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Research

A heuristic framework to portray agroecological transition initiatives in reflexive arrangements, illustrated with a conservation agriculture network in Denmark

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ABSTRACT. Agroecology has been proposed as an answer to the current global agri-food system crises. Transformation to agroecological agri-food systems can be enhanced through collaboration between societal agroecological initiatives and scientists in reflexive arrangements. Effective collaboration is fostered by a shared understanding of the history and current state of the societal initiative among all participants of the reflexive arrangement. To achieve this, we developed a heuristic framework to outline agroecological initiatives at the start of a reflexive arrangement based on three pillars: (1) context; (2) actors; and (3) barriers and levers. In this study, we present the framework and illustrate its application to an initiative, specifically an established Danish conservation agriculture (CA) network identified as a driver in agroecological transformation with its collaborative and knowledge-sharing approach for biodiversity enhancement, soil health, and input reductions. Drawing on a literature review, context information was categorized into six dimensions: (1) biophysical environment; (2) knowledge; (3) society; (4) policy and governance; (5) economy; and (6) farming system. Key actors within the network and key barriers and levers were identified from interviews with a limited number of diverse actors, applying network metrics as part of cognitive mapping and social network analysis. Applying the framework to the case study shed light on the main themes of the Danish CA network and its position in the agroecological transformation. Interpreting the results in terms of the multi-level perspective, we found a new advisory role to be emerging, where advisors facilitate horizontal knowledge structures and construct networks, and thereby enhance niche development with technological and network anchoring processes. However, institutional anchoring was found to be limited by contested knowledge. Our heuristic framework provides insights into salient aspects of agroecological initiatives, points out strengths and major issues to take on as part of reflexive arrangements, and by its systematic nature, enables comparison and learning across initiatives. Its usefulness as a relatively rapid instrument for reflecting on the history and current state of an initiative as part of a reflexive arrangement was confirmed by the case-study actors.

Key Words: *cognitive mapping; Living Labs; multi-actor approach; multi-level perspective; science–society interaction; social capital*

INTRODUCTION

Transformation of agri-food systems is urgently needed to face current global crises (Mier y Terán Giménez Cacho et al. 2018, Egmose et al. 2021, Giller et al. 2021). Agroecology is seen by many as a key element of such a transformation, intertwining science, social movements, and agricultural practices (International Forum for Agroecology 2015, Food and Agriculture Organization (FAO) 2018, Wezel et al. 2020). Méndez et al. (2017) describe 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." To support the development of agroecological initiatives, transdisciplinary knowledge development thus has an important role to play (Levidow et al. 2014, López-García et al. 2021).

As a temporary collaboration of scientists and non-scientists with the goal of facilitating learning and promoting structural change, a reflexive arrangement aims to co-create new knowledge that is translated into joint transformative action (Hendriks and Grin 2007). Reflexive arrangements are situated in the specific context of a societal initiative (Guzmán et al. 2013, Méndez et al. 2016, Rossing et al. 2021) and recognize the importance of actor networks for change (Elzen et al. 2012, Magrini et al. 2019). A shared understanding of an initiative's transformative history and current state provides valuable insights for joint action and contributes to building trust and social capital necessary for effective science–society interactions (Hoffecker 2021, Koole 2022).

In Europe, agroecology is part of the Farm to Fork policy of the European Commission (European Commission 2020). A range of policy instruments are in place to support transformations of the agri-food system by benefiting from agroecological principles. Among these, the Horizon 2020 research and innovation funding scheme and its successor Horizon Europe feature multi-actor, multi-country approaches through which researchers connect to societal innovators in what are essentially reflexive arrangements. Such transdisciplinary approaches are also sought after by global research donors, such as the Bill and Melinda Gates Foundation (BMGF) and the CGIAR (formerly the Consultative Group for International Agricultural Research). Analyses of the efficacy of research projects in bringing about societal change have shown a range of disabling factors at different levels (see, e.g., Cronin et al. 2022 for Horizon 2020 projects; Schurman 2018 for BMGF projects; Leeuwis et al. 2018 for CGIAR projects). A common shortcoming is a lack of an agri-food systems perspective as a basis for a theory of change that is legitimate for all involved in

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a reflexive arrangement (Zurek et al. 2023). With the aim of filling this gap, we present a heuristic, learning-oriented framework for systemically portraying societal agroecological initiatives at the start of reflexive arrangements. The framework was developed and tested in a Horizon Europe multi-actor project. We adopted the verb "portray" to emphasize the intention to combine scientific craftsmanship with local actor knowledge and objectives to arrive at a shared representation of the history and current state of the agroecological initiative. In developing the framework, we integrated both quantitative (e.g., López-Ridaura et al. 2002, Mottet et al. 2020) and qualitative approaches (e.g., Vanwindekens et al. 2013, Morel et al. 2020, Holmén et al. 2022, Rocker et al. 2022) for systems characterization and diagnosis. We also drew on participatory reflexive approaches (e.g. Engel 1997, Bos et al. 2009, van Mierlo et al. 2010, Elzen and Bos 2019, Rossing et al. 2021, Leclère et al. 2024) and approaches that address the evolution of societal initiatives (e.g., Gremler 2004, Britt and Wilson-Grau 2012, Coupaye 2015, Douthwaite and Hoffecker 2017, Polge and Pagès 2022).

Funded for 4 yr from September 2022 under the Horizon Europe funding scheme, the Agroecology-TRANSECT project connected researchers and 11 agroecological initiatives under the common objective of unfolding agroecology for Europe (https://www.agroecology-transect.net/). Each initiative consists of a network of societal and academic actors collaborating to develop systemic, agroecological solutions that address climate change mitigation, enhance biodiversity, and improve socio-economic resilience (i.e., the three overarching themes of the project). As selection criteria, the agroecological initiatives were chosen to cover a diversity of European geographical regions and farming systems. At the start of the project, each initiative had been functioning for at least 4 yr, showing the ability to function autonomously in terms of human and material resources. This selection process led to 11 initiatives representing a diversity of transformation levels toward agroecology, from efficiency gains to food system redesign (Gliessman 2016). The project was designed to engage participant scientists and those agroecological initiatives in learning cycles toward greater achievement of agroecological principles in real-world settings. The Danish initiative was selected as exemplary of the reflexive arrangements in the Agroecology-TRANSECT project. This initiative is a conservation agriculture (CA) network evolved because of farmer decision making motivated by keeping the yield potential while increasing economic net returns from reduced labor expenses (time in the field) and machine investment costs (Hansen et al. 2020). Using CA principles: (1) minimum mechanical soil disturbance by using reduced or no tillage; (2) permanent soil cover using cover crops and/or crop residues; and (3) spatial and temporal crop diversification through a variety of cropping strategies and crop rotations (FAO 2022), the network expects to meet political targets like 55–65% reductions in total greenhouse gas emissions from forestry and agriculture by 2030 (Ministry of Food, Agriculture and Fisheries 2021) and nitrogen leaching as part of ongoing Danish implementation of the EU water framework and nitrate directives (Environment Agency 2023). Through its collaborative and knowledge-sharing approach, the network is identified as a key driver for change across the sector, facilitating wider adoption of agroecological principles such as infield biodiversity enhancement, soil health improvement, and input reductions.

The objective of this study was to develop a heuristic framework to portray agroecological initiatives as a starting point for reflexive arrangements. In developing the framework, we aimed to balance thoroughness and ease of application to enable adequate time for subsequent project activities to benefit from its outcomes. The heuristic framework aimed 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 who are the key actors? (3) What are the barriers and levers for the development of the initiative, and which ones are key? We illustrate the use of the heuristic framework by portraying the Danish reflexive arrangement and discussing the way in which a shared understanding of the initiative's transformative history and current state provided insights into options for joint action within the Agroecology-TRANSECT project's mandate.

METHODS

Heuristic framework to portray agroecological initiatives for reflexive arrangements

Based on a systematic review of approaches used to evaluate projects and societal initiatives that aimed at transformative change, we propose a heuristic framework to portray agroecological initiatives in reflexive arrangements comprising three pillars: context, actors, and barriers and levers. Below we review each of these.

Context

Context reflects the situated nature of agroecological initiatives (Méndez et al. 2017, Barrios et al. 2020). Drawing on a variety of frameworks capturing socio-technical (Geels and Schot 2007, Ghosh et al. 2022), socio-environmental (Millenium Ecosystem Assessment 2005), food (Nesheim et al. 2015, shiftN 2023) and farming systems (Schoonhoven and Runhaar 2018, Escobar et al. 2019, Agroecology Europe 2020, Mottet et al. 2020), the context of agroecological initiatives is described by six broad dimensions, covering the biophysical environment, knowledge, society, policy and governance, economy and farming systems. Each dimension is subdivided into elements to specify relevant features of agroecological initiatives. In Table 1, the elements and key references are summarized.

Actor network

Social networks mediate agroecological transitions by acting as conduits of information, collaboration, and material resources (see review in Anderson et al. 2019*a*). The capacity of a social network to support innovation is determined by its structure and by the position of individual actors (Gaitán-Cremaschi et al. 2022). Studying relations between actors gives insight into strengths and weaknesses of the network and highlights possible levers of change through reorientation of relationships (Rocker et al. 2022).

Network of barriers and levers

Innovation scholars consider barriers as innovation system failures, slowing down system change and blocking actors in their learning (van Mierlo et al. 2013). A leverage points perspective reveals areas in complex systems for transformative change interventions (Meadows 1999, Fischer and Riechers 2019). Drawing from these definitions, we have defined barriers and levers as factors that negatively or positively, respectively, influence the implementation, operation, maintenance, scaling, or replication of an agroecological initiative. Barriers and levers

Table 1. Specification of the context pillar in terms of the six dimensions and their elements, illustrated for the Danish CA network.

Dimension	Elements	Results for Danish CA network
Biophysical environment[4, 5, 9, 10, 47, 49]	Climate (e.g., average annual temperature, annual precipitation, impact climate change)[1,2,3,4]	Temperate climate, average annual temperature: 9.0°C, annual precipitation: 698mm[15]; impact and prediction climate change: generally increasing precipitation, summer: dry spells and heavy precipitation events more frequent[16]
	Landscape (e.g., slope, land use, soil type)[1,4,5,6]	Flat, average elevation 31m[17]; landscape dominated by agricultural land[18]; field size increasing[19,20]; agricultural area decreasing[21]; soil types in Zealand mainly coarse sandy clay and fine clayey sand[22]
Knowledge[3, 4, 5, 47, 48, 50]	Research (e.g., universities and research centers)[3,5,7,9]	Historically high public investments in agricultural research and development[23]; important universities in agricultural research are Aarhus University and Copenhagen University, which have a focus on natural scientific and technical aspects of farming systems[24]
	Education and Learning (e.g., agricultural education, available courses)[3,4,8,12]	Vocational training: 14 mo of study and 28 mo practical internship[18]; educational level of farmers increasing; 76% of the farmers completed vocational training (2020)[25]; agricultural education focused on natural sciences and technical aspects and oriented toward specialized and intensified farming[18,24,26]
	Information (e.g., peer-to-peer knowledge exchange, advisory services)[1,3,8,10,12,13]	Most consultancy companies: large, farmer-funded, separate advice for different agricultural products[27,28,29]; many consultancy companies provide experience groups for farmers[27,18]; consultancy focused on yield gains[18]
Society[3, 4, 9, 47, 48, 49, 50]	Farmer community (e.g., farmer groups, activities)[3,14]	Farmers historically built cooperatives to get access to technologies[30], production facilities often still owned by farmer cooperatives[31]; farmers connected with each other and with government, but not with non-farming community[31]; farmers frustrated about regulations[29]
	Consumer preferences (e.g., diet, demand for AE products)[1,2,3,5,10,11]	High meat and low fruit and vegetable consumption; awareness of healthy food; decreasing meat consumption[32]; 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[33]
	Wealth (e.g., Human development index, GDP, Gini Coefficient, poverty rate)[4,5]	Human development index: 0.948 (2021), rank 6 worldwide[34]; GDP: 64'898 US$/capita, above European average[35]; income inequality (Gini: 0.269[36]) and poverty rate (0.065[37]) among lowest of OECD countries
Policy and governance[3, 5, 9, 10, 47, 48, 50]	Policies (e.g., policies concerning natural resource management, nutrition, food safety, labor, agricultural production, risk management, emissions, subsidies, taxes)[3,4,5,9]	Agricultural sector highly coordinated through state[31]; governmental support for organic farming integrated it into mainstream[31]; many environmental regulations; Denmark often ahead of other countries[29]; harmony rule (since 1998): requirement of the manure application area of livestock farm to be proportional to the number of livestock[38]; Climate Act launched in 2020 is one of the world's most ambitious: Denmark climate neutral by 2050[39]; currently policy development to limit GHG emissions in agriculture[29]; the 4% of non-productive area required in the CAP reform only implemented in Denmark[28]; land tenure open for international investment[19]
	Social movements (e.g., political actors)[3,5]	Three main nature-related NGOs: the Hunting Federation DJ, the Danish Society for Nature Conservation DN, and BirdLife Denmark DOF[29]
Economy[3, 4, 5, 9, 10, 47, 48, 49, 50]	Agricultural sector (e.g., economic importance of farming, globalization)[1]	Liberal market regulation led to export-oriented agriculture: 25% of production is exported[30]; farms highly reliant on world market prices[40]; food production volume could feed three times the DK population[18]
	Markets and Supply chain (e.g., market structure, supply chains, local markets, labels, contracts)[1,2,3,4,5]	Farms are rarely integrated in local economies; common to have contracts with national supermarkets, which are organized as cooperatives[31]; big food companies, which originated from cooperatives, are dominating[24]; collective business traditions disappeared over the last 50–75 yr[24]
	Financial system (e.g., capital, funding, investment possibilities)[3]	Real-estate mortgage system has been one of the cheapest in Europe: access for farmers to cheap finance[40]; 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[40]; many farmers (mainly pork and dairy producers) have high debts, low liquidity, and operate with a deficit[40]
Farming system[1,3]	Infrastructure (e.g., farm infrastructure, roads, infrastructure related to value chain)[2,3,4,8]	Agriculture shaped by high productivity[30] and high specialization[18], based on high energy use and modern machinery[20]; high levels of technological investment on Danish farms[30]
	Farmers and Employees (e.g., age and gender of farmers, wage, labor availability, migration)[3]	94% of the farmers are male (2017)[41]; average age of farmers: 57; 50% over 55 yr old; 7% young farmers (under 40 yr)[41]; strict farm labor laws and strong labor unions[31]
	Farm structure and Ownership (e.g., farm size, ownership)[2,3,4]	Number of full-time farms decreasing[19]; 10% of farms cultivate <40 ha, 11% 40–100 ha, 47% 100–400 ha, and 32% >400 ha[42]; average field size 28 ha (2019)[20]; 85% of farms privately owned[40]
	Agricultural production (e.g., common crops, livestock, diversity of farms, sustainable farming practices)[2,3,4]	Mainly grain production until European grain crisis 1870, then transition to dairy farming and export[30]; main livestock: pigs and cattle, then poultry, horses, and sheep[43]; pork and dairy products are the main agricultural products, more than half of agrarian exports[44]; 25% of livestock feed is imported[19]; 81% of agricultural land used for fodder crops, 9% food crops, 10% non-food crops[19]; main crops: grass-clover, cereals, maize, potatoes, sugar beets and oilseed-rape[45]; organic farming increased to 12% of the cultivated area (2022)[45]; reduced tillage practices increased to 23% of the cultivated area (2022)[46]

[1]Moraine et al. 2016, [2]Alvarez et al. 2018, [3]Schoonhoven and Runhaar 2018, [4]Mottet et al. 2020, [5]Nesheim et al. 2015, [6]Ryschawy et al. 2021, [7]Knierim et al. 2015, [8]Mozzato et al. 2018, [9]Millenium Ecosystem Assessment 2005, [10]Agroecology Europe 2020, [11]Blanch-Ramirez et al. 2022, [12]Fieldsend et al. 2021, [13]Anderson et al. 2019*b*, [14]Hazard et al. 2022, [15]Climate-Data n.d., [16]International Energy Agency 2023, [17]World topographic map n.d., [18]Hansen et al. 2020, [19]Arler et al. 2015, [20]Lohrum et al. 2021, [21]Statistics Denmark 2021, [22]Adhikari et al. 2014, [23]Averbuch et al. 2022, [24]Keyactor4, personal communication, 2023, [25]Pedersen et al. 2022, [26]Keyactor2, personal communication, 2023, [27]Barzman and Dachbrodt-Saaydeh 2011, [28]Keyactor1, personal communication, 2023, [29]Keyactor3, personal communication, 2023, [30]Averbuch et al. 2021, [31]Averbuch et al. 2022, [32]Reipurth et al. 2019, [33]Denver et al. 2019, [34]UNDP 2022, [35]OECD 2021, [36]OECD 2019*a*, [37]OECD 2019*b*, [38]Willems et al. 2016, [39]Hastrup et al. 2022, [40]Grivins et al. 2021, [41]Statistics Denmark 2018, [42]StatBank Denmark 2023, [43]Statistics Denmark n.d.*b*; [44]Osei-Owusu et al. 2021, [45]Statistics Denmark n.d.*a*, [46]StatBank Denmark n.d., [47]shiftN 2023, [48]Geels and Schot 2007, [49]Escobar et al. 2019, [50]Ghosh et al. 2022.

for the development of agroecological initiatives can arise within an initiative or external to it (Schoonhoven and Runhaar 2018). Barriers often present potential levers for change. The identification of barriers and levers allows reflection on factors and their role in the development of the agroecological initiative and provides learning across initiatives (Holmén et al. 2022). Recognizing that barriers and levers are not mutually exclusive and may influence each other (Hurley et al. 2023), we approach them from a systems perspective, considering their connections over the course of time.

Case study: the Danish Conservation Agriculture Network

Since 2016, on the island of Zealand (Denmark), a voluntary demand-driven network of about 50 farmers with cereal-dominated crop rotations has been involved in developing CA on their farms. Their ultimate objective is to foster the adoption and expansion of CA by stimulating peer-to-peer knowledge exchange focusing on modified technical solutions. The farmers reduced soil tillage by not ploughing and keeping the soil covered after harvesting the main crop during autumn and winter. Rotational crop diversification is less developed due to animal feed dominating land-use traditions and connected markets (Hansen et al. 2020). Over the years, the farmers noticed a range of positive changes in the CA fields compared with traditional and neighboring tillage-based systems and became highly convinced of its benefits for their farm operations and for society at large (Hansen et al. 2020). At the same time, financial and social rewards remained low to absent, prompting questions about what factors blocked wider adoption. In Denmark, reduced tillage is practiced on 25.5% of the utilized agricultural area, more than doubling since 2016 (Statistics Denmark 2024).

From the start, the farmers were organized into five "knowledge exchange groups," each facilitated by an advisor from a mid-sized, nationally operating agricultural advisory company. For years, the advisory company had been working in interdisciplinary and transdisciplinary approaches with scientists (agronomists and environmental planners) from national universities. In 2022, the Horizon Europe Agroecology-TRANSECT project stimulated the knowledge exchange groups to organize their activities as a reflexive arrangement, with a senior advisor and a connected national university colleague acting as facilitators of the arrangement. To foster connections with the other partners in the project and take the opportunity to reflect on the network's strategy, the facilitators agreed to apply and evaluate, in their context, the heuristic framework described in this paper.

Data collection

The data collection consisted of three steps: (1) a preparatory exploratory interview with the case-study facilitators and document analysis in month 3 of the Agroecology-TRANSECT project, (2) in-depth semi-structured interviews with key actors in month 5, and (3) online discussion and written feedback with case-study facilitators in month 6.

In step 1, a 30-min exploratory interview was held with the case-study facilitators as part of a project workshop. In a setting around a table, the facilitators were asked to draw up a timeline of what they considered important events for the CA network and to map the current actors and their interrelations. Following the exploratory interview, the case study's timeline was combined with information from the case study's action plan for the first project year and a learning history document, both resulting from the co-innovation approach in the project. The resulting updated timeline and actor map were input for the second step and were used to draft a list of potential interviewees. In consultation with one case-study facilitator, two key actors from this list were selected for in-depth interviews next to the two case-study facilitators. Key actors were defined as case-study actors who had a good understanding of the case study's history and current situation. The key actors should have different roles in the case study to add different perspectives. As part of the preparatory work for step 2, the framework guided a preliminary context description of the case study through document analysis and literature research.

In step 2, additional information on context, actors and their relationships, and barriers and levers was collected using a semi-structured interview guide (Append. 1). The interviewees included the main case-study facilitator, who worked for the agricultural advisory company, a pioneer CA farmer who at the time worked at the same company, a pioneer CA farmer who was part of a knowledge-exchange group, and the second case-study facilitator, who was a university scientist. Three interviews took place in person at the workplaces of the interviewees, and one took place online. Two interviewers were present: one leading the exchange and one with a supportive role. The interviews took 2–3 h each and were recorded.

The in-depth interviews consisted of two parts. First, the updated version of the case study's timeline was presented to the interviewee. Each interviewee was then asked to describe significant events in the case study's evolution, either from the timeline or from their own perspective and to elaborate on these. Drawing on the critical incident technique (Gremler 2004), the interviewer asked probing questions aimed at clarifying the interviewees' perspectives on the barriers, levers, and actors related to the events. In the second part of the interview, the preliminary actor map was discussed with the interviewee. The actors and their connections, discussed in the first part of the in-depth interview, were drawn on the actor map. The interviewee was asked to add or delete actors and connections and to comment on them. The case-study facilitators were additionally asked to clarify aspects of the context that were not clear from the preparatory work.

In step 3, the maps describing (1) actors and their interconnections and (2) barriers and levers, derived from steps 1 and 2 and subjected to a first layer of analysis (i.e., identification of nodes and edges based on coded interview data—see data analysis section), were presented to the case-study facilitators. This step gave them the opportunity to confirm or adjust those maps. Although no major changes were made by the facilitators to the nodes and connections during this step, some clarifications were provided regarding specific terms employed.

Data collection thus resulted in a draft context analysis, and maps describing (1) actors and (2) barriers and levers, with their interconnections.

Data analysis

Interviews from steps 1 and 2 of the data collection were all transcribed and coded with the codes "actors," "context," "barriers," and "levers," and subcodes were used to group barriers,

Table 2. Definitions and interpretations of the metrics degree, weighted degree, and closeness centrality, used to quantitatively analyze actor network and out-degree, (positive or negative) in-degree, in-degree balance, and betweenness centrality used to quantitatively analyze barriers and levers network (Opsahl et al. 2010, Rocker et al. 2022).

Network	Metric	Definition	Interpretation
Actor network	Degree	Number of edges linked to the node	A high degree indicates a central actor in the network, as the actor is connected to many other actors.
	Weighted degree	Sum of the weights of the edges linked to the node	A high weighted degree indicates a central actor in terms of both the strength and number of relations.
	Closeness centrality	Measure for the shortest path connecting the node to all other nodes	A high closeness centrality indicates that an actor is in close connection with many actors, indicating centrality.
Barriers and levers network	Out-degree	Number of outbound edges from a node	A high out-degree reflects a greater impact of the node (barrier or lever) on the network.
	(Positive or Negative) In-degree	Number of (positive or negative) inbound edges to a node	Larger absolute in-degree values reflect a greater influence from the network on the node (barrier or lever). Positive in-degree reflects positive external influence, whereas negative in-degree reflects negative external influence.
	In-degree balance	Difference between positive and negative in-degree (i.e., the sum of positive edges minus the sum of negative edges)	In-degree balance indicates whether a node represents a barrier being reinforced (negative in-degree balance) or eased (positive in-degree balance) and a lever being blocked (negative in-degree balance) or enhanced (positive in-degree balance) in the network.
	Betweenness centrality	Measure of the fraction of shortest paths between all pairs of nodes that are passing through the concerned node	A high betweenness centrality indicates a greater role of a node (barrier or lever) in connecting elements of the network.

levers, and their impact (i.e., connections between them) thematically. The information on context was used to enrich the preliminary context description and elaborate the six dimensions (Table 1). Information on actors, barriers, and levers was used in the network analyses described below.

Actor network analysis

The actor network was analyzed using social network analysis (SNA), mixing both quantitative and qualitative methods (Bellotti 2014, Cornu et al. 2023). A growing body of research (e.g., Heath et al. 2009, Edwards 2010, Hollstein 2014, Bellotti 2014, Ahrens 2018, Yousefi Nooraie et al. 2020) highlights the benefits of integrating quantitative and qualitative approaches in SNA to gain a more comprehensive understanding of social phenomena. Quantitative analysis reveals patterns, network structures, and the positions of key actors, and qualitative methods provide rich contextual insights that enhance the interpretation of the quantitative structural metrics.

A social network consists of nodes representing the actors connected by edges, the relations between actors. Actors are represented at organizational level, and the edges are weighted according to the number of interaction types (Append. 2). These interaction types were identified inductively through the analysis of interview data, where any different form of interaction between two actors was coded and assigned a weight of 1. Following an inductive approach, the boundaries of the case-study network were defined according to the perception of the interviewees. Actors and their relationships were included or excluded depending on how relevant interviewees considered them to be. This aligns with what Heath et al. (2009) describe as the realist approach. Each actor considered relevant by at least one interviewee was included in the network.

Drawing on Castella et al. (2022), the actors were categorized according to their roles in the network. The network was analyzed quantitatively using the network metrics degree, weighted degree, and closeness centrality (Table 2). Key actors are those that have a high degree, high weighted degree, or a high closeness centrality. Analysis and visualization of the social network were performed with Gephi (Bastian et al. 2009).

Barriers and levers analysis

The barriers and the levers and their impact were organized as a cognitive map (Garini et al. 2017) by representing them as nodes in a directed network. Cognitive mapping is used to represent individuals' perceptions related to a particular issue at a given moment in time (ElSawah et al. 2013, Vanwindekens et al. 2013). The edges in the network were classified as either positive (indicating a beneficial influence from a node on another) or negative (indicating a detrimental influence), following the convention of signed networks (Meng et al. 2022). All outgoing arrows from levers have a positive impact on connected nodes, thus reinforcing other levers or mitigating the effects of barriers. In contrast, all outgoing arrows from barriers exert a negative impact on connected nodes, reinforcing the negative effect of other barriers or reducing the positive influence of levers that are connected to the node. The initial network of barriers and levers was drafted by the principal investigator of the study based on the thematic sub-codes derived from the exploratory (step 1) and in-depth interviews (step 2) described in data collection section. This network was then confirmed and refined with the case-study facilitators (step 3), before being analyzed quantitatively and visualized with the Gephi software (Bastian et al. 2009).

Similar to actor network analysis, network metrics 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). The metrics' out-degree, (positive or negative) in-degree, in-degree balance and betweenness centrality were calculated to analyze the network of barriers and levers (Table 2).

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

Table 3. Key barrier and lever types and criteria to identify them as such, using network metrics.

Key barrier and lever type	Criteria
Blocking barrier	High impact (out-degree ≥ 2) and are potentially reinforced (in-degree balance ≤ 0).
Recurring barrier	Low impact (out-degree = 0) and high external influence (positive and negative in-degree ≥ 2).
Eased barrier	Influenced only by levers (in-degree balance > 0 and negative in-degree = 0).
Powerful lever	High impact (out-degree ≥ 2) and enhanced by the network (in-degree balance > 0).
Influential lever	High impact (out-degree ≥ 2) and neutral influence from the network (in-degree balance = 0).
Connecting lever	High centrality (betweenness ≥ 20), large influence from the network (total in-degree ≥ 3) and low impact (out-degree ≤ 1).
Minor lever	Negatively influenced by the network (in-degree balance < 0).

balance, a high out-degree or a high betweenness. Using the metrics, the key barriers and levers were classified into initiative-specific types, reflecting their position in the network. The key barriers were classified as blocking, recurring, and eased barriers (Table 3). The key levers were classified as powerful, influential, connecting, and minor levers (Table 3).

RESULTS

Context of the Danish case study

The context framework (Table 1) highlighted a highly technologized, export-oriented agricultural production sector under strict environmental policies. The biophysical landscape is dominated by agricultural land use on which mostly fodder crops are grown. The main agricultural products are pork and dairy. Most of the farms exceed 100 ha and operate with high debts and low margins. Large food companies that originated from farmer cooperatives are dominating the agricultural market. Denmark is among the countries with the highest consumption of organic products.

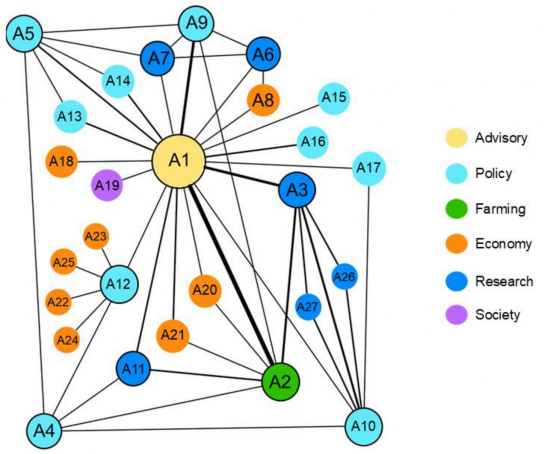
Case-study actors and their network

In total, 27 actors were identified, including the three actors constituting the core of the reflexive arrangement (advisory company (A1; Fig. 1), CA farmers (A2) and researchers from National University A (A3)). Among the 27 actors, one played an advisory role (A1), another was directly involved in farming (A2), 10 were engaged in influencing or developing agricultural policies (A4, A5, A9, A10, A12, A13, A14, A15, A16, A17), eight had predominant economic impacts and interests (A8, A18, A20, A21, A22, A23, A24, A25), six were linked to research (A3, A6, A7, A11, A26, A27), and one was categorized under society (A19). The 27 actors, their characterization in terms of the metrics degree, weighted degree, and closeness centrality, as well as the relationships among them, are illustrated in Fig. 1.

The agricultural advisory company (A1) appears as the most important actor, with the highest values for degree (19), weighted degree (37), and closeness centrality (0.79). Conservation agriculture farmers (A2) are highly connected (degree of 7) but more distant to other actors than the agricultural advisory company (A1). National University A (A3) has fewer (degree of 5) but strong relations (weighted degree of 14), indicated by the high weighted

Fig. 1. Actor network of the Danish CA network. (A) Complete network visualized with Gephi. The size of the circles reflects the value of the closeness centrality metric. Circles with bold outlines represent key actors. The thickness of relationships reflects their weight. (B) List of actors characterized by the network metrics degree, weighted degree and closeness centrality.

A



B

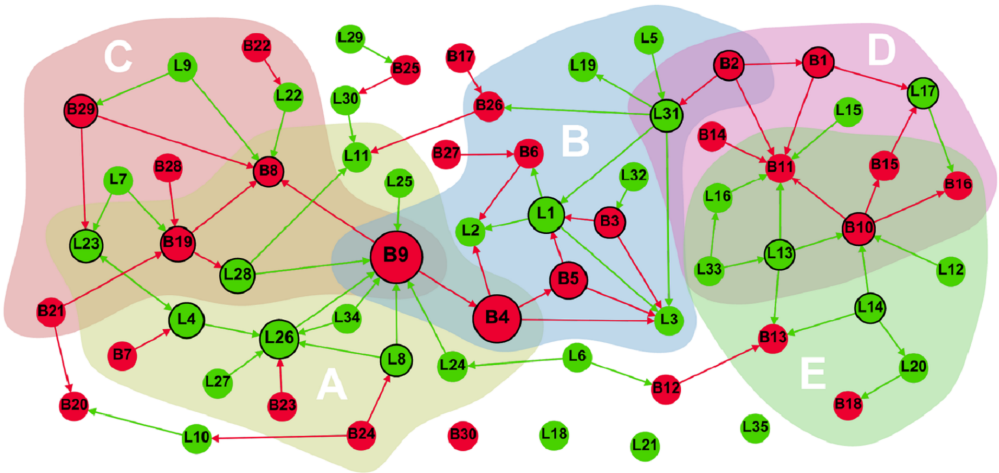
ID	Actor	Degree	Weighted Degree	Closeness Centrality
A1	Advisory company	19	37	0.79
A2	CA farmers	7	16	0.53
A3	National University A	5	14	0.51
A4	National ministries	5	5	0.49
A5	Danish parliament	6	7	0.50
A6	National University C	4	4	0.47
A7	National University B	4	4	0.48
A8	Private foundation	2	2	0.46
A9	National reduced tillage farmer association	5	8	0.49
A10	European Union	6	10	0.52
A11	Non-profit research center	3	5	0.47
A12	Danish Agriculture and Food Council	6	6	0.54
A13	Birdlife organization	2	3	0.46
A14	Environmental organization	2	3	0.46
A15	Hunting organization	1	1	0.45
A16	Thinktank	1	2	0.45
A17	European federation promoting CA	2	2	0.48
A18	Multinational brewery	1	1	0.45
A19	Journalists	1	1	0.45
A20	Machine manufacturers	2	2	0.46
A21	Carbon credit company	2	3	0.46
A22	Multinational dairy	1	1	0.36
A23	International Danish food company	1	1	0.36
A24	Danish farm supply cooperative B	1	1	0.36
A25	Danish farm supply cooperative A	1	1	0.36
A26	French research institution	2	4	0.36
A27	Dutch university	2	4	0.36

degree in comparison to the degree. Other key actors are related to policy or research. Key policy actors are more strongly related and closer to non-research actors. They include the Danish Agriculture and Food Council (A12), the European Union (A10), the Danish parliament (A5), the national farmer association for reduced tillage (A9), and Danish ministries (A4). Key research actors are National University B (A7), the non-profit research center (A11), and National University C (A6).

Barriers, levers, and their interrelations

We found, in total, 30 barriers and 35 levers (Fig. 2) (see Append. 3 for a comprehensive list and description of the barriers and levers), from which 11 key barriers and 10 key levers were identified. The key barriers included 5 blocking, 2 recurring, and 4 eased barriers, whereas the key levers included 1 powerful, 3 influential, 2 connecting, and 4 minor levers (Table 4).

Fig. 2. Network of barriers and levers (visualized with Gephi). (A) Knowledge about CA; (B) Transdisciplinary collaborations; (C) Yield-centric farming; (D) CA support; (E) CA visibility. Red nodes represent barriers, and green nodes represent levers. A red edge represents a negative impact, and a green edge represents a positive impact. Nodes surrounded by a dark border are key barriers/levers. The size of the node reflects its betweenness centrality.



B1 Contested knowledge about the relevance of CA for C sequestration
B2 Dominance of National University B's natural science approach in policy making
B3 Traditions impeding new forms of collaboration
B4 Difficult for advisors and scientists to leave the expert role
B5 Advisory company limited in innovation which doesn't fulfil their customers' expectations
B6 Advisors lack training in social skills for facilitation and co-creation with farmers
B7 Challenge to keep Healthy Soil conference interesting for frontrunners
B8 Risk of yield reduction due to CA
B9 Lack of practical knowledge about CA in DK
B10 Lack of visibility of CA in society
B11 Current legislation not supporting CA
B12 Use of glyphosate
B13 Lack of understanding of CA in society
B14 Agricultural council representing interests of major companies and majority of farmers
B15 Value of CA soil not considered in value of farm
B16 Lack of remuneration for adopting CA
B17 Lack of investment in development of CA
B18 Many farmers too old to change their farming practices
B19 Farmers' focus on yield and big machinery
B20 Difficult social position for CA farmers
B21 Masculinity in agriculture
B22 Cultivation of rented land
B23 Lack of formal knowledge collection and reporting
B24 Conflicts in knowledge-exchange group due to different mindsets
B25 Limited capacity of key person
B26 Difficult for advisory to find funding
B27 Focus on technical aspects in agricultural education leads to neglect of social aspects
B28 Farmers education: plough is part of farming
B29 Financial pressure on farms
B30 Not possible to assure that the next generation continues CA

L1 Collaboration of social scientists and advisors
L2 Facilitative advice
L3 Collaboration of social scientists and farmers
L4 Healthy Soil conference provides a platform for farmers to discuss CA
L5 EU support and funding enables further development of the CA network
L6 Experiments for pesticide reduction
L7 Fascination with soil and soil life that many farmers share
L8 Knowledge-exchange groups enable to build up trust and share experiences honestly
L9 Reduced farming costs through CA
L10 Knowledge-exchange groups create identity of being pioneers
L11 Agricultural advisory company being attractive for CA farmers
L12 Promotion of CA through connecting it to food
L13 Collaboration with nature NGOs
L14 Collaboration with Thinktank
L15 Farmer association for reduced tillage advocating for CA politically
L16 Bring CA farmers in contact with politicians
L17 CO_2 certificates for CA
L18 Big companies asking for RA products
L19 Grant from a foundation
L20 Get in contact with young farmers
L21 CA is a more interesting way of farming
L22 High yields and increased environmental robustness of farm
L23 Stories of inspiring CA farmers show that CA works
L24 Contact with agricultural experts is assuring when trying something new
L25 Access to knowledge through social media
L26 Knowledge-sharing between farmers
L27 Newsletter of agricultural advisory company supports farmers in current issues
L28 Field demonstrations
L29 Young advisors taking over some of key person's tasks
L30 Pioneer CA farmer working for advisory
L31 National University A's interdisciplinary and transdisciplinary approach
L32 Build up trust in collaboration relationships
L33 Connect to political actors by inviting them to give a speech at the Healthy Soil conference
L34 Knowledge-exchange groups enable farmers to be the source of CA development
L35 Being part of the future is motivating farmers for CA

Table 4. Key barriers and levers for the development of the case study, characterized by network metrics (out-degree, positive in-degree, negative in-degree, in-degree balance, betweenness centrality) and classified into key barrier and lever types.

Type[†]	ID	Description	Out-degree	Positive in-degree	Negative in-degree	In-degree balance	Betweenness centrality
Blocking barriers	B4	Difficult for advisors and scientists to leave the expert role	3	0	1	-1	100
	B5	Advisory company limited in innovation, which doesn't fulfil their customers' expectations	2	0	1	-1	42
	B19	Farmers' focus on yield and big machinery	2	1	2	-1	30
	B1	Contested knowledge about the relevance of CA for C sequestration	2	0	1	-1	2
	B2	Dominance of National University B's natural science approach in policy making	3	0	0	0	0
Recurring barriers	B11	Current legislation not supporting CA	0	3	4	-1	0
	B8	Risk of yield reduction due to CA	0	2	3	-1	0
Eased barriers	B9	Lack of practical knowledge about CA in DK	2	6	0	6	127
	B10	Lack of visibility of CA in society	3	3	0	3	14
	B29	Financial pressure on farms	2	1	0	1	10
	B3	Traditions impeding new forms of collaboration	3	1	0	1	4
Powerful levers	L13	Collaboration with nature NGOs	3	1	0	1	5.5
Influential levers	L4	Healthy Soil conference provides a platform for farmers to discuss CA	2	1	1	0	35
	L31	National University A's interdisciplinary and transdisciplinary approach	4	1	1	0	14
	L14	Collaboration with Thinktank	3	0	0	0	0
Connecting levers	L26	Knowledge sharing between farmers	1	4	1	3	54
	L23	Stories of inspiring CA farmers show that CA works	1	2	1	1	20
Minor levers	L1	Collaboration of social scientists and advisors	3	1	2	-1	33
	L28	Field demonstrations	2	0	1	-1	32
	L8	Knowledge-exchange groups enable participants to build up trust and share experiences honestly	2	0	1	-1	9
	L17	CO_2 certificates for CA	1	0	2	-2	3

[†] Key barriers and levers are classified in blocking (out-degree ≥ 2, in-degree balance ≤ 0), recurring (out-degree = 0, positive and negative in-degree ≥ 2), and eased barriers (in-degree balance > 0 and negative in-degree = 0) and in powerful (out-degree ≥ 2, in-degree balance > 0), influential (out-degree ≥ 2, in-degree balance = 0), connecting (betweenness ≥ 20, total in-degree ≥ 3, out-degree ≤ 1), and minor levers (in-degree balance < 0).

The lack of practical knowledge about CA in Denmark (B9) (Fig. 2A) is the barrier with the highest betweenness, indicating a connecting role in the network. Its reinforcing effect on the risk of yield reduction due to CA (B8) and on the difficulty for advisors and scientists to leave the expert role (B4) are outweighed by six levers: the access to knowledge through social media (L25), knowledge-exchange groups enabling farmers to be the source of CA development (L34), knowledge-sharing between farmers (L26), knowledge-exchange groups enabling to build trust and share experiences honestly (L8), field demonstrations (L28), and the contact with agricultural experts being reassuring when trying something new (L24). The high in-degree balance of 6 indicates that the barrier of lack of practical knowledge is potentially overcome, which is in line with a statement from one of the interviewed farmers "I believe the farmers can fix that [practical problems with CA]. We can fix that in the knowledge groups."

Knowledge sharing between farmers (L26) connects different ways of knowledge production (Fig. 2A). Knowledge-exchange groups enhance knowledge sharing by enabling their members to build up trust and share experiences honestly (L8) and to be the source of CA development (L34), even though conflicts due to different mindsets (B2) can inhibit the members from building mutual trust. The lack of formal knowledge collection and reporting (B23) limits knowledge sharing (L26), whereas it is enhanced by the newsletter of the agricultural advisory company (L27). Furthermore, the Healthy Soil conference enhances knowledge sharing by providing farmers a platform to discuss CA (L4) and motivates farmers with stories of inspiring CA farmers who show that CA works (L23). Even though the Healthy Soil Conference has been successful in attracting a large number of farmers, it is challenging to keep it interesting for frontrunners (B7), who are key for knowledge sharing among farmers (L26). Also, field demonstrations (L28) address the lack of practical knowledge (B9) and make the agricultural advisory company more attractive for CA farmers (L11). The field demonstrations showed the technical aspects and machinery, influenced by the focus of farmers on yield and big machinery (B24).

National University A's interdisciplinary and transdisciplinary approach (L31) (Fig. 2B) is an influential lever, facilitating the collaboration of social scientists with advisors (L1) and farmers (L3). Thereby, it enabled the advisory company (A1) to join a European research and innovation action project, also addressing the difficulty of getting funding (B26). The interviews indicated that the approach of National University A (L31) is valued by the EU (L5) but, besides a grant from a foundation (L19), not much supported at the national level where traditional natural science approaches dominate in agricultural transition research (B2). The collaboration of social scientists and advisors (L1) enhances the collaboration of social scientists and farmers (L3), with advisors as intermediaries. This opportunity comes with constraints, as advisors tend to self-censor by keeping information on novel approaches that they consider too risky and potentially harmful for the (economic) relationship away from their customers. Thereby the advisory company is limited in innovation through novel approaches that do not fulfil their customers' expectations (B5), a blocking barrier. Also impeding the emerging

collaborations of social scientists with advisors and farmers are traditions that shape the aims and expectations of the partners (B3), the overcoming of which requires building trust (L32) through personal interactions over time. The collaboration of social scientists and advisors (L1) emerges as a minor lever with the potential to advance a facilitative advisory role (L2) and to overcome the barrier of the advisors' lacking training in facilitation skills and co-creation with farmers (B6). The difficulty of leaving the expert role for advisors and scientists (B4) constitutes a strong blocking barrier that also impacts the collaboration of social scientists and farmers (L3) and advisory companies' limited innovativeness (B5). Moving away from the expert role will be necessary, considering the context specificity of CA and the limited practical knowledge about CA in Denmark (B9). Still, farmers' expectations of receiving advice and services rather than being included in strategic and operational knowledge development make it difficult.

Farmers' focus on yield and big machinery (B19) (Fig. 2C), is a blocking barrier that is reinforced by masculinity in agriculture (B21) and farmers' education, in which ploughing is taught as a central part of farming (B28). The fascination with soil and soil life that many CA farmers share (L7) has potential to shift farmers' focus and contributes to stories of inspiring CA farmers who show that CA works (L25). The predominant farmers' focus on yield and big machinery (B19) reinforces the recurring barrier of risking a yield reduction due to CA (B8). This risk is especially high during the conversion to CA, when context-specific knowledge on the application of CA still has to be acquired, and the beneficial effects of CA are not yet occurring, such as the increase in the farm's environmental robustness (L22) through reduced erosion and higher drought resilience stabilizing yields in the long-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 (B29) makes farmers reluctant to take risks. A focus on economic benefits (B29) potentially limits the success of stories of inspiring CA farmers (L23).

The blocking barrier Contested knowledge (B1) (Fig. 2D) is reinforced by the blocking barrier B2: The dominance of National University B's natural science approach in policy making. Both barriers impact the barrier of the current legislation not supporting CA (B11). This recurring barrier is also enforced by the agricultural council representing the interests of major companies and the majority of farmers (B14) and thereby not being interested in supporting CA. Approaches to bring CA farmers in contact with politicians (L16) and the farmer association for reduced tillage advocating CA farmers' interests politically (L15) constitute levers to bring about legislative support for CA. Carbon dioxide certificates for CA (L17) represent a minor lever (L17) with the potential to generate direct additional income (B16) from CA but are blocked by contested knowledge (B1) and CA not being considered in the value of the land (B15).

Conservation agriculture is lacking visibility in society (B10) (Fig. 2E), which reinforces other barriers: the current legislation that does not support CA (B11), the use of CA not being considered in the value of land (B15), and the lack of remuneration for adopting CA (B16). The lack of visibility of CA in society (B10) is eased by the collaboration with nature NGOs (L13) and the Thinktank (L14), and the promotion of CA by connecting it to food (L12). The collaboration with the nature NGOs (L13) evolved from the advisory company inviting nature NGOs to give a speech for farmers at the company's annual Healthy Soil conference (L33) and has the potential to promote legislative support for CA (B11). Besides enhancing visibility, the collaboration with nature NGOs (L13) and the Thinktank (L14) can also further the understanding of CA in society (B13). The collaboration with the Thinktank (L14) additionally provides an opportunity to get into contact with young farmers (L20).

DISCUSSION

We developed a heuristic framework to portray agroecological initiatives at the start of reflexive arrangements. The framework captures the context, the actor network, and the barriers and levers for the development of the agroecological initiative. The novelty of the framework resides in the combination of elements and in its heuristic rather than comprehensive purpose to fit its use in a transdisciplinary research context. The application of the framework to the case of the Danish CA network highlighted a highly technologized, export-oriented agricultural sector, with a focus on feed crops in arable farming, producing under strict environmental policies, with many farms operating with high debts and low margins. Next to the three actors that are part of the reflexive arrangement, key actors were related to policy and research. In comparison with researchers, policy actors were more strongly related to and embedded in the network. Connections with economy actors existed, but they were loosely related to the network, while society actors were almost non-present. Key barriers and levers comprised a broad range of themes, such as the role of advisory actors and scientists, the mobilization of horizontal knowledge structures and the lack of financial reward and visibility for CA.

In this section, we discuss the framework in relation to its aim of providing a starting point for scientist–societal actor collaborations in reflexive arrangements. The results for the Danish CA network are elaborated using the multi-level perspective. The state of technological, network, and institutional anchoring is discussed using the main themes that emerged from the context-related analysis of actors and barriers and levers. We describe how the results may influence the development of the reflexive arrangement.

Portraying agroecological initiatives as a starting point in reflexive arrangements

This study was inspired by the need to establish working relations between societal actors in agroecological initiatives and scientists, collaborating for 4 yr in a European research and innovation project. To establish connections between scientific capabilities and the development status of the agroecological initiatives, a methodology was needed that balanced scientific rigor, salience for the users, and timeliness. Scientific rigor of the framework resides in the constituent elements that were selected from various methods proposed to characterize or map socio-ecological systems. Although the context characterization sketches the setting of agroecological initiative in the overarching agri-food system, the networks of actors, barriers, and levers provide

actionable knowledge (Geertsema et al. 2016) by focusing on the agroecological initiative and its history. Salience for the users was achieved by data collection in various rounds, providing feedback on results and asking for user input on credibility of results and relevance for the agroecological initiative. These cycles of data collection, analysis, and reflection were part of the overarching project's learning-oriented approach that built on earlier co-innovation approaches of the team (Rossing et al. 2021, 2023). Thus, developing the agroecological initiative's portrait was one of the means of building social capital in the project. We estimate that data collection and analysis took around 2 mo, allowing relatively fast scientific input into the innovation dynamics of the agroecological initiative.

Insights for the Danish conservation agriculture network

From a multi-level perspective, agroecological initiatives may be seen as niches that are external to the regime, characterized by a divergent structure and alternative values compared with the industrialized agriculture regime (Levidow et al. 2014, Morel et al. 2020). The Danish case study, in contrast, shared values with the dominant regime, such as the focus on high yields and the use of pesticides, whereas other values, such as the care for beneficial insects by avoiding use of insecticides (Hansen et al. 2020) and for soil quality by reducing or abstaining from tillage differed radically. The case study thus constituted a niche in the regime, which Elzen et al. (2012) refer to as a hybrid.

An important goal of the Danish case study was to make CA mainstream, i.e., to anchor CA in the regime to achieve, for example, sector targets for climatic mitigation (Ministry of Food, Agriculture and Fisheries 2021) and nitrogen leaching reduction (Environment Agency 2023). 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 an expansion or intensification of the network of actors that support CA practices. Institutional anchoring means the development of new rules related to CA practices, which can be cognitive, normative, or economic (Elzen et al. 2012).

Technological anchoring: advisors as knowledge facilitators

Technological anchoring appeared in the development and sharing of practical CA knowledge. The number and diversity of levers addressing lack of knowledge as a key barrier was found to be large, and one of the interviewees concluded that the technical difficulties could be overcome on-farm. The key levers, all initiated by the advisory company (A1), facilitated knowledge sharing between farmers and included the organization of the Healthy Soil Conference as a platform for farmers to discuss CA, demonstrations, and knowledge-exchange groups providing safe spaces for farmers to learn and experiment. This focus on horizontal knowledge structures through a facilitative and participatory advisory approach was distinct from the dominant centralized knowledge production and top-down knowledge diffusion (Anderson et al. 2019*a*).

The traditional, top-down advisory role has been questioned as to whether it effectively addresses current challenges in agriculture (Landini et al. 2021, Krafft et al. 2022), as it neglects the complexity of systems and their context specificity (Charatsari et al. 2019). This is supported by earlier studies involving some of the farmers in the network (Hansen et al. 2020). To support agroecological practices through the use of CA principles, more systemic, facilitative, and participatory approaches of advisory actors are needed (Heleba et al. 2016, Charatsari et al. 2019, Landini et al. 2021, Krafft et al. 2022). Such an advisory approach strengthens horizontal knowledge structures (Anderson et al. 2019*a*, Bourne et al. 2021) and enhances the development of farmer skills to solve complex problems arising in their specific context (Cristofari et al. 2017, Charatsari et al. 2019, Bourne et al. 2021, Krafft et al. 2022), which makes it more effective (Ataei et al. 2019, Anderson et al. 2019*a*).

The facilitative and participatory approaches in the case study were hampered by the dominant regime. Our analysis identified as key barriers the traditional role of advisors and the risk of customer loss associated with the new ways of operating. To overcome such limitations, Krafft et al. (2022) point out the importance of advisors' skills, interdisciplinary collaboration, and farmer engagement in discussions. The development of advisors' facilitation skills in their evolving role requires time and support from diverse disciplines, notably facilitated through collaboration with National University A (A3).

In summary, the advisory company at the core of the case study facilitated knowledge development and sharing among farmers through a variety of activities, including workshops, field demonstrations, and conferences, thereby enhancing farmers' skills to solve complex problems. This appeared to have overcome a lack of knowledge as a barrier, indicative of the successful technological anchoring process. Although successful, the advisory actor's approach to strengthening horizontal knowledge structures remained a niche within the overarching dominating top-down advisory structure.

Network anchoring: advisors as network constructors

Network anchoring is evident in the collaboration of the Danish case study with regime-related actors, including hybrid actors who are part of the regime but hold differing views (Elzen et al. 2012, Diaz et al. 2013).

The network analysis and the analysis of barriers and levers revealed the dominance of regime actors related to policy and research and their blocking effect for anchoring. Key policy actors shaped the dominant regime of public policies and political power, by which CA is not supported. Key research actors reinforced the dominant regime of centralized knowledge production and top-down knowledge diffusion, which hampered the mobilization of horizontal knowledge structures in the case study.

As the most central and connected actor in the network, the advisory company held a crucial position for network anchoring to progress the agroecological transition (Heleba et al. 2016, Bourne et al. 2021, Krafft et al. 2022). The advisory company recognized the potential of relations with hybrid actors in connecting with the Thinktank and nature NGOs, as indicated by key levers. The Thinktank included regime actors in dialogs but aimed to disrupt dominant discourses. The nature NGOs were embedded in the regime structures but questioned regime values. The ties between the agricultural advisory and nature NGOs were especially novel, considering their commonly different perspectives. Hybrid actors related to society and economy were either loosely related or non-present in the network and may provide useful entry points for enhancing network anchoring.

In summary, the advisory company took the role of network constructor. To overcome the dominance of regime actors, enhancing the building of connections with hybrid actors is promising for network anchoring.

Institutional anchoring: contested knowledge as a barrier

Conservation agriculture in Denmark largely lacked institutional support. The analysis brought out contested knowledge as a key barrier to agreement on the relevance of CA for C sequestration. Beneficial, less contested aspects of CA (Farooq and Siddique 2015) were only highlighted to a very limited degree. Researchers from National University B (A7) concluded that data from a national long-term experiment did not show significant differences in soil organic C concentrations in the 0–50 cm soil profile when comparing direct drilling and ploughing and did not fully confirm a positive effect of straw retention on soil organic C content (Gómez-Muñoz et al. 2021). The experiment, established in 2002 at two different research farm sites, combined four tillage treatments with four crop rotations and ways of straw management in a split-plot design (Hansen et al. 2010, 2015). The findings did not match with practitioners' perceived changes of their soil after transition to CA. Proponents of CA questioned whether research farm plots were suitable to draw conclusions about the effects of farmers' situated CA practices. Successful CA application lies in the combination of adapting the three CA principles to the local context, which is not the case in standardized treatments in plot experiments (Rodenburg et al. 2020). Plot experiments, such as the Danish long-term research trial, produce generalizable agronomic insight but fail to capture the situated complexity of activities and interactions related to farming practices (Lacoste et al. 2022). Additionally, they are difficult for practitioners to relate to (Hansen et al. 2020), indicating that the effects of CA observed on CA farms need to be measured in that context. The relevance of on-farm experiments was recently emphasized by Lacoste et al. (2022), pointing out how the engagement with farming realities creates value for both scientists and farmers. Engaging in on-farm experiments, however, challenges current scientific approaches such as dealing with variability of farmer management, requiring more frequent communication between researchers and farmers, and maybe also different cross-disciplinary analytical tools (González-Sánchez et al. 2012, Anderson et al. 2019*a*).

Situations like the disagreement about the effect of CA on C sequestration have been described as part of wicked problems. Wicked problems are characterized by a lack of agreement on problem definition, i.e., the contextualized nature of CA effects on C sequestration, due to conflicting values and interests on the one hand, and by uncertainty of knowledge on proposed solutions on the other, i.e., the effect of size of the experimental treatments (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). The results of the on-station experiments were reported in a white paper (Munkhom et al. 2020) that was accepted by government as a basis for policy making, thus reinforcing the difficulty of institutional anchoring. A scientifically validated objectification of the performance of contextualized on-farm CA practices, compared with on-station experiments, may provide an avenue to overcome the current stalemate. Nevertheless, from a scientific perspective, a shift in the focus is needed, by not only looking at a single factor of the practice, such as C sequestration, but rather restructuring farmer–researcher relationships and addressing complexity and uncertainty through joint farm system exploration.

Methodological considerations

The actor network required simplification by representing actors in terms of organizations, thereby overlooking relationships between individuals. Including the degree of human agency that individual actors exhibit could significantly strengthen the relevance of the results (Gaitán-Cremaschi et al. 2022). We considered the simplification of the actor network acceptable as it enhanced the clarity of representation, and crucial human agency of individual actors was captured in the barriers and levers (e.g., the pioneer CA farmer working in advisory capacity (L30)). Nevertheless, considering the level of individuals in organizations is likely a necessary next step for use of the results.

The weights of the edges of the actor network were determined as the number of interaction types mentioned in the interviews, with no consideration of the intensity of each type of interaction. Also, the network of barriers and levers does not currently account for the intensity of the relationships between nodes or the initial magnitude of each barrier and lever individually. This limitation may be overcome by introducing an additional step, in which key actors themselves assign weights to nodes and relationships.

Additionally, it is important to emphasize that this "portrait" is guided by the perceptions of four key case-study actors and shaped by the analysts' interpretation. Therefore, the potential for incompleteness as well as interviewees' and researchers' bias constitute potential threats to the validity of the findings. Assessing validity depends on the types of knowledge claims and methods used, involves trade-offs between different threats, and requires judgment based on background knowledge (Hammersley 2008). In this study, the focus on reaching a shared understanding of the case study as a starting point for a reflexive arrangement has guided the development of our methods. Rather than aiming for time-consuming comprehensive network analysis, the result of our framework provides contextualized hypotheses for elaboration during the reflexive arrangement. The initiative's portrait is considered a tool for further investigation that can be continuously updated and reinterpreted based on the feedback and perspectives of the participants. The lack of comprehensiveness and possible biases are thus purposefully traded off with the timeliness and actionability of the knowledge generated. At the same time, efforts were made to reduce the threats on the validity of the findings. First, reliability of the conceptual model derived from a combination of literature sources, resulted in theoretical triangulation based on three pillars (i.e., context, actor network, and barriers and levers); reliability of the data base was enhanced by data source triangulation—through interviews with different stakeholders. Second, the different rounds of data collection and analysis helped ensure data accuracy through member-checking (Lincoln and Guba 1985, as cited in Mabry 2008), where key participants from the case study were asked during interviews to confirm, elaborate on, and, where needed, refute the data and interpretations. Given that validity is always a matter of judgment based on background knowledge (Hammersley 2008), we assume that case-study

participants are well-positioned to assess the validity of research findings. Finally, rather than aiming to produce grand grounded theory, we instead seek local theory (Mabry 2008) at the scale of the specific case study (i.e., the Danish CA Network), in line with the aim of alignment in reflexive arrangements.

Finally, it would be valuable to explore how alternative approaches to studying complex phenomena might offer new perspectives, using different system concepts. This could complement—or reshape—the portrait of the Danish CA Network derived according to the three pillars of our framework. For instance, whereas the actor network analysis primarily focuses on human actors and their interactions, innovation scholars have also recognized the critical role non-human actors play in innovation networks (Jarrahi and Sawyer 2019, Granstrand and Holgersson 2020). In this context, investigating how applying actor-network theory to conceptualize socio-technical assemblages (Jarrahi and Sawyer 2019) could present a promising analytical alternative.

CONCLUSION

Drawing on more elaborate characterization and assessment approaches, we proposed a learning-oriented framework to develop a shared portrait of an agroecological initiative as a starting point for a reflexive arrangement. This framework is illustrated through its application to a real-world farm management initiative, namely the Danish CA network. Relying on interviews with a limited but diverse set of actors from the initiative, comprehensiveness is deliberately sacrificed for the purpose of timeliness and actionability of the results, without compromising scientific rigor. The Danish CA network facilitators commented how the analytical results helped them to see the position of their initiative differently. In particular, they mentioned the perspective of CA as a niche in the regime and the lack of connections to actor groups that could enhance the visibility and recognition of CA farmers' positive contributions. They also emphasized the innovative development of horizontal networks by the advisory company and the need to assess objectively CA performance on-farms. Such reframing of "how we see the world" has been denoted as social learning, which is considered by many scholars essential for transformative change.

The process of applying the framework, i.e., having face-to-face working sessions at group and individual levels, online feedback, and frequent questioning by the researchers of the facilitators, contributed to trusting working relationships among the participants. The credibility and transparency of the approach, the attention to local details, the respectful use of the information provided by the actors, and the salience of the results all contributed to social capital, which is another important element in transformative change.

This study is an example of how research can be designed inclusively for the purpose of answering how-to questions associated with transformative change. Comparative analysis of the several agroecological initiatives that are part of the overarching Agroecology-TRANSECT project using the approach presented is expected to result in actionable knowledge for the initiatives, as well as enhance learning across transformative efforts.

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Pauline Cassart and Anina Frei made equal contributions to this work and are designated as co-first authors.

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Data Availability:

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Appendix 1. 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 case studies for the project by exploring their history, network of actors and barriers and levers. Our outcomes support others in the project to understand the case studies but will also support the case study to develop their action plans and move further in their agroecological transition.
- **Aim of the interviews:** get different perspectives on the same case study, deepen our understanding of most significant events (and thereby find barriers and levers to the case study's agroecological transition and learn more about actors of the case study, 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 case study, new perspective on the case study, 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 Co-Innovation Workshop 1 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 analyze 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 (with case study 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

Get to know the interviewee

For us and the project it is very important to get the views of different actors of the case studies: to understand the case study, its actors' network and the barriers and levers faced

- We understand you are *e.g. 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 *case study*?

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 *case study* 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 case study? (Choose around 3 events)
- Can you explain to us how it happened? Why was it so significant?

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

- What were 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 case study 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 haven't talked 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 *case study*? What is their role? How do they relate to the *case study*?
- Who do you talk to about the *activities of the case study*?

PART 3: REVIEW TIMELINE (case study 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 *case study* better.
- Info about next contact
  Facilitator: we will analyze the data and come back to you to validate results
  Key actor: we will analyze the data and come back to the case study once we have results to share, reports finished in November 2023
- Can we come back to you if we have questions?

Keep the recorder on.

Appendix 2. Actor network relations.

Actor1	Actor2	Weight	Type relationship	Description relationship
Danish butchery exporter cooperative	Danish agriculture and food council	1	Influence	One of the major companies controlling the Danish agriculture and food council (Keyactor4 2023)
Danish farm supply cooperative B	Danish agriculture and food council	1	Influence	One of the major companies controlling the Danish agriculture and food council (Keyactor4 2023)
Danish farm supply cooperative A	Danish agriculture and food council	1	Influence	One of the major companies controlling the Danish agriculture and food council (Keyactor4 2023)
Multinational dairy	Danish agriculture and food council	1	Influence	One of the major companies controlling the Danish agriculture and food council (Keyactor4 2023)
Danish agriculture and food council	National ministries	1	Influence	Danish agriculture and food council has access to ministries, negotiates directly with politicians (Keyactor4 2023)
Danish agriculture and food council	Advisory company	1	Influence	Danish agriculture and food council controlling main national advisory body and many local advisory centers. Advisory company independent, but also a member of that (Keyactor4 2023)
Birdlife organization	Danish parliament	1	Influence	Two powerful nature ngos [birdlife organization, environmental organization] which are very close to the parliament (Facilitator 2 2022)
Environmental organization	Danish parliament	1	Influence	Two powerful nature ngos [birdlife organization, environmental organization] which are very close to the parliament (Facilitator 2 2022)
Birdlife organization	Advisory company	2	Project A	Contact with nature ngos [birdlife organization, environmental organization, hunting organization] in project A (Keyactor3 2023)
			Bird counting	Counted birds on a CA farm (Facilitator 1 2022)
Environmental organization	Advisory company	2	Speech	Speech at CA conference from agricultural employee of environmental organization (Keyactor1 2023)
			Project A	Contact with ngos [birdlife organization, environmental organization, hunting organization] in project A (Keyactor3 2023)
Hunting organization	Advisory company	1	Project A	Contact with ngos [birdlife organization, environmental organization, hunting organization] in project A (Keyactor3 2023)
Thinktank	Advisory company	2	Collaboration	We [Advisory company] had some collaboration with a Thinktank (Keyactor3 2023)
			Support admin	Advisory company made Thinktanks' tax report (Keyactor3 2023)
Advisory company	European federation promoting CA	1	Board	Employee was board member of the Danish branch of the European federation promoting CA (Keyactor1 2023)
Advisory company	Multinational brewery	1	Meetings	Advisory company had meetings with multinational brewery (Keyactor1 2023)
Journalists	Advisory company	1	Visit	Visits of journalists on farm of employee (Keyactor1 2023)
Advisory company	Carbon credit company	2	Employees	Some employees from the advisory company work for carbon credit company now (Keyactor1 2023)

			Exchange	Advisory company interested in carbon credit company and support them with information (Keyactor1 2023)
Carbon credit company	CA farmers	1	Certification	Carbon credit company bought carbon credits of two farmers of the Danish CA network (Keyactor1 2023, Keyactor2 2023)
Advisory company	CA farmers	7	Visit	CA farmers from farming schools and universities come to visit advisory company (Keyactor1 2023)
			CA conference	Between 100 and 150 CA farmers come to CA conference (Facilitator 2 2022)
			Knowledge-exchange groups	5 knowledge-exchange groups were built over the years (Facilitator 1 2022)
			Project B	Core actors of project B; 50 CA farmers committed (Facilitator 1 2022)
			Advise	Agricultural advice on plant production systems (Keyactor2 2023, Keyactor3 2023)
			Demonstrations	Advisory company organized demonstrations for CA farmers (Keyactor3 2023)
			Speech	CA farmer who works for advisory company invites inspiring CA farmers to give speeches at CA conference (Keyactor3 2023)
Advisory company	Danish parliament	2	CA conference	Politicians came to the CA farm of an employee of the advisory company to discuss this way of farming (Facilitator 1 2022)
			Speech	Advisory company gave speeches to the part of the parliament that has to do with environment and farming (Keyactor1 2023, Keyactor3 2023)
Advisory company	National reduced tillage farmer association	4	Project A	Contact with national reduced tillage farmer association especially during the project A; speech of advisory company at parliament was enabled by national reduced tillage farmer association (Keyactor3 2023)
			Foundation	National reduced tillage farmer association was founded by CA farmer working for advisory company and colleagues (Facilitator 2 2022)
			Board	CA farmer working for advisory company was vice chairman, now another advisor is part of the board (Keyactor3 2023)
			Knowledge exchange	CA farmer working for advisory company has been moving knowledge from advisory company to national reduced tillage farmer association (Keyactor3 2023)
National reduced tillage farmer association	Danish parliament	1	Lobbying	National reduced tillage farmer association created access to parliament for advisory company; “I would also call them lobbyists” (Keyactor3 2023)
National university B	National reduced tillage farmer association	1	Project C	Project C (Keyactor1 2023)
Advisory company	National university B	1	Research project	New project about non-chemical weed control with a new system (Keyactor1 2023)
Non-profit research center	Advisory company	2	Conference	Two day conference, mostly for advisors (Keyactor2 2023)
			Umbrella	Non-profit research center is kind of an umbrella organization […] Advisory company can get supervision from non-profit research center (Keyactor2 2023)
Advisory company	Private foundation	1	Project A	Project A (Facilitator 1 2022)

National university C	Advisory company	1	Project A	Project A; national university C got the grants, but that was just technical, because advisory company took the initiative (Keyactor3 2023)
Private foundation	National university C	1	Project A	Project A (Facilitator 1 2022)
National university B	Danish parliament	1	Advice	National university B wrote white paper for parliament (Keyactor3 2023)
National ministries	CA farmers	1	Subsidy	Danish Energy Department gives CA farmers support to buy a direct drill (Keyactor2 2023)
CA farmers	National reduced tillage farmer association	1	Member	Some CA farmers of the knowledge-exchange groups are part of national reduced tillage farmer association (Keyactor3 2023)
Advisory company	National university A	4	Project A	Project A (Facilitator 1 2022)
			Project D	Project D started collaboration between a researcher and CA farmer working for advisory company through old knowledge-exchange group of CA farmer (Keyactor3 2023, Keyactor4 2023)
			Project B	Core actors of project B (Facilitator 1 2022); national university A invited advisory company to join project (Keyactor3 2023)
			Project E	National university A needed contact to CA farmers for project E and asked advisory company (Keyactor3 2023, Keyactor4 2023)
Advisory company	Machine manufacturers	1	Demonstration	The machine manufacturers who join advisory company's' demonstrations (Keyactor1 2023)
Machine manufacturers	CA farmers	1	Buy	CA farmers buy machines such as direct drill (Keyactor2 2023)
National university A	CA farmers	3	Project D	Collaboration with old knowledge-exchange group of CA farmer working for advisory company through project D; still in touch with them (Keyactor4 2023)
			Project B	Core actors of project B (Facilitator 1 2022); future vision workshop with two groups of CA farmers (Keyactor4 2023)
			Paper	National university A publishing a paper about a CA farmer (Keyactor4 2023)
Non-profit research center	CA farmers	2	Conference	CA farmers are now also invited to conference of non-profit research center (Keyactor2 2023)
			Project F	Project F of non-profit research center about pesticides including a CA farmer; enables farmer contact to agricultural experts (Keyactor2 2023)
Non-profit research center	National ministries	1	Contact	"And they [non-profit research center] are very much in contact with the Environment Ministry (Keyactor2 2023)
National university A	Dutch university	2	Project D	Project D
			Project B	Project B; support from European colleagues [Dutch university, French research institution…] (Keyactor4 2023)
National university A	French research institution	2	Project B	Project B; support from European colleagues [Dutch university, French research institution…] (Keyactor4 2023)
			Project D	Project D
EU	National university A	3	Project E	Project E was a Horizon 2020 project
			Project D	Project D was a European project (Keyactor4 2023)

			Project B	Project B
EU	Dutch university	2	Project D	Project D
			Project B	Project B
EU	French research institution	2	Project D	Project D
			Project B	Project B
National university B	National university C	1	Project C	Project C
National university C	National reduced tillage farmer association	1	Project C	Project C
EU	Advisory company	1	Project B	New to Advisory company to be part of an EU project (Keyactor4 2023)
National ministries	Danish parliament	1	State	Part of the Danish state
National ministries	EU	1	Europe	Part of Europe
European federation promoting CA	EU	1	Europe	European federation promoting CA is the European Organization for Conservation Agriculture; almost all European countries are members (Keyactor1 2023)

Appendix 3. Barriers and levers.

ID	Name	Description
B1	Contested knowledge about the relevance of CA for C sequestration	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). 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).
B2	Dominance of National University B's natural science approach in policy making	National University A's department of Agroecology, which has a 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).
B3	Traditions impeding new forms of collaboration	New types of collaboration diverge from traditions and are challenged by different aims and expectations of the actors (Keyactor4 2023).
B4	Difficult for advisors and scientists to leave the expert role	Expert role is expected from them and associated with prestige. Advisors especially don't want to disappoint farmers expectations (Keyactor3 2023, Keyactor4 2023).
B5	Advisory company limited in innovation which doesn't fulfil their customers' expectations	The advisory company is dependent on their customers and adjusts the activities they engage in to their customers' requirements (Keyactor3 2023). From the farmers' perspective, the advisory is expected to provide advice and services rather than including farmers in strategic and operational knowledge development (Keyactor4 2023).
B6	Advisors lack training in social skills for facilitation and co-creation with farmers	Advisors received only technical education and are challenged by social interactions with farmers (Keyactor4 2023).
B7	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).
B8	Risk of yield reduction 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).
B9	Lack of practical knowledge about CA in DK	Practical knowledge is limited to the context-specific experiences of a minority of farms that practice CA and minimum tillage in DK (Keyactor3 2023, Keyactor4 2023).
B10	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).
B11	Current legislation not supporting CA	Politicians are not aware of CA and therefore CA is not supported through legislation (Keyactor2 2023, Keyactor3 2023).
B12	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 (Keyactor2 2023).
B13	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).
B14	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 farmer's cluster to a food cluster, representing big food companies and the majority of farmers. It has no interest to support CA (Keyactor4 2023).
B15	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).
B16	Lack of remuneration for adopting 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).
B17	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).

B18	Many farmers 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).
B19	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).
B20	Difficult social position for CA farmers	Critique from colleagues brings CA farmers in a difficult social position (Keyactor1 2023, Keyactor4 2023).
B21	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).
B22	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).
B23	Lack of formal knowledge collection and reporting	No documentation of shared knowledge and trials are not followed up upon (Keyactor1 2023).
B24	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).
B25	Limited capacity of key person	Key person, a CA farmer working for the agricultural advisory company, is involved in many different activities (Keyactor3 2023).
B26	Difficult for advisory to find funding	It is challenging for agricultural advisory company to find projects or funding to further develop CA (Keyactor3 2023).
B27	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).
B28	Farmers education: plough is part of farming	Ploughing is taught as an inherent part of farming in farmers education (Keyactor2 2023).
B29	Financial pressure on farms	Farms in DK often work with a low margin and high debts (Grivins et al. 2021, Keyactor3 2023).
B30	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 of social scientists and advisors	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). The collaboration with National University C enabled agricultural advisory company to get a fund from a foundation and the collaboration with National University A enabled them to get into AE-T (Keyactor3 2023).
L2	Facilitative advice	To apply context-specific farming practices such as CA, farmers knowledge is essential to consider. Rather than giving recipes, advisors can take a more facilitative approach when giving advice to farmers, which includes asking questions and finding solutions together (Keyactor4 2023).
L3	Collaboration of social scientists and farmers	Scientists are present in events for farmers provided by advisory and thereby approachable. In the project, scientists facilitate future vision workshops for farmers. Scientists 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 agricultural advisory company 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 Danish CA network to get into AE-T. They get funding but advisors and farmers are not fully convinced that the outcomes are worth the effort (Keyactor4 2023).
L6	Experiments for pesticide reduction	Agricultural advisory company is part of non-chemical weed control project with National University B. A CA farmer takes part in an experiment of A non-profit research center that investigates reduction of pesticides in CA compared to other tillage practices (Keyactor2 2023, Keyactor3 2023).
L7	Fascination with soil and soil life that many farmers share	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	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	Agricultural advisory company being attractive for CA farmers	Agricultural advisory company gives powerful and clear advice and they provide different services to support CA farmers (Keyactor2 2023).
L12	Promotion of CA through connecting it to food	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	Agricultural advisory company supported the Thinktank with their tax report and later on collaborated with them, for The Thinktank to promote CA (Keyactor3 2023).
L15	Farmer association for reduced tillage advocating for CA politically	The farmer association for reduced tillage 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	CO_2 certificates for CA can provide CA farmers an additional income (Keyactor1 2023, Keyactor2 2023, Keyactor3 2023, Keyactor4 2023).
L18	Big companies asking for RA products	Big companies 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).
L19	Grant from a foundation	A grant from a foundation enabled the project of the agricultural advisory company to further explore CA (Keyactor1 2023)
L20	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).
L21	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).
L22	High yields and increased environmental robustness of farm	CA increases long-term resilience in relation to erosion and drought and thereby sustains robustness of yield (Keyactor3 2023, Keyactor4 2023).
L23	Stories of inspiring CA farmers show that CA works	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).
L24	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).
L25	Access to knowledge through social media	Social media is an independent source for knowledge-sharing but requires critical thinking and competences (Keyactor4 2023)
L26	Knowledge-sharing between farmers	When farmers discuss about CA and share their experiences (Keyactor4 2023).
L27	Newsletter of agricultural advisory company supports farmers in current issues	Reports about newest knowledge developments related to CA in Denmark (Keyactor3 2023).
L28	Field 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).
L29	Young advisors taking over some of key person's tasks	They have more time than key person and thereby give him more time for other tasks (Keyactor3 2023).

L30	Pioneer CA farmer working for advisory	A pioneer CA farmer working for the agricultural advisory company is exemplary and makes them a key person (Keyactor3 2023, Keyactor4 2023).
L31	National University A's interdisciplinary and transdisciplinary approach	National University A encourages collaboration between scientists of different disciplines and collaboration of scientists with practitioners (Keyactor4 2023).
L32	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)
L33	Connect to political actors by inviting them to give a speech at the Healthy Soil conference	Agricultural advisory company invited NGOs and politicians to give a speech at the Healthy Soil conference (Keyactor3 2023).
L34	Knowledge-exchange groups enable farmers to be the source of CA development	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).
L35	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)