consisted of two parts. First, the prepared timeline was presented to the interviewee (see Appendix C). Each interviewee was asked to choose significant events in the evolution of the IH from their perspective, inspired by the timeline and to elaborate on the chosen events. Questions were asked to deepen their elaboration, targeting more precisely the barriers, levers and actors related to the event. This approach was inspired by the critical incident technique, which aims to understand incidents from the perspective of an individual. Critical incidents are occurrences which make a positive or negative contribution to a phenomenon of interest (Gremler, 2004). This positive or negative contribution can be a barrier or a lever when the phenomenon of interest is related to the evolution of the IH.

In the second part of the interview, the preliminary actor map was discussed with the interviewee (see Appendix C). The actors and links that were mentioned during the development of the significant events in the first part were marked during the interview. The interviewee was asked to add or delete actors and relations and to elaborate them. Additionally, the facilitators were asked specific questions about aspects of the context that were missing from the literature review.

The interviews were done individually with the two IH facilitators and with two additional key actors of the IH, who were selected together with one of the IH facilitators. Key actors were defined as actors who are part of the IH and have a good understanding of it. Each key actor should have a different role in the IH and add a different perspective. The facilitators were supported with an information sheet to inform the key actors about the purpose and practicalities of the interviews. The interviewees were the main IH facilitator, who was working for the consultancy company Agrovi, a pioneer CA farmer who was also working at Agrovi, a pioneer CA farmer who was part of a knowledge-exchange group and the second IH facilitator, who was a researcher at Roskilde University. Three interviews took place in-person at the workplaces of the interviewees and one took place online. Two interviewers were present: I took the leading role and my colleague the supportive role. The interviews took two to three hours each. All interviews were recorded.

When collecting qualitative data, the position from which we see the world around us shapes our research interests, our way to approach the participants, and what questions we ask. Differences in positionality between interviewer and interviewee shape the answers we get (Jacobson and Mustafa 2019). I therefore want to point out a few aspects on the issue of positionality related to our data collection. A striking difference between the interviewers and the interviewees was that the interviewers were women in their mid-twenties and the interviewees were all male and older. Besides this difference, I perceived all people who were present at the interviews to be cis, white, able and European. Our data therefore needs to be used with the awareness that marginalized groups are not represented in this study.

Data analysis

All interviews were transcribed and coded in a first step with the codes actors, context, barriers and levers. The context framework was complemented with information from the interviews. The actors, barriers and levers were categorized into different fields of action. Drawing on the categories for actors in agroecology networks of Castella et al. 2022 and the results of my colleague, who simultaneously coded the interviews with the Belgian IH, the categories that resulted were: consultancy, cultivation, economy, farmers, policy, research, society and transdisciplinary relations (Table 2).

Table 2 Categories for the fields of action of actors and barriers and levers described with examples of what they comprise

Field of action	Examples
Consultancy	Activities, events, characteristics and skills of consultants
Cultivation	Experiments, knowledge and technical aspects of farming
Economy	Market, companies and financial aspects
Farmers	Identity, mindset and interaction amongst farmers
Policy	Legislation, dynamics considering political actors
Research	Scientific knowledge, dynamics in academia
Society	Interests, awareness
Transdisciplinary relations	Collaborations between actors in different roles and disciplines

Social network analysis

A social network consists of nodes representing the actors and edges, which are relations between actors (Rocker et al. 2022). The preliminary actor map (see Appendix C) was extended with the data from the interviews and adjusted so that the nodes represented actors at the level of organisations. The undirected edges were weighted according to the number of different interactions (see Appendix E).

The software Gephi was used for social network analysis and visualisation. The metrics to analyse the actor network and identify central actors were density, degree, weighted degree and closeness centrality. The density of a network measures how close it is to be complete. A high density indicates many relations between all actors. The degree is the number of edges linked to a node. A high degree indicates a central actor in the network, as the actor is connected to many

other actors (Rocker et al. 2022). The weighted degree was defined as the sum of the weights of the edges linked to a node. A high weighted degree indicates a central actor considering the strength and number of relations (Opsahl et al. 2010). Closeness centrality measures the shortest path from one node to all other nodes. High closeness centrality indicates an actor who is in close connection to many actors, and therefore high closeness centrality is associated with central actors (Rocker et al. 2022). Thus, central actors have a high degree, high weighted degree or a high closeness centrality.

Cognitive map analysis

A social cognitive map in the form of a directed network of barriers and levers was created from the coded interviews and validated with one of the IH facilitators. The relations were categorized as positive or negative, depending on originating from a barrier or a lever following the convention of signed networks (Meng et al. 2022). The network was analysed and visualized with the software Gephi.

To analyse the network of barriers and levers and identify key barriers and levers, the metrics out-degree, in-degree and betweenness centrality were calculated. The out-degree measures the number of outbound edges from a node and relates to the impact of the barrier or lever on the network. The in-degree measures the number of inbound edges to a node and shows how much the node is affected by other nodes (Rocker et al. 2022). Barriers and levers with high out-degrees or in-degrees are more embedded in the network and I therefore considered them as more important. As the edges were categorized as having positive or negative impacts, positive and negative in-degree was distinguished. The balance between positive and negative in-degree was calculated as an indicator of a barrier being reinforced (negative in-degree balance) or eased (positive in-degree balance) and of a lever being blocked (negative in-degree balance) or enhanced (positive in-degree balance) in the network. Betweenness centrality measures the fraction of shortest paths between all pairs of nodes that are passing through the concerned node. Betweenness centrality indicates the importance of a node to connect other nodes (Rocker et al. 2022). A high value indicates a barrier or lever with a connecting function. To sum up, a key barrier has a low positive in-degree, a neutral or negative in-degree balance, a high out-degree or a high betweenness. A key lever has low negative in-degree, a neutral or positive in-degree balance, a high out-degree or a high betweenness.

The key barriers were further divided in blocking, reflecting and eased barriers. Blocking barriers have a high impact (out-degree ≥ 2) and are potentially reinforced (in-degree ≤ 0). Reflecting barriers are characterized by a low impact (out-degree = 0) and being under high influence (positive and negative in-degree ≥ 2). Eased barriers are only influenced by levers (in-degree balance > 0 and negative in-degree = 0).

The levers were classified in powerful, influential, connecting and limited levers. Powerful levers were defined to have a high impact (out-degree ≥ 2) and being additionally enhanced by the network (in-degree balance > 0). Influential levers have a high impact (out-degree ≥ 2) but are neither positively nor negatively influenced by the network (in-degree balance = 0). Connecting levers are indicated by a high centrality (betweenness ≥ 20) combined with a high influence of the network (total in-degree ≥ 4) and a low impact (out-degree ≤ 1). Limited levers were defined to be negatively influenced by the network (in-degree balance < 0).

The definition of the individual barriers and levers was dependent on my personal perception of the Danish IH. Therefore, I want to highlight some points regarding my positionality (Jacobson and Mustafa 2019). I am passionate about agroecological ways of farming and getting to know new farms and people with innovative positions in agriculture. I worked on different organic and small-scale farms and buy mostly organic food. In some points, my personal values with regards to farming differ from the values of the interviewees. Though, that didn't hinder my interest in the Danish IH. It was personally a pleasure for me to interview the key actors of the Danish IH. I was inspired by their approach to enhance CA and am optimistic about CA to contribute to a more agroecological way of farming.

RESULTS

Context of the Danish Innovation Hub

The investigation of the context of the Danish IH according to the Context Pillar of the mapping framework highlighted a highly technologized, export-oriented agricultural production sector under strict environmental policies. The landscape is dominated by agricultural land, where mostly fodder

crops are grown. The main agricultural products are pork and dairy. Most of the farms exceed 100 hectares and operate with high depths and low margins. Originating from the Danish tradition of farmer cooperatives, nowadays big food companies are dominating the agricultural market. Denmark is among the countries with the highest consumption of organic products. The context of the Danish IH is described in detail in Table 3.

Actors of the Danish Innovation Hub

I identified 27 actors related to the Danish IH (Table 4), of which 3 were core actors and 24 actors externally related to the IH. Of the actors 10 were related to policy, 8 to economy, 6 to research, and 1 to society, farmers, and consultancy, respectively (Figure 3).

Table 3 Context of the Danish Innovation Hub

Biophysical environment	Climate	▪ Temperate climate, average annual temperature: 9.0°C, annual precipitation: 698mm (Climate-Data n.d.) ▪ Climate change: generally increasing precipitation, summer: dry spells and heavy precipitation events more frequent (International Energy Agency 2023)
	Landscape	▪ Flat, average elevation 31m (World topographic map n.d.) ▪ Landscape dominated by agricultural land (Hansen et al. 2020); field size increasing (Arler et al. 2015, Lohrum et al. 2021); agricultural area decreasing (Statistics Denmark 2021) ▪ Soil types in Zealand mainly coarse sandy clay and fine clayey sand (Adhikari 2013)
Knowledge	Research	▪ Historically high public investments in agricultural research and development (Averbuch et al. 2022) ▪ Important universities in agricultural research are Aarhus University and Copenhagen University, which have a focus on natural scientific and technical aspects of farming systems (Keyactor4 2023)
	Education & Learning	▪ Agricultural education: 14 months of study and 28 months practical internship (Hansen et al. 2020) ▪ Educational level farmers increasing; 76% of the farmers completed vocational training (2020) (Pedersen et al. 2022) ▪ Agricultural education focussed on natural sciences and technical aspects and oriented towards specialized and intensified farming (Hansen et al. 2020, Keyactor2 2023, Keyactor4 2023)
	Information	▪ Most consultancy companies: large, farmer-funded, separate advise for different agricultural products (Barzman and Dachbrodt-Saaydeh 2011, Keyactor1 2023, Keyactor3 2023) ▪ Many consultancy companies provide experience groups for farmers (Barzman and Dachbrodt-Saaydeh 2011, Hansen et al. 2020) ▪ Consultancy focussed on yield gains (Hansen et al. 2020)
Society	Farmer community	▪ Farmers historically built cooperatives to get access to technologies (Averbuch et al. 2021), production facilities often still owned by farmer cooperatives (Averbuch et al. 2022) ▪ Farmers connected amongst each other and with government, but not with non-farming community (Averbuch et al. 2022) ▪ Farmers frustrated about regulations (Keyactor3 2023)
	Consumer preferences	▪ High meat and low fruit and vegetable consumption; awareness healthy food; decreasing meat consumption (Reipurth et al. 2019) ▪ High consumption of organic products (2016 highest in world: 9.7% of food budgets spent on organic food); supermarkets purchase high share of organic products (Denver et al. 2019)
	Wealth	▪ Human Development Index: 0.948 (2021), rank 6 worldwide (UNDP 2022) ▪ GDP: 64’898 US$/capita, above European average (OECD 2021) ▪ Income inequality (Gini: 0.269 (OECD 2019a)) and poverty rate (0.065 (OECD 2019b)) amongst lowest of OECD states

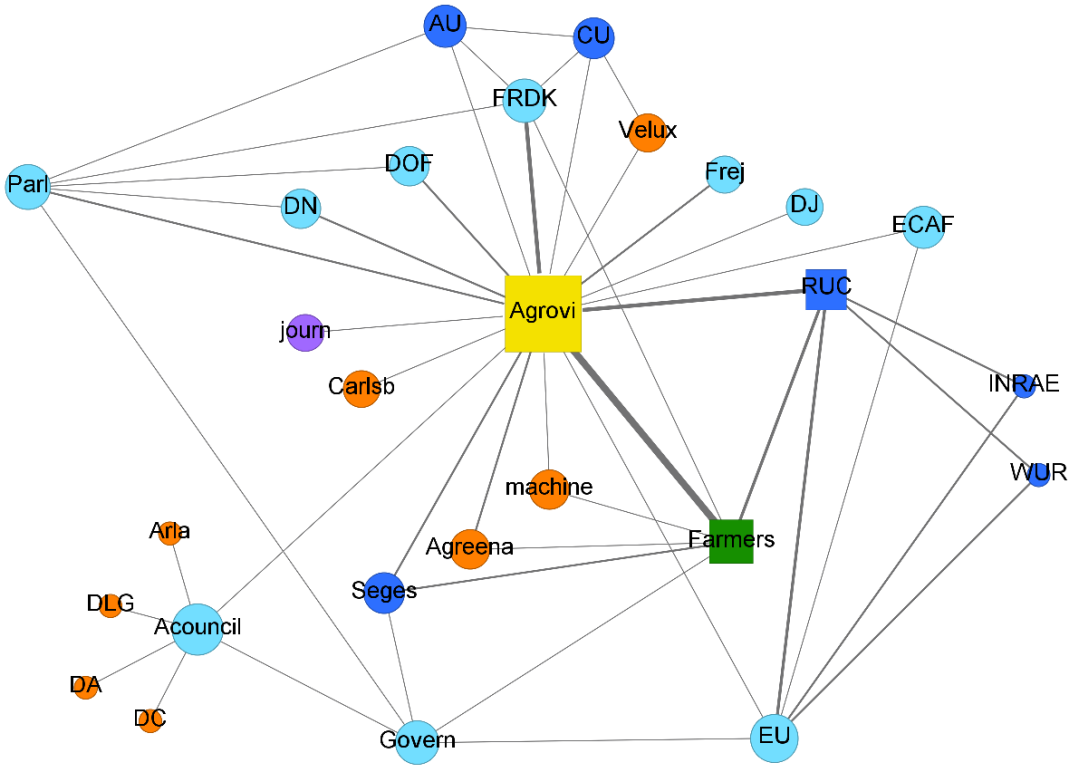
Table 3 Context of the Danish Innovation Hub (continued)

Policy & Governance	Policies	▪ Agricultural sector highly coordinated through state (Averbuch et al. 2022) ▪ Governmental support for organic farming integrated it into mainstream (Averbuch et al. 2022) ▪ Many environmental regulations; Denmark often ahead of other countries (Keyactor3 2023) ▪ Harmony rule (since 1998): Requirement of the manure application area of livestock farm to be proportional to the number of livestock (Willems et al. 2016) ▪ Climate Act launched in 2020 is one of the world's most ambitious: DK climate neutral by 2050 (Hastrup et al. 2022); currently policy development to limit GHG emissions in agriculture (Keyactor3 2023) ▪ The required 4% of non-productive area in the CAP reform only implemented in Denmark (Keyactor1 2023) ▪ Land tenure open for international investment (Arler et al. 2015)
	Social movements	▪ Three main nature related NGOs: The Hunting Federation DJ, the Danish Society for Nature Conservation DN, and BirdLife Denmark DOF (Keyactor3 2023)
Economy	Agricultural sector	▪ Liberal market regulation led to export-oriented agriculture: 25% of production is exported (Averbuch et al. 2021); farms highly reliant on world market prices (Grivins et al. 2021) ▪ Food production volume could feed three times the DK population (Hansen et al. 2020)
	Markets & Supply chain	▪ Farms are rarely integrated in local economies; common to have contracts with national supermarkets, which are organized as cooperatives (Averbuch et al. 2022) ▪ Big food companies which originated from cooperatives are dominating (Keyactor4 2023) ▪ Collective business traditions disappeared over the last 50-75 years (Keyactor4 2023)
	Financial system	▪ Real estate mortgage system has been one of the cheapest in Europe: access for farmers to cheap finance (Grivins et al. 2021) ▪ Many small rural banks with high proportion of agricultural loans (up to 35%) ▪ Financial crisis 2008: asset-based loans for land tenure and high-tech production facilities became a burden due to decreasing land prices and equity loss, resulting in high rate of bankruptcies (Grivins et al. 2021) ▪ Many farmers (mainly pork and dairy producers) have high depts, low liquidity and operate with a deficit (Grivins et al. 2021)
Farming system	Infrastructure	▪ Agriculture shaped by high productivity (Averbuch et al. 2021) and high specialization (Hansen et al. 2020), based on high energy use and modern machinery (Lohrum et al. 2021) ▪ High levels of technological investment on Danish farms (Averbuch et al. 2021)
	Farmers & Employees	▪ 94% of the farmers male (2017) (Statistics Denmark 2018) ▪ Average age farmers: 57; 50% over 55 years old; 7% young farmers (under 40 years) (Statistics Denmark 2018) ▪ Strict farm labour laws and strong labour unions (Averbuch et al. 2022)
	Farm structure & Ownership	▪ Number of full-time farms decreasing (Arler et al. 2015) ▪ 10% of farms cultivate < 40ha, 11% 40 - 100ha, 47% 100 - 400ha and 32% > 400ha (StatBank Denmark 2023) ▪ Average field size 28ha (2019) (Lohrum et al. 2021) ▪ 85% of farms privately owned (Grivins et al. 2021)
	Agricultural production	▪ Mainly grain production until European grain crisis 1870, transition to dairy farming and export (Averbuch et al. 2021) ▪ Main livestock: pigs and cattle, then poultries, horses and sheep (Statistics Denmark n.d.); pork and dairy products are the main agricultural products, more than half of agrarian exports (Osei-Owusu et al. 2021) ▪ 25% of livestock feed imported (Arler et al. 2015) ▪ 81% of agricultural land fodder crops, 9% food crops, 10% non-food crops (Arler et al. 2015); main crops: grass-clover, cereals, maize, potatoes, sugar beets and canola (Statistics Denmark n.d.) ▪ Organic farming increased to 12% of the cultivated area (2022) (Statistics Denmark n.d.) ▪ Reduced tillage practices increased to 23% of the cultivated area (2022) (StatBank Denmark n.d.)

Table 4 Actors related to the Danish Innovation Hub

Label	Full name	Description
Acouncil	Agricultural Council	The Danish Agriculture and Food Council represents the farming and food industry and is Denmark's largest industry grouping.
Agreena	Agreena	Company that sells carbon credits for carbon sequestration through CA.
Agrovi	Agrovi	Consultancy company whose plant production unit is focussed on CA in Denmark. They facilitate knowledge-exchange groups for farmers, organize events and demonstrations and do other activities to promote CA.
Arla	Arla	Multinational cooperative based in Denmark, which is the largest dairy producer in Scandinavia.
AU	Aarhus University	Aarhus University is the dominating university in the field of agriculture in Denmark.
Carlsb	Carlsberg	Danish multinational brewery, which is interested in launching a regenerative beer.
CU	Copenhagen University	
DA	Danish Agro	Danish, cooperative farm supply company.
DC	Danish Crown	Danish, cooperative, internationally oriented butchery and the worlds largest pork exporter.
DJ	Danish Hunting Association	One of the main nature related organisations in Denmark.
DLG	DLG	Danish, cooperative farm supply company.
DN	Danish Society for Nature Conservation	One of the main nature conservation and environmental organisations in Denmark.
DOF	Danish BirdLife	One of the main nature conservation organisations in Denmark who is partner of BirdLife international.
ECAF	European CA Federation	A European federation promoting the interests of CA farmers.
EU	EU	Funding European research projects.
Farmers	Farmers	Farmers which are related to the Danish Conservation Agriculture Network, for example costumers of Agrovi, farmers in knowledge-exchange groups and farmers joining the Healthy Soil conference
FRDK	FRDK	Association for reduced tillage in Denmark, who is involved in research, advise and lobbying.
Frej	Frej	A thinktank about food aiming to connect different actors in Denmark through dialogue.
Govern	Danish Government	Mainly the Ministry of Energy, Utilities and Climate, the Environmental Ministry and the Ministry of Food, Agriculture and Fishery.
INRAE	INRAE	French research institute for agriculture, food and environment
journ	Journalists	Journalists reporting about the Danish Conservation Agriculture Network
machine	Machine manufacturers	Machine manufacturers of no-till seeding machines
Parl	Danish Parliament	Danish parliament
RUC	Roskilde University	University with an interdisciplinary and transdisciplinary approach, seen as a left-wing university in Denmark.
Seges	Seges	Non-profit research centre, which used to be financed by the state and is now private.
Velux	Velux Foundations	Funded the project GMSR (Green Fields and Strong Roots, 2017-2021) of Copenhagen University and Agrovi to further CA.
WUR	Wageningen University and Research	Dutch University of Life Sciences

Figure 3 Actor network of the Danish Innovation Hub (visualized with Gephi). Node shape – square: core actor; circle: external actor; node colour – yellow: consultancy; green: farmers; orange: economy; light blue: policy; dark blue: research; purple: society; node size – closeness centrality; edge thickness – relationship weight.



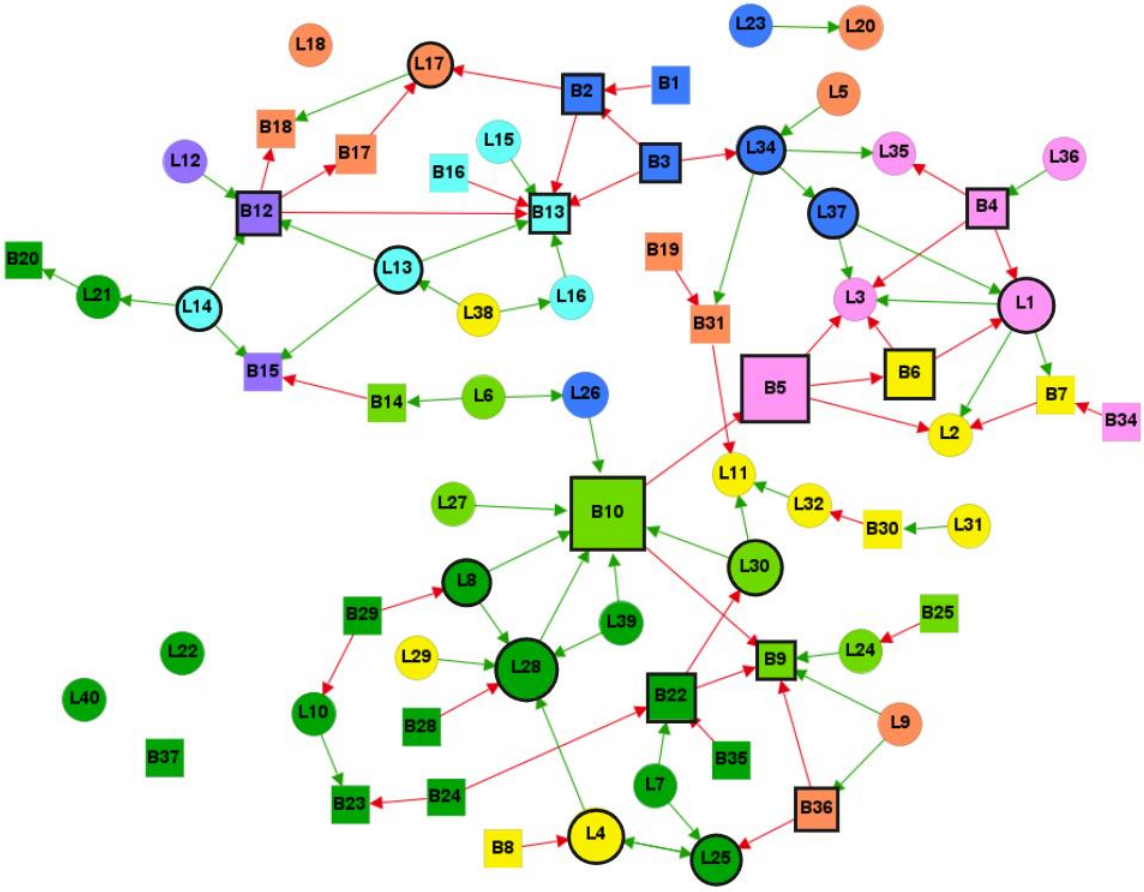
The network density of 13.4% is low. Most of the actors are related to only one (8 actors) or two (8 actors) other actors. Agrovi is the actor with most relations (degree: 19). Other actors with degrees higher than 3 are farmers (7), the Agricultural Council, the EU, and the Danish Parliament (6 each), Roskilde University, FRDK and the Danish Government (5 each) and Aarhus and Copenhagen University (4 each). Besides the core actors (the square symbols in Figure 3), all actors with degrees higher than 2 are related to policy or research, indicating a focus on these fields of action in the IH. The highest weighted degrees have the core actors Agrovi (37), farmers (16) and Roskilde University (14). Weighted degrees above 4 have the EU (10), FRDK (8), the Danish Parliament (7), the Agricultural Council (6), the Danish Government and Seges (5). With regards to the weighted degree it is remarkable that apart from the core actors, 5 policy related actors have the highest weighted degrees. With regards to closeness centrality, Agrovi reaches by far the highest value (0.79). Closeness centrality values above 0.5 are also reached by the Agricultural Council (0.54), Farmers (0.53), EU (0.52) and Roskilde University (0.51). A complete list of the actors and their network metrics can be found in Appendix F.

The most important actor in the Danish IH is Agrovi, reaching the highest values in degree, weighted degree and closeness centrality. Farmers are also highly connected but less close to the rest of the actors than Agrovi. Roskilde University has fewer but strong relations, indicated by the high weighted degree in comparison to the degree. Most important key actors external to the IH are related to policy and research. Policy actors are more strongly related and closer to the rest of the actors than research actors. Key policy actors are the Agricultural Council, EU, the Danish Parliament, FRDK, and the Danish Government. Key research actors are Aarhus University, Seges, and Copenhagen University.

Barriers and levers for the development of the Danish Innovation Hub

I identified 31 barriers and 39 levers for the development of the Danish IH (Figure 4)(see Appendix G). Most barriers and levers are related to farmers, consultancy and economy. Most barriers and levers are clustered according to their field of action, whereas consultancy and economy are dispersed.

Figure 4 Network of barriers and levers (visualized with Gephi). Node label – B: barrier; L: lever; Node shape – square: barrier; circle: lever; Node colour – yellow: consultancy; dark green: farmers; light green: cultivation; orange: economy; light blue: policy; dark blue: research; purple: society; pink: transdisciplinary relationships; Node size – betweenness centrality; Edge colour – red: negative impact; green: positive impact.



Key barriers

11 key barriers were identified (Table 5). They are ordered in three groups, according to their role in the network.

Blocking barriers

Blocking barriers have a high impact (out-degree ≥ 2) and are potentially reinforced (in-degree ≤ 0). Five key barriers have a blocking effect through a high impact (out-degree: 2 or 3) and in some cases additionally reinforcement by the network (in-degree: -2 or -1) and a high centrality. The strongest blocking barrier is the difficulty for scientists and consultants to leave the expert role (B5) that they traditionally take. The application of CA depends on the farm context, and practical knowledge about CA and minimum tillage is still limited in DK (B10). Therefore, there is no general expertise, but farmers expectations of clear advice, prestige issues of scientists and consultants, and high prices for consultancy make it difficult for consultants and scientists to move away from the expert role. The result is a potential limitation of facilitative advice (L2), where farmers are supported with questions to find solutions together with the advisor, and the collaboration between social scientist and farmers (L3).

The second blocking barrier, the consultancy company being limited in innovation which doesn't fulfil their costumers' expectations (B6) is reinforced by the difficulty for scientists and consultants to leave the expert role (B5). The dependency of the consultancy on their customers unfolds in a caution to confront their customers with novel approaches which do not fit their expectations of consultancy. The consultancy is expected to provide advice and services rather than including farmers in knowledge development or the envisioning the future of the IH. It limits the collaboration between social scientists and consultants (L1) and the collaboration between social scientists and farmers (L3), in which the consultancy is the intermediary. The third blocking barrier is the farmers' focus on yield and big machinery (B22), which is reinforced by masculinity in

Table 5 Key barriers for the development of the Danish Innovation Hub, classified in blocking, reflecting and eased barriers

Label	Barrier	Out-degree	Positive in-degree	Negative in-degree	In-degree balance	Betweenness centrality
B5	Difficult for consultants and scientists to leave the expert role	**3**	0	1	**-1**	100
B6	Consultancy company limited in innovation which doesn't fulfil their costumers expectations	**2**	0	1	**-1**	42
B22	Farmers' focus on yield and big machinery	**2**	1	2	**-1**	30
B2	Disagreement about the relevance of CA for C sequestration	**2**	0	2	**-2**	5
B3	University with classical natural science approach dominates authority advisory	**3**	0	0	**0**	0
B13	Current legislation not supporting CA	**0**	**3**	**4**	-1	0
B9	Risk of reduced yield due to CA	**0**	**2**	**3**	-1	0
B10	Lack of practical knowledge about CA and minimum tillage in DK	2	6	**0**	**6**	127
B12	Lack of visibility of CA in society	3	3	**0**	**3**	14
B36	Financial pressure on farms	2	1	**0**	**1**	10
B4	New forms of collaboration are hindered by tradition	3	1	**0**	**1**	5

agriculture (B24) and farmers' education, in which ploughing is taught as a central part of farming (B35). This perception of farmers makes the risk of a reduced yield (B9) a bigger hurdle to convert to CA. CA also reduces the need of big machinery, what makes it less attractive to farmers who are focussed on that. A lever to shift farmers' focus is the fascination about (living) soil, which many CA farmers share (L7).

The fourth blocking barrier is the disagreement about the relevance of CA for C sequestration (B2). This disagreement results from a lack of scientific knowledge on effect of CA on C sequestration (B1) and different approaches of verification among scientists and practitioners. The barrier of disagreement is reinforced by the fifth blocking barrier: the dominance of a university with classical natural science approach over authority advisory (B3), a barrier with a high impact (out-degree: 3). The result is a limited potential of CO_2-certificates for CA (L17) and reinforcement of the key barrier of the current legislation not supporting CA (B13).

Reflecting barriers

Reflecting barriers are characterized by a low impact (out-degree = 0) and being under high influence (positive and negative in-degree ≥ 2). Two key barriers have a high positive and negative in-degree and a low impact (out-degree: 0). Additionally, both have a low centrality (betweenness: 0). The first reflecting barrier is that current legislation is not supporting CA (B13). It is a result of the agricultural council representing interests of major companies and majority of farmers (B16) with no interest in CA, the lack of visibility of CA in society (B12), the university with classical natural science approach dominating authority advisory (B3) and the disagreement about the relevance of CA for C sequestration (B2). Approaches to bring CA farmers in contact with politicians (L16), FRDK grouping CA farmers (L15) to forward their interests politically and the collaboration with nature NGOs (L13) aim to achieve legislative support for CA.

The second reflecting barrier is the risk of reduced yield due to CA (B9). This risk is especially high during the conversion to CA. Practical knowledge to apply CA in the specific context of the farm still has to be acquired and the soil organic matter is still low. Through building up the soil organic matter and gaining experience, conventional yields can be reached again. Challenges in the cultivation are slugs due to the lacking soil disturbance, the establishment of spring crops because the soil takes longer to dry especially when the soil organic matter of the topsoil is still low, and the equal spreading out of organic material such as straw. The lack of practical knowledge about CA and minimum tillage in DK (B10) reinforces this barrier. Farmers' focus on yield

and big machinery (B22) and the financial pressure on farms (B36) additionally strengthen the relevance of yield in the short term. Even though farming costs are reduced (L9), according to the interviews even to the point that yield losses are compensated, the financial pressure on farms (B36) makes farmers reluctant to take potential risks. CA increases farm robustness (L24) through reduced erosion and higher drought resilience thus stabilizes yields in the long-term.

Eased barriers

Eased barriers are only influenced by levers. Four key barriers are eased, which all have a high impact in the network (out-degree: 2 or 3). Their actual impact is reduced by easing levers. The lack of practical knowledge about CA and minimum tillage in DK (B10) is the barrier with the highest betweenness, indicating a connecting role in the network. Its reinforcing effects on the risk of reduced yield due to CA (B9) and the difficulty for consultants and scientists to leave the expert role (B5) are outweighed by six levers: the access to knowledge through social media (L27), knowledge-exchange groups enabling farmers to be at the source of CA development in DK (L39), knowledge-sharing between farmers (L28), knowledge-exchange groups enabling to build up trust and share experiences honestly (L8), demonstrations (L30), and the contact with agricultural experts being re-assuring when trying something new (L26). The high in-degree balance of 6 indicates that the barrier of lack of practical knowledge is potentially surpassed, which is in line with a statement from one of the interviewed farmers "I believe the farmers can fix that [practical problems with cropping on the farm]. We can fix that in the knowledge groups."

The second barrier eased by the network is the lack of visibility of CA in society (B12). It has potential reinforcing effects on the current legislation not supporting CA (B13), on the value of CA soil not being considered in the value of a farm (B17), and on the lack of direct additional income from CA (B18). Three levers counteract the lack of visibility of CA (B12), which include the collaboration with nature NGOs (L13) and the thinktank Frej (L14), and the connection of CA to food to promote it (L12).

The financial pressure on farms (B36) is an eased barrier through the lever of reduced farming costs (L9). It has a potential reinforcing effect on the risk of reduced yield (B9) and possibly impairs the success of stories of inspiring CA farmers that show that CA can work (L25) when farmers apply CA primarily for financial reasons.

The last eased barrier is the hindrance of new forms of collaboration by tradition (B4). Unusual ways of interaction might cause conflicting aims and expectations from the collaborating actors. This barrier potentially hinders three types of unusual collaborations in the Danish IH, which are the collaboration between scientists from different disciplines (L35), the collaboration between social scientists and consultants (L1) and the collaboration of social scientists and farmers (L3). The hindrance of new forms of collaboration by tradition (B4) is eased by building up trust (L36), which requires time and was previously enhanced through personal interactions such as common lunch breaks or sharing an office.

Key levers

We identified 11 key levers (Table 6). They are grouped according to their role in the network.

Powerful levers

Powerful levers were defined to have a high impact (out-degree ≥ 2) and being additionally enhanced by the network (in-degree balance > 0). Two key levers were found to be powerful levers with a high impact (outdegree: 2 or 3) and enhancement by the network (in-degree balance: 1). First, the collaboration with nature NGOs (L13), which developed from the consultancy company inviting nature NGOs to give a speech at the annual Healthy Soil conference (L38). The collaboration with nature NGOs can further the visibility (B12) and understanding of CA in society (B15) and thereby counteracts the barrier of current legislation not supporting CA (B13).

Second, the agronomist in social sciences (L37) appears as a lever to the collaboration of social scientists with more technical agronomic actors such as consultants (L1) and farmers (L3). The agronomist working with social scientists is enabled through Roskilde university's interdisciplinary and transdisciplinary approach (L34), which is different from how universities usually work.

Influential levers

Influential levers have a high impact (out-degree ≥ 2) but are neither positively nor negatively influenced by the network (in-degree balance = 0). Three key levers with a high impact (out-degree: 2-3) and a neutral in-degree balance were found to be influential. The first influential lever is the Healthy Soil conference, which

Table 6 Key barriers for the development of the Danish Innovation Hub divided in powerful, influential, connecting and limited levers

Label	Lever	Out-degree	Positive in-degree	Negative in-degree	In-degree balance	Betweenness centrality
L13	Collaboration with nature NGOs	**3**	1	0	**1**	5.5
L37	Agronomist in social sciences	**2**	1	0	**1**	12
L4	Healthy Soil conference provides a platform for farmers to discuss CA	**2**	1	1	**0**	36
L34	Roskilde University's interdisciplinary and transdisciplinary approach	**3**	1	1	**0**	16
L14	Collaboration with thinktank Frej	**3**	0	0	**0**	0
L28	Knowledge-sharing between farmers	**1**	**4**	**1**	3	**54**
L25	Stories of inspiring CA farmers show that CA can work	**1**	**2**	**1**	1	**20**
L1	Collaboration between social scientists and consultants	3	1	2	**-1**	35
L30	Demonstrations	2	0	1	**-1**	32
L8	Knowledge-exchange groups enable to build up trust and share experiences honestly	2	0	1	**-1**	9
L17	CO_2 certificates for CA	1	0	2	**-2**	4

is providing a platform for farmers to discuss CA (L4), which enhances knowledge-sharing between farmers (L28). It is an event, where stories are told of inspiring CA farmers, which show that CA can work (L25). Even though the Healthy Soil conference has been a successful event with a high interest of farmers, it is challenging to keep it interesting for frontrunners (B8), who are key for its contribution to knowledge-sharing between farmers (L28).

The second influential lever is Roskilde University's interdisciplinary and transdisciplinary approach (L34). Roskilde University's approach facilitates their researchers to work interdisciplinarily (L35) and therefore also enables the agronomist to work in social sciences (L37). Through their collaboration with practitioners, they enabled the consultancy to join AE-T and thereby support them in their challenge to find funding (B31). The interviews indicated that the approach of Roskilde University is not much supported at national level, where traditional, natural scientific approaches dominate (B3), but valued and supported by the EU (L5).

The third influential lever is the collaboration with the thinktank Frej (L14). This collaboration is a way to enhance visibility (B12) and understanding of CA in society (B15) and also a lever for the IH to get in contact with young farmers (L21).

Connecting levers

Connecting levers are indicated by a high centrality (betweenness ≥ 20) combined with a high influence of the network (total in-degree ≥ 4) and a low impact (out-degree ≤ 1). Two key levers with a connecting role were found, which both are enhanced by the network (in-degree balance: 1 and 3).

First, knowledge-sharing between farmers (L28), which takes place in different ways is connecting the levers pointing at it. Knowledge-exchange groups enhance knowledge-sharing because they enable their members to build up trust and share experiences honestly (L8) and to be at the source of CA development in DK (L39). Furthermore, the Healthy Soil conference enhances knowledge-sharing through proving a platform for farmers to discuss CA (L4) and the newsletter of Agrovi supports farmers in current issues (L29) and thereby enhances knowledge-sharing. Knowledge-sharing between farmers is limited by the knowledge which is getting lost in the IH (B28), because what is shared is not collected and reported. Knowledge-sharing between farmers is a lever to the lack of practical knowledge (B10).

Second, stories of inspiring CA farmers which show that CA can work (L25). Contributing to this key lever is the fascination about (living) soil (L7) and the Healthy Soil conference provides a platform (L4) to tell them. The success of the good stories is potentially limited by CA farmers with a narrow focus on economic benefits due to financial pressure on the farm (B36).

Limited levers

Limited levers were defined to be negatively influenced by the network (in-degree balance < 0). Four key levers are limited (in-degree balance: -2 or -1). The collaboration between social scientists and consultants (L1) is a limited lever, which is central (betweenness: 35) and has a high impact (out-degree: 3). Mobilizing it provides a high potential. It is furthered through the agronomist in social sciences (L37) but blocked by the consultancy company's limit in innovation which doesn't fulfil their costumers expectations (B6) and traditions, which hinder new forms of collaboration (B4). The collaboration between social scientists and consultants enhances the collaboration with social scientists and farmers (L3), as consultants are the middlemen between these two groups. Also facilitative advice (L2) is furthered through the collaboration of social scientists with consultants and it addresses the barrier of consultants lacking training in social skills for facilitation and co-creation with farmers (B7).

Another limited key lever which is central (betweenness: 32) and impacting (out-degree: 2) are demonstrations (L30). As one of Agrovis' activities, it supports Agrovi in being an attractive consultancy for CA farmers, which attracts farmers to the IH (L11). They address the lack of practical knowledge (B10), but it was also reported that they didn't bring insights which increased the application of CA principles among farmers. The extend of demonstrations was until now limited to technical aspects and machinery, influenced by the focus of farmers on yield and big machinery (B22).

Another limited lever are the knowledge-exchange groups, which enable members to build up trust and share experiences honestly (L8). Conflicts in knowledge-exchange groups due to different mindsets (B29) can inhibit the members from gaining trust in the group. Knowledge-exchange groups contribute to knowledge-sharing between farmers (L28) and address the barrier of lacking practical knowledge (B10).

Finally, CO_2 certificates for CA (L17) are a limited lever. Disagreement about the relevance of CA for C sequestration (B2) and the value of CA soil not being considered in the value of the farm (B17) limit this lever, which has the potential to generate direct additional income (B18) from CA.

DISCUSSION

We developed an analytical framework to map AE initiatives to further their development towards agroecology as part of reflexive arrangements. The framework captures the context, the actor network, and the barriers and levers for the development of the AE initiative. The application of the framework to the case of the Danish Conservation Agriculture Network highlighted a highly technologized, export-oriented agriculture, with a focus on fodder crops in arable farming, under strict environmental policies, where many farms operate with high depths and low margins. Next to the core actors, key actors were related to policy and research, whereas policy actors were stronger related and closer embedded in the network. Key barriers and levers shed light on a broad range of themes in the development of the Danish IH, such as the role of consultancy and scientists, the construction of horizontal knowledge structures, the lack of financial reward for CA, the visibility of CA and the collaboration with a wide range of different actors.

In this section, I shed light on the position of the Danish IH in agroecological transition using the multi-level perspective. The state of technological, network and institutional anchoring is demonstrated using the main themes in the development of the Danish IH that emerged from the context-related analysis of actors and barriers and levers. In the reflections, the contributions of the analytical framework are highlighted and limitations are complemented with recommendations for further research.

A niche within the regime

From a multi-level perspective, AE initiatives are typically seen as niches which are external to the regime, characterized by a divergent structure and strong alternative values compared to the regime of conventional agriculture (Levidow et al. 2014, Morel et al. 2020). The Danish IH though shared certain values with the dominant regime, such as the focus on

high yields and the use of pesticides, whereas other values, such as the reduction or renunciation of tillage differed radically from the dominant regime. Referring to the actors being split into regime, niche and hybrid actors, where hybrid actors share some important rules with the regime but bring in new requirements which diverge from the regime (Elzen et al. 2012), the Danish IH could be characterized as hybrid – a niche within the regime.

From a multi-level perspective, the Danish IH aims to anchor CA in the regime. Three types of anchoring have been distinguished: Technological anchoring occurs when technical characteristics of an innovation become defined by involved actors. Network anchoring refers to a change in the network of actors that support the innovation. Institutional anchoring means the development of new rules related to the innovation, which can be cognitive, normative or economic (Elzen et al. 2012).

Technological anchoring: Consultants as knowledge facilitators

Technological anchoring appears in practical knowledge development and sharing in the Danish IH. The lack of practical knowledge about CA and minimum tillage in DK, which is the most central key barrier was estimated to be surpassed, indicated by the amount and variety of levers tackling it. Related key levers, which are all initiated by the consultancy company include the provision of a platform for farmers to discuss CA through the Healthy Soil conference, knowledge-sharing between farmers, demonstrations and knowledge-exchange groups which enable participants to build up trust and share experiences honestly. A focus on horizontal knowledge structures through a facilitative and participatory consultancy approach is recognizable, an approach which diverges from the dominant regime of centralized knowledge production and top-down knowledge diffusion (Anderson et al. 2019a).

Traditional, top-down consultancy has been questioned to be effective to address current challenges in agriculture (Landini et al. 2021, Krafft et al. 2022), as it neglects the complexity of systems and processes (Charatsari et al. 2019). Especially in CA, which is reliant on ecological processes, adjustment to the specific context is necessary and impedes the use of general recipes for its implementation (Cristofari et al. 2018). There is general agreement today that the role of consultancy goes beyond knowledge delivery. To further agroecological practices such as CA, more systemic, facilitative and participatory approaches of consultancy are needed (Heleba et al. 2016, Charatsari et al. 2019, Landini et al. 2021, Krafft et al. 2022), which requires consultants to be trained in new skills (Bourne et al. 2021, Krafft et al. 2022).

Consultancy which strengthens horizontal knowledge structures has the potential to enhance collective action and social learning and thereby plays a crucial role for agroecological transition (Anderson et al. 2019a, Bourne et al. 2021). Participatory learning processes enhance the development of farmers skills to solve complex problems arising in their specific context (Charatsari et al. 2019, Bourne et al. 2021, Krafft et al. 2022) and increase the diffusion of knowledge, which makes them highly effective (Ataei et al. 2019, Anderson et al. 2019a).

Still, the alternative approach of knowledge development and sharing in the Danish IH is hampered by the dominant regime. Our analysis identified the difficulty of changing the role of consultants and the limitation of consultancies to innovate due to their costumers expectations as key barriers with blocking effect, which appears also in literature (Krafft et al. 2022).

In summary, the consultancy company at the core of the Danish IH facilitates knowledge development and sharing among farmers through a variety of activities and thereby enhances farmers skills to solve complex problems, knowledge diffusion and collective action. This removed the barrier of the lack of practical knowledge for the future development of the IH, what indicates a successful technological anchoring process, even though the approach of the consultancy to strengthen horizontal knowledge structures is still challenged by the dominant regime.

Institutional anchoring: Contested knowledge as a blocker

Institutional anchoring of CA in Denmark is challenging. The network analysis emphasized the blocking effect of contested knowledge to the development of the Danish IH, indicated by the blocking key barriers of the disagreement about the relevance of CA for C sequestration and the university with a classical natural science approach which dominates authority advisory.

The disagreement about the relevance of CA for C sequestration emerges from different approaches of

verification among scientists and practitioners. In the dominant regime, the effects of farming practices are verified scientifically with on-station plot experiments. Aarhus University is running a split-plot experiment called CENTS on two different sites, which were established in 2002. Four different tillage treatments (direct drilling, harrowing to 3-4cm, harrowing to 8-10cm, and ploughing) combined with four different crop rotations are investigated, which mainly differ in the straw management (removed or chopped straw left on soil surface) (Hansen et al. 2010, Gómez-Muñoz et al. 2021). The crop rotations mainly consist of cereals. Catch crops are grown before spring crops in all rotations (Hansen et al. 2015). Comparing direct drilling and ploughing, the results of the experiment do not show differences in the soil organic C concentrations in the 0-50cm soil profile and also do not fully confirm a positive effect of straw retention on soil organic C content (Gómez-Muñoz et al. 2021). These findings do not match with practitioners perceptions of the changes of their soil with the transition to CA (Keyactor4 2023). It is questioned whether the CENTS plots are suitable to draw conclusions about the effects of CA on soil properties, because a successful application of CA lies in the combination of the three principles adapted to the local context, which is not the case in plot experiments (Rodenburg et al. 2020). Plot experiments, such as CENTS, produce generalizable agronomic insight but fail to seize the complexity of activities and interactions related to farming practices (Lacoste et al. 2022). Also, they are hard for practitioners to relate to (Lacoste et al. 2022, Keyactor3 2023). Practitioners of CA argue, that the effects of CA can only be found and therefore need to be measured on CA farms (Keyactor1 2023). The relevance of on-farm experiments was recently emphasized by a high-level publication, pointing out how the engagement with farming realities creates value for both, scientists and farmers (Lacoste et al. 2022). The approach of on-farm experiments challenges the current regime of plot experiments through working with a high variability of factors like climate, soil type and crop rotation (González-Sánchez et al. 2012, Anderson et al. 2019a).

Situations like the disagreement about the effect of CA on C sequestration, have been described as a wicked problems. Wicked problems are characterized through a lack of agreement on problem definition and conflicting values and interests (Xiang 2013). Uncertainty about ecological processes and conflicting social values have been found to be a breeding ground of wicked problems in socio-ecological systems (Norris et al. 2016). Challenging the development of the Danish IH and thereby institutional anchoring of CA is, that in the current regime the voice of natural scientists strictly working with on-station experiments is dominating, visible for example by Aarhus University who had the power to give advice about CA to the government in form of a white paper (Munkhom et al. 2020).

Network anchoring: Consultants as network constructors

Network anchoring unfolds in the collaboration of the Danish IH with different actors. The social network analysis highlighted the consultancy company as the most central and connected actor, which points out their crucial role for the Danish IH in forming bridging ties with external actors.

Heleba et al. (2016) pointed out a need for practitioners who construct networks, in order to enhance agroecological transition. This role can be taken by consultancies. Thereby they mobilize information and skills from outside and enhance collective action (Bourne et al. 2021, Krafft et al. 2022). The interviews indicated that the consultancy company Agrovi has recognized this potential and started to actively form ties with external actors to the IH, such as nature NGOs and the thinktank Frej.

Actors can be grouped in regime actors, niche actors and hybrid actors, which are part of both (Elzen et al. 2012). The network analysis emphasized the dominance of policy and research related actors, which besides FRDK included only regime actors. Policy key actors, such as the Danish Parliament, the Danish Government and the Agricultural Council shape the dominant regime of public policies and political power (Smith and Raven 2012), by which CA is not supported. Research key actors, such as Aarhus University, Copenhagen University and Seges reinforce the dominant regime of centralized knowledge production and top-down knowledge diffusion (Anderson et al. 2019a), which is contradictory to the horizontal knowledge structures in the Danish IH.

Hybrid actors play a crucial role for anchoring (Elzen et al. 2012, Diaz et al. 2013). They are key to exploit contradictions within the regime in order to change the regime (Diaz et al. 2013). In the network of the Danish

IH, next to the core actors, nature NGOs and the thinktank Frej can be considered as hybrid actors. Nature NGOs are embedded in the structures of the regime, but questioning regime values. Frej includes regime actors in their dialogues but disrupts dominant discourses.

The role of nature NGOs and Frej as hybrid actors confirms the potential of the influential key levers, which include the collaboration with nature NGOs and Frej. Especially the collaboration of a consultancy with nature NGOs is novel, considering that their value systems with regards to agriculture are usually opponent.

Furthermore, the social network analysis identified many economic actors to be loosely related and few societal actors to be involved. Considering the potential of hybrid actors, it could be interesting to expand networking with such actors in society and economy.

In summary, the consultancy company at the core of the Danish IH takes the role of network constructor. To conquer the dominance of regime actors, bridging ties with hybrid actors seems to be promising for network anchoring.

Impact of the reflexive arrangement

At the core of the reflexive arrangement in the Danish IH is the collaboration between social scientists from Roskilde University and consultants from Agrovi. The collaboration between social scientists and consultants was identified as a limited, relatively high connected key lever. It is limited by new forms of collaboration being hindered by tradition and two blocking barriers, which include the difficulty for consultants and scientists to leave the expert role and the university with a classical natural science approach which dominates authority advisory. Enablers are the powerful key lever of the agronomist working in social sciences and the influential key lever of Roskilde University's interdisciplinary and transdisciplinary approach. These levers influence facilitative advice and the barrier that consultants lack training in social skills for facilitation and co-creation with farmers.

The novelty of the collaboration between Roskilde University and Agrovi has been highlighted, referring to Roskilde University being associated with left-wing, whereas consultancies are typically in the liberal sector. The interviews brought to light, how they complemented each other in different situations. Through the incorporation of a range of perspectives, the collaboration of researchers from various disciplines with non-academic actors has the potential to generate contextualized and socially sound knowledge through and thereby contributes significantly to agroecological transition (Fernández González et al. 2021).

From a multi-level perspective, the contribution of the reflexive arrangement in the Danish IH until now unfolds mainly in technological anchoring processes. By strengthening the development of consultancy approaches which support horizontal knowledge structures, CA in Denmark will be further developed and more clearly defined. The reflexive arrangement is limited by traditional values and knowledge structures of the dominant regime. Still, considering the hybrid trades of the Danish IH, the reflexive arrangement has potential to support institutional and network anchoring by developing alternative approaches of knowledge verification and mobilizing hybrid research actors for it.

Reflections and prospects

The analytical framework to map AE initiatives was developed as part of the research project AE-T and will be applied to 10 other IHs which are part of the project. It furthers the in-depth analysis of AE initiatives through a systematic approach which is novel. The systematisation of qualitative data allows to compare AE initiatives, which are inherently very diverse. Thereby it fosters learning processes in reflexive arrangements and furthers up-scaling and out-scaling of agroecology.

The semi-qualitative context framework gives insight into diverse aspects of the context of AE initiatives. Even though the importance of understanding the context of AE initiatives is emphasized in similar approaches (Mottet et al. 2020b), such a systematic framework to capture the context of is new. It supports the analysis of AE initiatives by putting them into perspective and furthers the consideration of context in agroecology research. Still, the understanding of the context is limited to the included dimensions and elements, which were only tested for integrity with the case of the Danish IH. Considering the high diversity AE initiatives, further development through its application on AE initiatives in different places with focus on different farming practices or different parts of the value chain would increase its significance.

The social network analysis provides an overview over actors related to the AE initiative, their fields of action and the key actors. Understanding the role of different actors in the network is valuable for AE initiatives to mobilize actors strategically for their further development and contributes to the understanding of the impact of actor networks on agroecological transition processes.

The actor network is limited by the method of data collection, which was not designed to capture the relations between actors exhaustively and resulted in a focus on the interviewed actors in the network. Therefore the significance of the network metrics is limited in highlighting the relevance of relations external to the IH. To expand the understanding of the actor network surrounding the AE initiative, external actors which are related to the AE initiative would need to be included in data collection and more time to discuss the actor map in the interviews would need to be allocated.

The organisational level of the actor network required simplification by representing actors in terms of the organizations they work for and neglects relationships between individuals, which are crucial for the collaboration between different organisations. Key actors, such as the pioneer CA farmer who works for the consultancy and the agronomist who works in social sciences are visible in the levers but not in the actor network. The integration of human agency and the role of individuals in the actor analysis could significantly forward the impact of the framework (Gaitán-Cremaschi et al. 2022).

Our approach to analyse barriers and levers in a network is novel. It provides insight into the interrelations of barriers and levers and network metrics can be mobilized to highlight the functioning and effect of specific barriers and levers. It enables AE initiatives to recognize and understand their strengths and weaknesses and the impact of their actions and thereby furthers their development. From a research perspective, it allows to investigate the role of certain barriers and levers in agroecological transition.

The main limitation with regards to the barriers and levers is the selection of key actors as interviewees, which resulted in a limited perspective on the case study. All key actors are in outstanding and successful positions and therefore not representative for the actors involved in the Danish IH. Left out were for example farmers who are not fully converted to CA, even though they are the majority, plant production advisors, women and marginalized groups. A more comprehensive and critical understanding would be reached by interviewing a more representative sample of actors, including marginalized groups in the IH.

The analysis of barriers and levers in a network comes with constrains. The distinction of barriers and levers and the selection of their scope is subjective and affects the network metrics and thereby the key barriers and levers highlighted by the analysis. Also, the validation of the barriers, levers and their relations is limited due to time constraints and the network is likely to be incomplete. Further investigation of the potential of signed networks (Bonchi et al. 2019) and inquiry of additional network metrics, for instance structural balance property (Meng et al. 2022), is needed to strengthen the significance of analysing barriers and levers in a network.

CONCLUSION

We developed an analytical framework to map AE initiatives based on the three pillars context, actors and barriers and levers and applied it to the Danish Conservation Agriculture Network. The context was investigated with a framework based on the six dimensions biophysical environment, knowledge, society, policy and governance, economy and farming system. The application of the context framework to the Danish IH brought out a highly technologized, export-oriented agriculture, with a focus on fodder crops in arable farming, under strict environmental policies, where many farms operate with high depths and low margins. The Context pillar provided the basis for a context-related analysis of the actors as well as the barriers and levers.

Social network analysis gave an overview over related actors and gave insight into their roles in the network of the Danish IH. Next to the core actors, key actors were related to policy and research, whereas policy actors were stronger related and closer embedded in the network.

The network analysis of barriers and levers in a cognitive map brought out their interaction and highlighted key barriers and levers for the development of the Danish IH. Key barriers included the difficulty to change the role of consultancy and scientists, disagreement about the relevance of CA for C sequestration, the lack of support for CA through legislation, and the lack of practical knowledge. Key

levers included unusual collaborations with external actors, transdisciplinarity within the Danish IH, and knowledge development and sharing among farmers.

From a multi-level perspective, the Danish IH may be framed as a niche within the regime. Consultants engaging as knowledge facilitators and network constructors were found to enhance technological and network anchoring, whereas contested knowledge was identified as a blocker for institutional anchoring.

The framework provides a novel systematic approach for an in-depth analysis of AE initiatives. It can foster learning processes in reflexive arrangements with AE initiatives by providing scientific insights into the functioning of AE initiatives. Thereby it furthers up-scaling and out-scaling of agroecology and contributes to agroecological transition.

Contributions

This thesis was part of the research project Agroecology-TRANSECT and took place in close collaboration with researchers from CRA-W, namely Pauline Cassart, Adrien Swartebroeckx and Marie-Hélène Delhove. Anina Frei: Investigation methodologies, composition framework, development context framework, development interview procedure, preparation interviews (BE and DK), conduction interviews (lead), transcription, development actor analysis, development barrier and lever analysis, analysis Danish IH • Pauline Cassart: Investigation methodologies, composition framework, development interview procedure, conduction interviews (support), development actor analysis • Adrien Swartebroeckx: Investigation methodologies, composition framework, transcription • Marie-Hélène Delhove: Support development context framework, transcription

Journal of choice

The journal Ecology and Society has been selected for the paper format thesis to be oriented to.

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APPENDIX A

Descriptions investigated methods

Rapid Appraisal of Agricultural Knowledge Systems (RAAKS) provides a toolbox for the participatory assessment of the social organization of agricultural innovation systems to improve their performance (Engel 1997). Some tools are interesting to analyse the actors of agroecological initiatives. Especially the variety of diagrams and tables are inspiring to visualize the results.

Outcome Harvesting investigates social change in complex environments (Blundo-Canto et al. 2017). It works backwards from an outcome to identify its causes (Wilson-Grau 2019). For the analysis of agroecological initiatives, it might be difficult to define their current state as one specific outcome and the investigation of multiple outcomes would exceed the required level of depth and involve too much effort.

The **analytical framework for Sustainable Transition Labs** was developed to compare sustainability transition labs in their processes, effects and impacts. It consists of three pillars consisting of different categories (Holmén et al. 2022). This framework inspired us to compare qualitative data through a framework of different thematic categories.

Reflexive Monitoring in Action (RMA) provides participatory tools to improve the sustainability of system innovation projects (van Mierlo and Regeer 2010). Interesting for mapping is the system analysis through the IS framework, in which barriers and levers are related to actors and system features (Klein Woolthuis et al. 2005, van Mierlo and Regeer 2010, van Mierlo et al. 2010). Actors are analysed through the relation of their organisational level with their interest, which gives insight into their roles and who is interesting to involve for the future (van Mierlo and Regeer 2010). For mapping, this doesn't give enough insight into the relationships of actors. The causal analysis is interesting to deepen barriers. Starting from a central problem, the causes underneath are identified, creating a causal tree (van Mierlo and Regeer 2010). This is an inspiring perspective on how to deepen barriers and levers.

Reflexive Interactive Design (RIO) aims reorientate the current sociotechnical regime in order to solve sustainability issues. In focus is the resolution of a problem. Interesting for the mapping is the system analysis, in which the system is defined and key challenges and key actors and their needs are identified (Bos et al. 2009).

Cognitive maps reflect the perspective of an actor or a group of actors on a system through nodes which are linked through edges. The choice of the nodes defines what the map gives insight in (Vanwindekens et al. 2013). Edges can be weighted, resulting in a Fuzzy Cognitive Map (Averbuch et al. 2022). Cognitive maps are interesting to map the actors or the barriers and levers. They can also reflect parts of the context, which influence the initiative directly.

Social Network Analysis (SNA) investigates social structure through maps of nodes and edges, which represent actors and their relations. Through the analysis of the networks structural properties, its composition and diversity and the position and influence of actors, insights about the social network's potential to innovate are gained (Gaitán-Cremaschi et al. 2022). This methodology is interesting to map the actors of the IHs and analyse their relationships.

An outcome trajectory is defined as a system of interacting and co-evolving actors, knowledge, technology and institutions as a result of a policy. **Outcome Trajectory Evaluation (OTE)** analyses the outcomes of a policy by using a timeline and a suitable middle-range theory (Douthwaite et al. 2022). The approach of analysing an outcome trajectory is inspiring for mapping the evolution of the IHs, *but the method is too theoretical and specific.*

Agroecology Europe mapped the state of agroecology in Europe. An general analysis of individual countries was conducted, followed by an analysis of the country's initiatives through the identification of strengths and weaknesses with a set of categories. We have a similar goal of mapping agroecological initiatives, but aim to

analyse more in depth. The results of their study is a useful source of information for the context analysis (Agroecology Europe 2020).

The Critical Incident Technique (CIT) investigates events, processes or issues in order to gain an understanding of the barriers and levers of these critical events and how they are managed and perceived by actors. The interview procedure, which includes first an open-ended interview in which the interviewee tells the story of the project, and second the deepening of critical incidents, is interesting to investigate barriers and levers and the actors related to them (Gremler 2004).

Chaînes opératoires were developed to analyse technical processes including the involvement of actors. The process is broken down into a series of operations through two steps: First, drawing a trajectory and second deepening certain elements with the actor. The result is a diagram where the actions taken by actors are chronologically ordered (Coupaye 2009). This method is interesting to investigate barriers and levers and the actors involved.

Morel et al., 2020 used a multi-step procedure to **identify barriers** in towards crop diversification in food system innovation settings. Data is collected through the drawing of a problem tree in each innovation team and a complementary interview with each innovation team. The qualitative analysis of barriers was carried out through thematic matrix tools, followed by a multiple correspondence analysis (MCA) to relate barriers to food innovation settings (Morel et al. 2020). This approach was used in a similar setting as ours and is interesting to consider in order to map barriers and levers.

In the analysis of social sequences, common phases in trajectories of individuals are identified and typologized. In **social sequences and relational chain analysis**, Polge and Pagès (2022) combined the analysis of farmers trajectories with the analysis of relational chains, which focusses on the access of factors to resources. Their approach is interesting for mapping, as social sequence analysis enabled the identification of barriers and levers and the relational chain analysis is useful for the actor analysis. Furthermore, their typology of sequences and modes of access could be useful for mapping.

The **Tool for Agroecology Performance Evaluation (TAPE)** evaluates agroecological performance on farm or community level. The tool itself is not applicable at the level of IHs but there are some inspiring elements. Interesting for mapping the context is the first step which describes the main socio-economic and demographic characteristics of the system and its enabling environment including policy, market, technology, socio-cultural and historical drivers (Mottet et al. 2020b). Relevant actors are listed but the analysis doesn't reach the depth we aspire for.

MESMIS is a framework for the assessment of agricultural sustainability in different socio-ecological contexts (Cândido et al. 2015). Interesting for mapping are the first two steps. First, the description of the management system and the socioenvironmental context, which is interesting for the mapping of the context. Second, the determination of critical points, which are environmental, technical, social or economic factors that enhance or constrain the system (López-Ridaura et al. 2002) and can be associated with barriers and levers. Actors are part of the characterization of the management system but not analysed in depth.

APPENDIX B

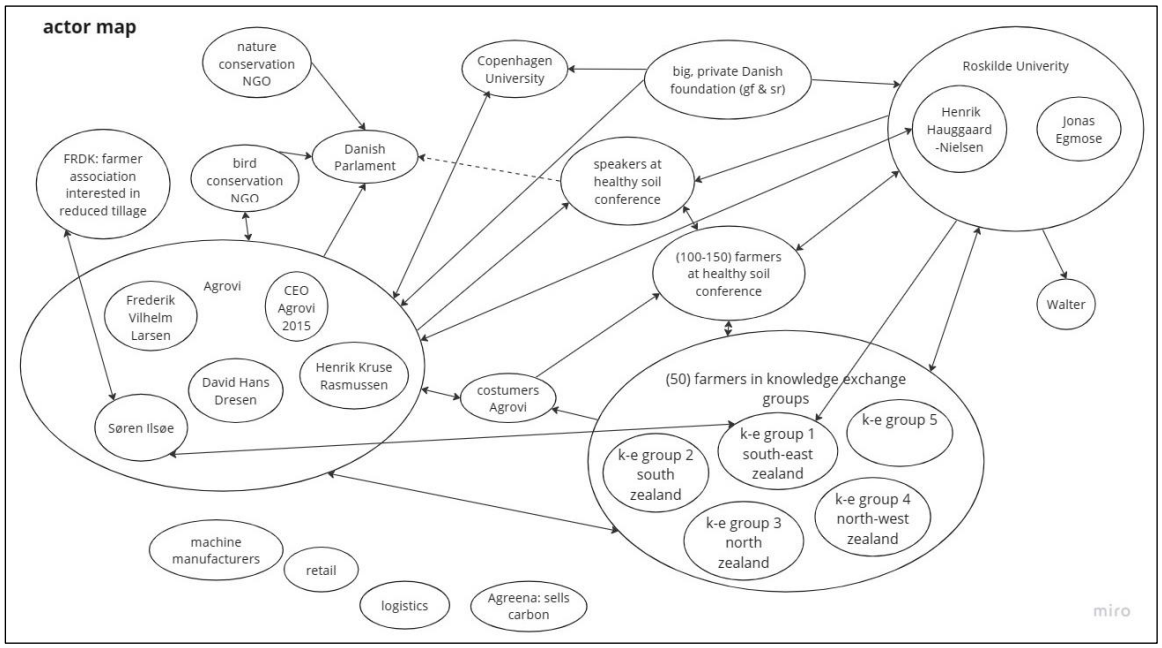
Table investigated methods

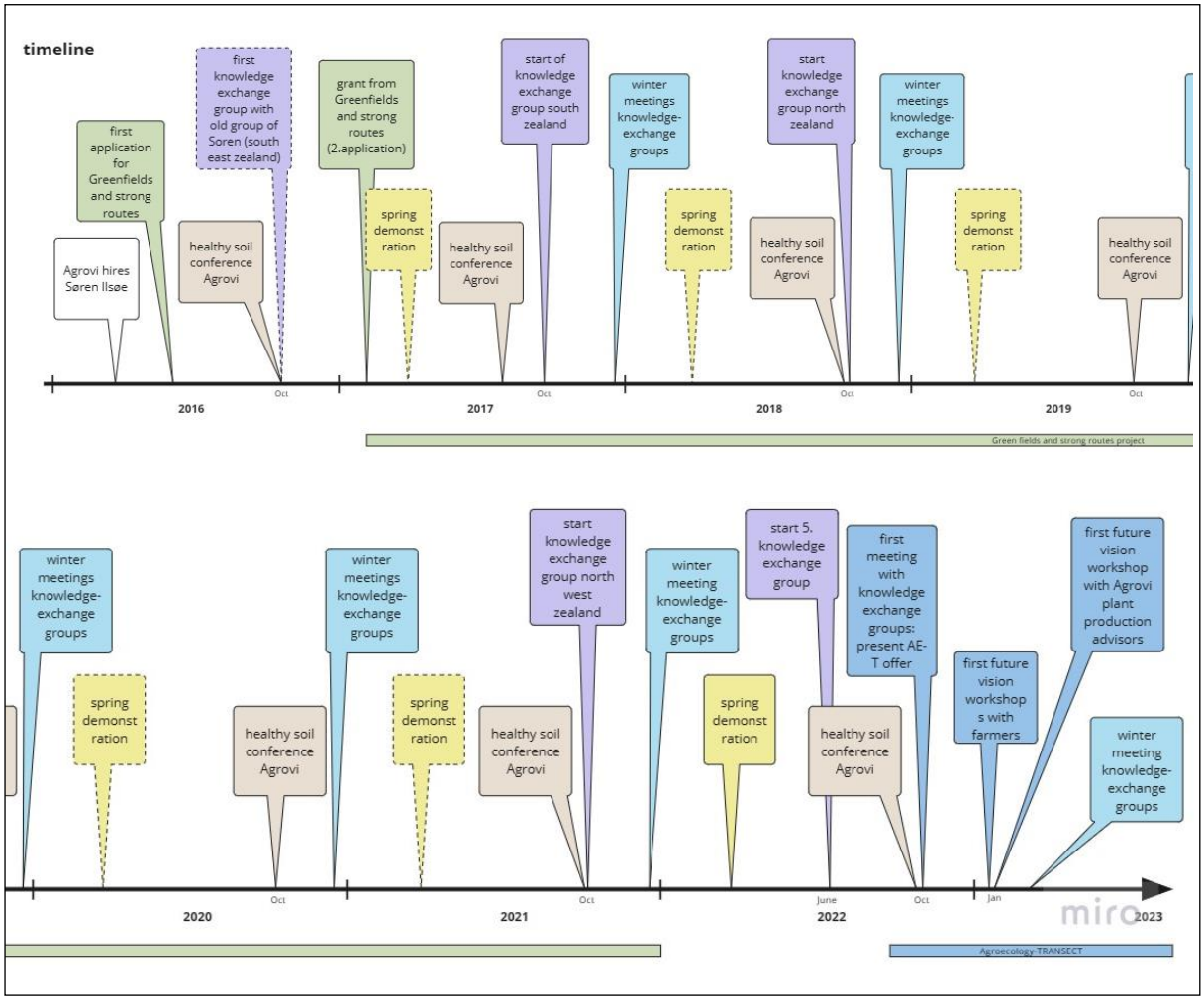
	Scope			Elements framework			Results		
	Scope	Level of AE initiative?	timeframe	Barriers and levers?	Actors, their impact and relationships?	Context?	Captured suitable?	Support AE initiatives?	Allow comparison?
RAAKS (Engel 1997)	agricultural knowledge systems	yes	present	no	yes	no	yes	yes	yes
Outcome Harvesting (Britt and Wilson-Grau 2012, Blundo-Canto et al. 2017)	system change initiative	yes	past	yes	impact	no	yes	yes	no
Analytical framework for Sustainable Transition Labs (Holmén et al. 2022)	sustainable transition labs	yes	present	no	partly	yes	partly	yes	yes
RMA (van Mierlo and Regeer 2010)	innovation system	yes	present	yes	yes	no	partly	yes	partly
RIO (Bos et al. 2009, van Mierlo et al. 2013, Elzen and Bos 2019)	innovation system	yes	present and future	yes	identification	yes	no	yes	no
Cognitive mapping (Vanwindekens et al. 2013)	flexible scope	yes	present	yes	yes	partly	yes	yes	yes
Social Network Analysis (Rocker et al. 2022)	social networks	yes	present	no	yes	no	yes	yes	yes
Outcome Trajectory Evaluation (Douthwaite and Hoffecker 2017)	policy change	no	past	yes	partly	partly	yes	no	no
Mapping agroecological initiatives (Agroecology Europe 2020)	agroecological initiatives	yes	present	no	no	yes	yes	no	no
Critical Incident Technique (Gremler 2004)	flexible scope	yes	past and present	yes	yes	partly	yes	yes	no
Chaines opératoires (Coupaye 2015)	flexible scope	yes	past and present	yes	yes	partly	yes	yes	no

Characterising barriers (Morel et al. 2020)	food system innovation settings	yes	past and present	barriers	partly	partly	yes	yes	yes
Social sequences and relational chain analysis (Polge and Pagès 2022)	flexible scope	yes	past	yes	yes	partly	yes	yes	yes
TAPE (STEP 0 and 1) (FAO 2018)	farm	no	present	no	partly	yes	yes	no	yes
MESMIS (López-Ridaura et al. 2002)	flexible scope	yes	present and future	yes	partly	yes	yes	yes	partly

APPENDIX C

Interview materials





APPENDIX D

Interview guide

INTRODUCTION (15 min)

Introduce us and the project

- **Interviewers:** who are we and what are our roles in the interview
- **Task 4.1:** To gain an understanding of IHs for the project by exploring their history, network of actors and barriers and levers. Our outcomes support others in the project to understand the IHs but will also support the IH to develop their action plans and move further in their agroecological transition.
- **Aim of the interviews:** get different perspectives on the same IH, deepen our understanding of most significant events (and thereby find barriers and levers to the IH's agroecological transition and learn more about actors of the IH, their contribution and the relationships between them).
- **What makes interview interesting for interviewee:** reflection can give new insights about evolution, challenges and successes of the IH, new perspective on the IH, give ideas on how to deal with current challenges.
- **Procedure:**
    - Present timeline & actor map. Indicate that the timeline & actor map has been constructed on the basis of information received earlier. The Learning Histories and carousel activity of CIW1 were used as a starting point for its development.
    - Part 1: focus on timeline. Discuss the 2-3 most significant events according to you, our goal is from that to find the barriers and levers encountered and analyse the network of actors.
    - Part 2: complement map of actors. The supportive interviewer will mark the actors that are mentioned during Part 1.
    - Part 3: actor's perception of agroecology (WP2).
    - Part 4 (with IH facilitator only): specific questions about context and review the timeline.

Confidentiality and privacy

- No personal data shared with any third-party companies
- Anonymous results
- Ask permission to record interviews
- Make the actor sign the letter of consent (Annex)

Get to know the interviewee

- For us and the project it is very important to get the views of different actors on the IHs: to understand the IH, its actors' network and the barriers and levers faced
- We understand you are *eg a farmer who does strip cropping*. Can you describe a bit more about what you are doing?
- How do you see your role in the *IH*?

PART 1: DEEPEN EVENTS: BARRIERS, LEVERS AND ACTORS INVOLVED (60 min)

Now, we would like to learn about events that were crucial for the evolution of the *IH* from your perspective.

Timeline & most significant events

- Present the timeline & go through the events with the actor
    - Idea: get a deeper understanding of some of these events and through that find out what barriers and levers were involved
- Are there events that seem significant for you, you would like to add to the timeline?
- Which of those events were significant for you for the development of the IH? (Choose around 3 events)
- Can you explain us how it happened? Why was it so significant?

Possible questions to ask for barriers and levers (for the events discussed):

- What where the barriers/challenges/problems, which this event addressed / changed / solved / dealt with?
- What makes it a problem in your eyes? *(get an understanding of their understanding of subjective terms like "problem" or "difficulty")*
- What was crucial to solve the barrier / problem?
- How did it *(any type of lever mentioned) * solve the problem?
- What do you think was the reason it could be solved?
- What resulted from *this event*? What did it change? What were the consequences of the event?

Questions for actors

- Who was involved? Which people/connection of people were / was crucial for this?
- How was *actor* involved? What did *actor* do / contribute?
- How was *actor* related to other actors of the IH at that moment?

General questions to deepen

- Can you tell more about that?
- Can you explain that?
- Do I get it right that…?

To complement

- Are there still open points for you?
- Are there things we left out but would be important to talk about?

PART 2: ACTOR MAP (30 min)

Present marked actor map

- Are there other people/institutions involved, we don't have on the map? Are there actors who were involved, but are not anymore? Are there new actors, that start to become important?
- How are the actors we didn't talk about yet, related to the other actors?
- Are there relationships missing? What kind of relationship are they?
- Are there other people/institutions involved, we didn't mention yet? What is their influence on the *IH*? What is their role? How do they relate to the *IH*?
- Who do you talk to about the *activities of the IH*?

PART 3: REVIEW TIMELINE (IH facilitator only) (10 min)

We are finished with the main part of the interview now. For today, we wanted this timeline to be as complete as possible. However, do you feel that we should change it for the interviews with the key actors? If so, which events should not be mentioned?

CONCLUSION (5 min)

- Thank you very much for taking the time! It was very insightful and helped us to understand the *IH* better.
- Info about next contact
  Facilitator: we will analyse the data and come back to you to validate results
  Key actor: we will analyse the data and come back to the IH once we have results to share, reports finished in November 2023
- Can we come back to you, if we have questions?

Keep recorder on.

APPENDIX E

Relations actor map

Actor1	Actor2	Weight	Type relationship	Description relationship
Danish Crown	Agricultural Council	1	influence	one of the major companies controlling agricultural council (Keyactor4 2023)
Danish Agro	Agricultural Council	1	influence	one of the major companies controlling agricultural council (Keyactor4 2023)
DLG	Agricultural Council	1	influence	one of the major companies controlling agricultural council (Keyactor4 2023)
Arla	Agricultural Council	1	influence	one of the major companies controlling agricultural council (Keyactor4 2023)
Agricultural Council	Danish Government	1	influence	agricultural council has access to ministries, negotiates directly with politicians (Keyactor4 2023)
Agricultural Council	Agrovi	1	influence	Agricultural Council controlling main national advisory body and many local advisory centres. Agrovi independent, but also a member of that (Keyactor4 2023)
DOF	Danish Parliament	1	influence	Two powerful nature NGOs [DOF, DN] which are very close to the Parliament (Facilitator 2 2022)
DN	Danish Parliament	1	influence	Two powerful nature NGOs [DOF, DN] which are very close to the Parliament (Facilitator 2 2022)
DOF	Agrovi	2	GMSR	Contact with NGOs [DOF, DN, DJ] in green fields and strong routes project (Keyactor3 2023)
			Bird counting	Counted birds on Sørens farm (Facilitator 1 2022)
DN	Agrovi	2	speech	Speech at Healthy Soil conference from agricultural employee of Danish Natural Protection Organisation (Keyactor1 2023)
			GMSR	Contact with NGOs [DOF, DN, DJ] in green fields and strong routes project (Keyactor3 2023)
DJ	Agrovi	1	GMSR	Contact with NGOs [DOF, DN, DJ] in green fields and strong routes project (Keyactor3 2023)
Frej	Agrovi	2	collaboration	We [Agrovi] had some collaboration with an organisation called Frej (Keyactor3 2023)
			support admin	Agrovi made Frejs' tax report (Keyactor3 2023)
Agrovi	ECAF	1	board	Employee was board member of the Danish minimum tillage organisation ECAF (Keyactor1 2023)
Agrovi	Carlsberg	1	meetings	Agrovi had meetings with Carlsberg (Keyactor1 2023)
journalists	Agrovi	1	visit	Visits of journalists on farm of employee (Keyactor1 2023)
Agrovi	Agreena	2	employees	Some employees from Agrovi work for Agreena now (Keyactor1 2023)
			exchange	Agrovi interested in Agreena and support them with information (Keyactor1 2023)

Agreena	Farmers	1	certification	Agreena bought carbon credits of two CA farmers of the IH (Keyactor1 2023, Keyactor2 2023)
Agrovi	Farmers	7	visit	Farmers from farming schools and universities come to visit Agrovi (Keyactor1 2023)
			Healthy Soil conference	Between 100 and 150 farmers come to Healthy Soil conference (Facilitator 2 2022)
			knowledge-exchange groups	5 knowledge-exchange groups were built over the years (Facilitator 1 2022)
			AE-T	Core actors of AE-T; 50 farmers committed (Facilitator 1 2022)
			advise	Agricultural advise on plant production systems (Keyactor2 2023, Keyactor3 2023)
			demonstrations	Agrovi organized demonstrations for farmers (Keyactor3 2023)
			speech	Søren invites inspiring CA farmers to give speeches at Healthy Soil conference (Keyactor3 2023)
Agrovi	Danish Parliament	2	Healthy Soil conference	We have had politicians at Sørens farm discussing this way of farming (Facilitator 1 2022)
			speech	Agrovi gave speeches to the part of the parliament that has to do with environment and farming (Keyactor1 2023, Keyactor3 2023)
Agrovi	FRDK	4	GMSR	Contact with FRDK especially during the Green Fields and Strong Roots project; speech of Agrovi at Parliament was enabled by FRDK (Keyactor3 2023)
			foundation	FRDK was founded by Søren and colleagues (Facilitator 2 2022)
			board	Søren was vice chairman, now Frederik is part of the board (Keyactor3 2023)
			knowledge exchange	Søren has been moving knowledge from Agrovi to FRDK (Keyactor3 2023)
FRDK	Danish Parliament	1	lobbying	FRDK created access to Parliament for Agrovi; “I would also call them lobbyists” (Keyactor3 2023)
Aarhus University	FRDK	1	CarbonFarm	CarbonFarm project (Keyactor1 2023)
Agrovi	Aarhus University	1	research project	New project about non-chemical weed control with a new system (Keyactor1 2023)
Seges	Agrovi	2	Plantekongres	Two day conference in Herning, mostly for advisors (Keyactor2 2023)
			umbrella	Seges is kind of an umbrella organisation […] Agrovi can get supervision from Seges (Keyactor2 2023)
Agrovi	Velux Foundations	1	GMSR	GMSR (Green Fields and Strong Roots) project (Facilitator 1 2022)
Copenhagen University	Agrovi	1	GMSR	GMSR (Green Fields and Strong Roots) project; Copenhagen University got the grants, but that was just technical, because Agrovi took the initiative (Keyactor3 2023)
Velux Foundations	Copenhagen University	1	GMSR	GMSR (Green Fields and Strong Roots) project (Facilitator 1 2022)

Aarhus University	Danish Parliament	1	advice	Aarhus University wrote white paper for parliament (Keyactor3 2023)
Danish Government	Farmers	1	subsidy	Danish Energy Department gives farmers support to buy a direct drill (Keyactor2 2023)
Farmers	FRDK	1	member	Some farmers of the knowledge-exchange groups are part of FRDK (Keyactor3 2023)
Agrovi	RUC	4	GMSR	GMSR (Green Fields and Strong Roots) project (Facilitator 1 2022)
			Climate-CAFE	Climate-CAFE started collaboration between Henrik HN and Søren through old knowledge-exchange group of Søren (Keyactor3 2023, Keyactor4 2023)
			AE-T	Core actors of AE-T (Facilitator 1 2022); RUC invited Agrovi to join project (Keyactor3 2023)
			reMIX	RUC needed contact to farmers for reMIX and asked Agrovi (Keyactor3 2023, Keyactor4 2023)
Agrovi	Machine manufacturers	1	demonstration	The machine manufacturers who join Agrovis' demonstrations (Keyactor1 2023)
Machine manufacturers	Farmers	1	buy	Farmers buy machines such as direct drill (Keyactor2 2023)
RUC	Farmers	3	Climate-CAFE	Collaboration with old knowledge-exchange group of Søren through Climate-CAFE; still in touch with them (Keyactor4 2023)
			AE-T	core actors of AE-T (Facilitator 1 2022); future vision workshop with two groups of farmers (Keyactor4 2023)
			paper	RUC publishing a paper about a CA farmer (Keyactor4 2023)
Seges	Farmers	2	Plantekongres	Farmers are now also invited to Plantekongres of Seges (Keyactor2 2023)
			IPM project	IPM project of Seges about pesticides including a CA farmer; enables farmer contact to agricultural experts (Jensen 2023, Keyactor2 2023)
Seges	Danish Government	1	contact	"And they [Seges] are very much in contact with the Environment Ministry (Keyactor2 2023)
RUC	WUR	2	Climate-CAFE	Climate-CAFE (Vermue 2015)
			AE-T	Agroecology-TRANSECT; support from European colleagues [WUR, INRAE…] (Keyactor4 2023)
RUC	INRAE	2	AE-T	Agroecology-TRANSECT; support from European colleagues [WUR, INRAE…] (Keyactor4 2023)
			Climate-CAFE	Climate-CAFE (Vermue 2015)
EU	RUC	3	reMIX	ReMIX was a Horizon 2020 project (ReMIX 2018)
			Climate-CAFE	Climate-CAFE was a European project (Keyactor4 2023)
			AE-T	Agroecology-TRANSECT
EU	WUR	2	Climate-CAFE	Climate-CAFE (Vermue 2015)

			AE-T	Agroecology-TRANSECT
EU	INRAE	2	Climate-CAFE	Climate-CAFE (Vermue 2015)
			AE-T	Agroecology-TRANSECT
Aarhus University	Copenhagen University	1	Climate-CAFE	CarbonFarm project (FiBL 2022)
Copenhagen University	FRDK	1	CarbonFarm	CarbonFarm project (FiBL 2022)
EU	Agrovi	1	AE-T	New to Agrovi to be part of an EU project (Keyactor4 2023)
Danish Government	Danish Parliament	1	state	part of the Danish state
Danish Government	EU	1	Europe	part of Europe
ECAF	EU	1	Europe	ECAF is the European Organisation for Conservation Agriculture; almost all European countries are members (Keyactor1 2023)

APPENDIX F

Network metrics actors

Actor	Field of action	Degree	Weighted Degree	Closeness Centrality	Homepage
Aarhus University	research	4	4	0.481481	https://international.au.dk/
Agreena	economy	2	3	0.464286	https://agreena.com/
Agricultural Council	policy	6	6	0.541667	https://agricultureandfood.dk/
Agrovi	consultancy	19	37	0.787879	https://www.agrovi.dk/#
Arla	economy	1	1	0.356164	https://www.arla.dk/
Carlsberg	economy	1	1	0.448276	https://www.carlsberggroup.com/
Copenhagen University	research	4	4	0.472727	https://www.ku.dk/english/
Danish Agro	economy	1	1	0.356164	https://danishagro.com/
Danish BirdLife	policy	2	3	0.464286	https://www.dof.dk/en
Danish Crown	economy	1	1	0.356164	https://www.danishcrown.com/en-gb/
Danish Government	policy	5	5	0.490566	
Danish Hunting Association	policy	1	1	0.448276	https://www.jaegerforbundet.dk/
Danish Parliament	policy	6	7	0.5	
Danish Society for Nature Conservation	policy	2	3	0.464286	https://www.dn.dk/home/english-page/
DLG	economy	1	1	0.356164	https://www.dlg.dk/
EU	policy	6	10	0.52	
European CA Federation	policy	2	2	0.481481	https://ecaf.org/ecaf/
Farmers	farmers	7	16	0.530612	
FRDK	policy	5	8	0.490566	https://frdk.dk/
Frej	policy	1	2	0.448276	https://www.taenk-frej.dk/
INRAE	research	2	4	0.356164	https://www.inrae.fr/en
journalists	society	1	1	0.448276	
machine manufacturses	economy	2	2	0.464286	
Roskilde University	research	5	14	0.509804	https://ruc.dk/en
Seges	research	3	5	0.472727	https://international.au.dk/
Velux Foundations	economy	2	2	0.45614	https://veluxfoundations.dk/en
Wageningen University and Research	research	2	4	0.356164	https://www.wur.nl/

APPENDIX G

Barriers and levers

ID	Name	Description
B1	Lack of scientific knowledge about the effect of CA on C sequestration in soils	Plot experiments cannot reflect CA and reduced tillage sufficiently, because the implementation is farm specific and the soil changes over time. On the other hand, comparing the effects of CA on farms is difficult, due to high variability of conditions (Keyactor1 2023, Keyactor4 2023).
B2	Disagreement about the relevance of CA for C sequestration	Different approach of verification among scientists from different disciplines and practitioners. Natural scientists don't measure what practitioners observe (Keyactor1 2023, Keyactor2 2023, Keyactor4 2023).
B3	University with classical natural science approach dominates authority advisory	Aarhus University department of Agroecology, which has a classical natural scientific approach, is dominating the authority advisory and advised the government through a white paper on CA. Farmers voices are not heard on the political level (Keyactor1 2023, Keyactor4 2023).
B4	New forms of collaboration are hindered by tradition	New types of collaboration diverge from traditions and are challenged by different aims and expectations of the actors (Keyactor4 2023).
B5	Difficult for consultants and scientists to leave the expert role	Expert role is expected from them and associated with prestige. Consultants especially don't want to disappoint farmers expectations (Keyactor3 2023, Keyactor4 2023).
B6	Consultancy company limited in innovation which doesn't fulfil their costumers expectations	The consultancy company is dependent on their customers and adjusts the activities they engage in to their customers' requirements (Keyactor3 2023).
B7	Consultants lack training in social skills for facilitation and co-creation with farmers	Consultants received only technical education and are challenged by social interactions with farmers (Keyactor4 2023).
B8	Challenge to keep Healthy Soil conference interesting for frontrunners	Levels of experiences among CA farmers are increasing, what makes it difficult to provide them with new information to sustain their interest in the Healthy Soil conference, where they are key for knowledge-sharing among farmers (Keyactor4 2023).
B9	Risk of reduced yield due to CA	Especially in the conversion and the years when SOM is still low, there's a risk of a reduced yield. Different factors are more challenging with CA: slugs due to reduced mechanical disturbance; establishment of spring crops because the soil takes longer to dry; equal distribution of residues on the field and higher reliance on soil conditions (Keyactor1 2023, Keyactor2 2023).
B10	Lack of practical knowledge about CA and minimum tillage in DK	Practical knowledge is limited to the context-specific experiences of a minority of farms that practise CA and minimum tillage in DK (Keyactor3 2023, Keyactor4 2023).
B13	Current legislation not supporting CA	Politicians are not aware of CA and therefore CA is not supported through legislation (Keyactor2 2023, Keyactor3 2023).
B14	Use of glyphosate	Glyphosate is used in CA to kill previous crops and weeds. Pesticide use, especially Glyphosate is not well-perceived by society and possibly going to be limited by policies (efsa 2022, Keyactor2 2023).
B15	Lack of understanding of CA in society	Difficult to explain the environmental advantages of CA because of its pesticide use. Glyphosate use makes it hard to differentiate from conventional farming and therefore to compete with organic farming (Keyactor2 2023, Keyactor3 2023).
B12	Lack of visibility of CA in society	Consumers don't know that CA exists and there is no possibility for them to choose it in the supermarket (no brand) (Keyactor1 2023, Keyactor2 2023).
B16	Agricultural council representing interests of major companies and majority of farmers	The agricultural council has major influence on the parliament and legislation. It changed from being a farmers cluster to a food cluster, representing big food companies and the majority of farmers. It has no interest to support CA (Keyactor4 2023).

B17	Value of CA soil not considered in value of farm	Real estate doesn't recognize the value of CA fields when estimating the value of a farm (Keyactor4 2023).
B18	No direct additional income from CA	Despite indirect factors (cost reduction, less time in the field etc.), CA does not generate a direct additional income (Keyactor2 2023, Keyactor3 2023, Keyactor4 2023).
B19	Lack of investment in development of CA	CA not considered as big business and even reduces the market for some of the traditional suppliers, what results in a lack of investments in the development of CA (Keyactor1 2023).
B20	Many farmers are too old to change their farming practices	For old farmers the effort and risk to change farming practice is too high, considering the few years they will keep farming (Keyactor2 2023, Keyactor3 2023).
B22	Farmers' focus on yield and big machinery	Farmers traditionally measure their success on high yields and are interested in big machinery (Keyactor2 2023, Keyactor4 2023).
B23	Difficult social position for CA farmers	Critique from colleagues brings CA farmers in a difficult social position (Keyactor1 2023, Keyactor4 2023).
B24	Masculinity in agriculture	Most farmers in Denmark are males. Many farmers love technology and recognition is received for hardware such as big machinery or expensive buildings, but CA goes the opposite way. Also, showing vulnerability is not allowed (Keyactor4 2023).
B25	Cultivation of rented land	Currently, many farms increase their rented land activities. Investing in the long-term resilience of rented land is not motivating (Keyactor2 2023, Keyactor4 2023).
B28	Knowledge in IH gets lost	No documentation of shared knowledge and trials are not followed up upon (Keyactor1 2023).
B29	Conflicts in knowledge-exchange group due to different mindsets	Farmers have different motivations for CA (economic vs. idealistic). Discussions are furthermore influenced by hierarchical structures and power relations in the group (Keyactor4 2023).
B30	Limited capacity of key person	Søren Ilsøe is a key person and involved in many different activities (Keyactor3 2023).
B31	Difficult for consultancy to find funding	It is challenging for Agrovi to find projects or funding to further develop CA (Keyactor3 2023).
B34	Focus on technical aspects in agricultural education leads to neglect of social aspects	Social skills not part of the curriculum at universities neither at technical schools. There is a lack of awareness about the importance of training advisors in social skills (Keyactor4 2023).
B35	Farmers education: plough is part of farming	Ploughing is taught as an inherent part of farming in farmers education (Keyactor2 2023).
B36	Financial pressure on farms	Farms in DK often work with a low margin and high debts (Grivins et al. 2021, Keyactor3 2023).
B37	Not possible to assure that the next generation continues CA	When the farm is passed on to the next generation, they are free to decide on their farming practices (Keyactor4 2023).
L1	Collaboration between social scientists and consultants	This collaboration is novel, especially as the social scientists work at a university associated with left-wing, whereas consultancies are typically in the liberal sector. On the basis of open minds from both sides, their different skills and perspectives create a high potential for innovation and they complement each other in different situations (Keyactor3 2023, Keyactor4 2023).
L2	Facilitative advice	To apply context-specific farming practices such as CA, farmers knowledge is essential to consider. Rather than giving recipes, consultants can take a more facilitative approach when giving advice to farmers, which includes asking questions and finding solutions together (Keyactor4 2023).
L3	Collaboration between social scientists and farmers	Scientists are present in events for farmers provided by consultancy and thereby approachable. In the project, scientists facilitate future vision workshops for farmers. Scientist report the inspiration and motivation they get from interactions and critical discussions with farmers (Keyactor4 2023).

L4	Healthy Soil conference provides a platform for farmers to discuss CA	The Healthy Soil conference is an event of Agrovi to promote CA. The farmers are divided in small groups which enables them to chat and discuss and encourages them to speak up and discuss at the posts, what they really enjoy (Facilitator 1 2022, Facilitator 2 2022).
L5	EU support and funding enables further development of IH	EU supports multi-actor approaches what made it possible for the IH to get into AE-T. They get funding but consultants and farmers are not fully convinced that the outcomes are worth the effort (Keyactor4 2023).
L6	Experiments for pesticide reduction	Agrovi is part of non-chemical weed control project with Aarhus University. A CA farmer takes part in an experiment of Seges that investigates reduction of pesticides in CA compared to other tillage practices (Keyactor2 2023, Keyactor3 2023).
L7	Fascination about (living) soil motivates farmers for CA	The fascination of (CA) farmers for soil and inspiration through observing and understanding it (Keyactor2 2023, Keyactor4 2023).
L8	Knowledge-exchange groups enable to build up trust and share experiences honestly	Trust in the group facilitates a more honest and critical sharing of experiences what furthers fruitful discussions that enhance the development of CA (Keyactor4 2023).
L9	Reduced farming costs through CA are motivating farmers	CA reduces fuel consumption, use of big machinery and soil cultivation tools (plough) and labour time. But when economic motivation overrules biological fascination, positive environmental effects are sometimes reduced (Keyactor1 2023, Keyactor2 2023, Keyactor3 2023, Keyactor4 2023).
L10	Knowledge-exchange groups create identity of being pioneers	The knowledge-exchange groups bring together pioneer CA farmers and farmers that are especially interested in CA. This creates a feeling of being pioneers (Keyactor4 2023).
L11	Agrovi being an attractive consultancy for CA farmers attracts farmers to IH	Agrovi gives powerful and clear advise and they provide different services to support CA farmers (Keyactor2 2023).
L12	Connect CA to food to promote it	Food is closer to society than farming. A prominent chef from Copenhagen mentioned CA (Keyactor4 2023).
L13	Collaboration with nature NGOs	Nature NGOs are a connection to society and politicians. Traditionally, they disagree with CA due to pesticide us but through a collaboration, DOF stated its relevance for biodiversity (Keyactor3 2023, Keyactor4 2023).
L14	Collaboration with thinktank Frej	Agrovi supported Frej with their tax report and later on collaborated with them, for Frej to promote CA (Keyactor3 2023).
L15	FRDK grouping CA farmers	FRDK brings CA farmers together and fights politically for their interests (Keyactor1 2023, Keyactor3 2023).
L16	Bring CA farmers in contact with politicians	CA farmers are frustrated about not being considered by politicians. Bringing them in contact with politicians provides a platform for discussions (Keyactor2 2023, Keyactor3 2023).
L17	CO_2 certificates for CA	The company Agreena sells CO_2 certificates for CA, what provides CA farmers an additional income (Keyactor1 2023, Keyactor2 2023, Keyactor3 2023, Keyactor4 2023).
L18	Big companies asking for RA products	Big companies such as Carlsberg react on environmental issues on the political agenda with an interest in regenerative agriculture (RA). This could equate with an interest in CA but RA is inspired by organic which is opponent to CA farmers believes. Also there is a risk for greenwashing (Keyactor1 2023, Keyactor2 2023, Keyactor4 2023).
L20	Grant from a foundation	A grant from Velux foundation enabled the Green Fields and Strong Roots project (GMSR) (Keyactor1 2023)
L21	Get in contact with young farmers	Many farmers are old and therefore reluctant to change their farming practices. It is therefore important to find young ambassadors (Keyactor3 2023, Keyactor4 2023).
L22	CA is a more interesting way of farming	CA farmers spend more time in the field to observe the soil and less time on the tractor (Keyactor2 2023).

L23	Collaboration with universities provides access to funding for consultancy	The collaboration with Copenhagen University enabled Agrovi to get funds from Velux Foundations and the collaboration with Roskilde University enabled them to get into AE-T (Keyactor3 2023).
L24	High yields and increased farm robustness through CA is motivating farmers	CA increases long-term resilience in relation to erosion and drought and thereby sustains robustness of yield (Keyactor3 2023, Keyactor4 2023).
L25	Stories of inspiring CA farmers show that CA can work	Good stories or visits of inspiring farmers where CA works. They are challenged by CA farmers which are mainly economically motivated, because that may reduce their positive environmental impact (Keyactor1 2023, Keyactor4 2023).
L26	Contact with agricultural experts is assuring when trying something new	A CA farmer reported the contact to experts to be assuring in the conversion. But expert conservatism can also hinder innovation (Keyactor2 2023, Keyactor4 2023).
L27	Access to knowledge through social media	Social media is an independent source for knowledge-sharing but requires critical thinking and competences (Keyactor4 2023)
L28	Knowledge-sharing between farmers	When farmers discuss about CA and share their experiences (Keyactor4 2023).
L29	Newsletter of Agrovi supports farmers in current issues	Reports about newest knowledge developments related to CA in Denmark (Keyactor3 2023).
L30	Demonstrations	Demonstration of drilling machines with follow up after crop establishment (Keyactor1 2023, Keyactor3 2023). So far the focus was too much on machinery and too little on biological interactions (Keyactor4 2023).
L31	Young advisors taking over some of Sørens tasks	They have more time than Søren and thereby give him more time for other tasks (Keyactor3 2023).
L32	Pioneer CA farmer working for consultancy	Søren Ilsøe is a pioneer CA farmer in Denmark but also working for the consultancy company Agrovi, which is exemplary (Keyactor3 2023, Keyactor4 2023).
L34	Roskilde University's interdisciplinary and transdisciplinary approach	Roskilde University encourages collaboration between scientists of diffeent disciplines and collaboration of scientists with practitioners (Keyactor4 2023).
L35	Collaboration between scientists of different disciplines	An educated agronomist works together with social scientists (Keyactor4 2023).
L36	Build up trust in collaboration relationships	In the example of a relation between farmers and a scientist, personal interaction, giving it time and find common ground were key to build up trust which enabled an openness about challenges which is essential for a fruitful collaboration (Keyactor4 2023)
L37	Agronomist in social sciences	Henrik Hauggard-Nielsen is an educated agronomist and now works with social scientists and participatory research approaches (Keyactor4 2023)
L38	Connect to political actors by inviting them to give a speech at the Healthy Soil conference	Agrovi invited NGOs and politicians to give a speech at the Healthy Soil conference (Keyactor3 2023).
L39	Knowledge-exchange groups enable farmers to be at the source of CA development in DK	The knowledge-exchange groups bring together farmers that are interested in CA. They meet on farms and therefore see what the others are doing. The groups are a place where the farmers can get the latest news on CA but sometimes also create collective conclusions which might not be supported by newest research or experiences (Keyactor4 2023).
L40	Being part of the future is motivating farmers for CA	Voice of farmer to rather be part of the future than part of the past. But also many farmers are concerned about the future of the farming business and lose their trust in it (Keyactor2 2023, Keyactor4 2023)