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Drivers and barriers to climate-smart agricultural practices and technologies adoption: Insights from stakeholders of five European food supply chains

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ABSTRACT

The adoption of climate-smart agriculture (CSA) is a critical component in the transition to a more sustainable food system. However, the transition calls for significant changes in the food production system, in which stakeholders in the supply chain should work collaboratively. So far, most studies have focused on the perceptions of one actor, the farmer, on implementation of CSA practices. This study aims to include also other stakeholders' perceptions on drivers and barriers to CSA implementation in the primary production for five European food supply chains. Data were collected from stakeholders using a semi-structured interview guide, including farmers, producers and manufacturers, advisory service providers, advocacy institutions, policy officers, researchers, and consultants. The top three drivers to foster the adoption of CSA practices within the five food supply chains touched on economic, institutional and policy, as well as personal and psychological factors. Similarly, the top three barriers limiting adoption of CSA practices were seen to be economic, technology-related aspects, and institutional and policy factors. According to the stakeholders, addressing these barriers requires financial support, policy changes, and capacity-building efforts to make these practices attractive especially to farmers. They also emphasized that improved coordination among stakeholders, incentives for sustainable practices and customized strategies for communicating and disseminating CSA information can help catalyse effective understanding and implementation of CSA practices.

1. Introduction

The EU Green Deal Farm to Fork Strategy aims to transform the European agribusiness sector towards a sustainable food system by minimizing the negative impact of agriculture on the environment [24,47,61]. Research to study farmer behaviour and ways of thinking towards climate-smart agriculture (CSA) are needed, but this is not sufficient if we don't understand the behaviour of the remaining stakeholders within the value chains. A practical and scalable solution is required for transition to a sustainable food system [18,27,61]. However, complex decision-making occurs in the food value chain, where interlinkage of the actors such as advisors, agrifood industry, retailers

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and consumers may affect the transition to climate-friendly production [8,19,22,52,63]. A holistic approach is needed across the entire food system from farmers to consumers, which covers food production, transportation, marketing and consumption [47]. This calls for multi-stakeholder collaboration within the food value chain for sustainability-oriented innovation [5,16,22].

CSA is a FAO initiative, which focuses on three main pillars (i) increasing agricultural productivity in sustainable ways, (ii) adapting and building resilience to climate change, and (iii) reducing Greenhouse Gas GHG emissions. It is a globally acknowledged approach for addressing these challenges and fostering sustainable agricultural development under climate change pressures [40]. Implementation of CSA can also contribute towards the achievement of biodiversity and animal welfare improvement, and energy and water-use efficiency [25]. The implementation of CSA by farmers represents a crucial component of the shift towards a sustainable food system [61]. However, the transition to CSA requires changes across the food value chain, where each stakeholder must act collaboratively [1,19]. This transition may require changes at different technological, sociocultural, organizational, institutional, economic and political levels [24,47,48,63]. Understanding this process will support the design and implementation of policy interventions to overcome barriers to CSA adoption [23,41,62].

Although several types of drivers and barriers have been identified in the literature on CSA technologies, most deal with the developing world, with little focus on Europe [29,30]. Owing to the nature of location and context-specificity of CSA, it is necessary to evaluate the determinants of CSA practices and technologies adoption in European food systems [14,40,57]. In exploring CSA adoption determinants, not only focusing on farmers' views but also incorporating perspectives of other actors along the value chain is suggested [54,63,64]. Understanding stakeholder perceptions is important in transition to a sustainable food supply chain due to complexity of the CSA [33]. Most of the earlier studies concentrated on farmer perspectives, paving the way for the inclusion of other stakeholders regarding the drivers and barriers for implementation of sustainable practices [44,64]. This paper explores different stakeholders' perceptions of promising CSA initiatives within five selected European production systems as well as their perceptions of barriers and drivers for adoption: Wheat production in Lithuania, potato and onion production in the Netherlands, pig production in Denmark, apple production in Spain, and organic dairy production in Germany. Thereby, our study supplements earlier studies in CSA adoption by including not only farmers' views but also other stakeholder views and knowledge regarding CSA adoption in the primary production, thereby obtaining a deeper understanding of the challenges in behavioural change towards more climate-smart agriculture.

The aim of this study was to address the three research questions (RQs) listed below:

RQ1) What do different food supply chain stakeholders see as successful or promising CSA initiatives[1] in the primary agricultural production?
RQ2) What do food supply chain stakeholders see as drivers and barriers for implementation of CSA in the primary agricultural production?
RQ3) How are the drivers and barriers along the food supply chain interlinked?

2. Research methods

2.1. Data collection

Data were collected through personal interviews with the stakeholders in the food supply chain as part of the EU-project Behavioural Change Towards Climate-smart Agriculture (BEATLES)[2], a multi-stakeholder project which includes the five different case studies or use cases (UCs) representing different food production systems in Europe as described above. All interviews were conducted by partners in the five countries from January to March 2023. A semi-structured interview guide including 8 open-ended questions with 1–3 sub-questions focused on drivers and barriers of CSA adoption and the identification of successful or promising CSA practices for primary production. Information about the FAO definition of CSA was provided at the beginning of the interviews. This guide explored the initiatives in the food value chain that could support CSA and related drivers and barriers for adoption in the primary production with both livestock and crop production systems (see supplementary materials for details of the interview guide).

The interview guide was formulated in English by a team of researchers from the BEATLES-project and then translated into Dutch, German, Danish, Lithuanian and Spanish. The UC partners were responsible for recruiting and interviewing the interviewees in their local networks; for example, interviewees from Denmark were preferably part of, or linked to, the Danish pig production and pork supply chain. Stakeholders were selected purposefully based on their interest in being interviewed and their role in the value chain. The interviews were conducted either in person with physical presence or by using Zoom or Microsoft Teams and were recorded by the interviewer with the consent of the interviewee. Recordings of the interviews were stored safely and uploaded to the project's storage system. Subsequently, the anonymized summaries of the interviews were translated into English by the UC partner interviewer for each question.

We targeted to obtain 20 interviews from each case study with an aim to include stakeholders from different parts of the supply chain from the primary sector to retailers or food service. Although consumers are an important stakeholder in food production and land use, they are not directly included in this study because of the study design. The interview guide was designed to target stakeholders with some knowledge about agriculture and CSA and therefore consumers were not included. Instead, priority was given to include consumers indirectly by including stakeholders with consumers as their direct customers (e.g. retailers, food suppliers and manufacturing companies) views on food production.

In this study, a total of 69 interviews were conducted with the following: 14 pig sector stakeholders from Denmark, 16 onion and potato sector stakeholders from the Netherlands, 15 dairy sector stakeholders from Germany, 12 wheat sector stakeholders from Lithuania and 12 apple sector stakeholders from Spain (see Appendix A1 for the list of interviewed stakeholders and Fig. 1 for the distributions of different stakeholders across case studies and their role along the supply chain. All stakeholders were kept anonymous, but their place in the supply chain was identified, and a short name (code) for each stakeholder was given to identify their role.

51 stakeholders who are grouped as main actors in the food supply chain, include primary producers, producers and manufacturers, agro-industry, traders, cooperatives, restaurants, and technology providers. Other 18 stakeholders namely advisory service providers, advocacy institutions, policy officers, researchers, and consultants that provide research and demonstration services, are grouped under the supporting institutions category since they provide food supply chain enabling services.

2.2. Data coding and analysis

This study followed a top-down approach for content analysis based on predefined categories from review of literature [13]. The categorical themes for the barriers and drivers were identified and categorized

[1] Throughout the paper this study used the term CSA initiatives and CSA practices and technologies interchangeable depending on the context.

[2] Behavioural Change Towards Climate-Smart Agriculture (BEATLES) https://beatles-project.eu/

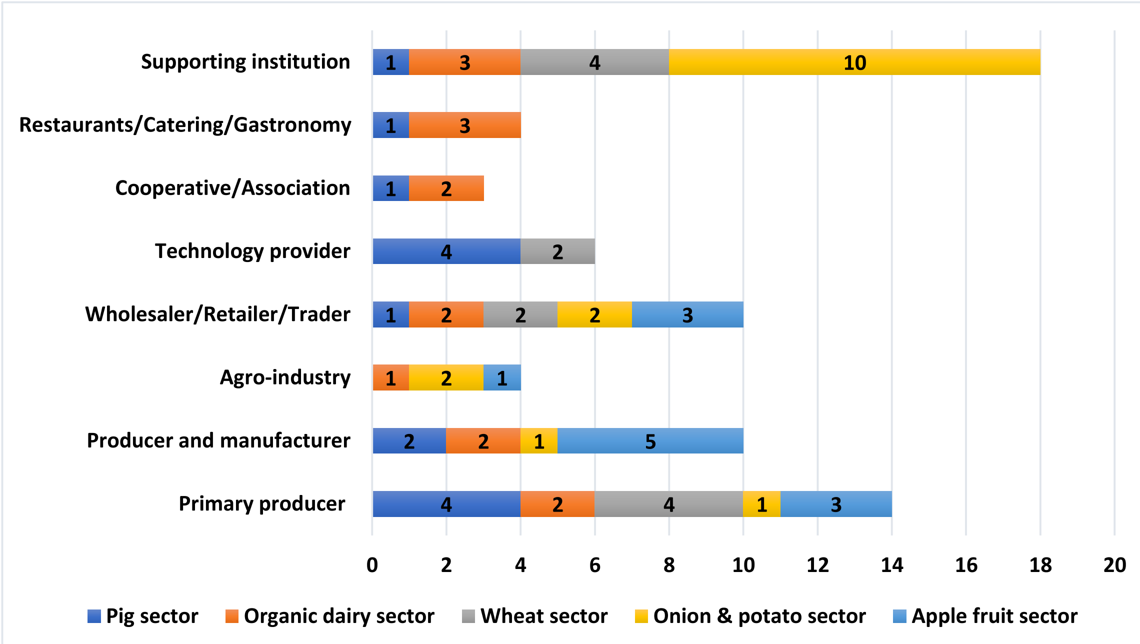

Fig. 1. Distribution of stakeholders by case studies.

previously from research that focused on stakeholder perspectives [6,19,22,26,44,46,63]. Accordingly, the stakeholder perceptions about drivers and barriers were categorized into personal, technological, economic, social, institutional, policy, and informational themes.

Personal themes include knowledge and experience, farmer motivation, beliefs, opinions and commitment, emotion, trust, pro-environmental attitude, resistance to change and risk attitude, responsibility as well as perceived benefits and costs [2,11,17,38,62].

Technology-related themes include factors related to capacity, skills, availability of technology, affordability, perception of ease of use and usefulness, data ownership, privacy and safety, compatibility and complexity of implementation [9,17,32,34,50,51].

Economic themes include factors linked to profitability, efficiency, cost reduction, availability of financial resources to implement practices, financial incentives such as compensation, and demand-side incentives such as consumer demand for premium prices for sustainable practices, value chain development, and product certification [9,11,17,26,32,38,49,50].

Social themes include factors related to existing social norms and culture, social pressure, and social image [9,34,36,38,50,51,62].

Institutional and policy themes include policy measures, regulations, schemes for incentives and subsidies, regulatory frameworks, prescriptive standards, conflicting interests between value chain stakeholders, extension and advisory services, access to the market and credit (loans) [2,8,11,17,32,38,50,55].

Informational themes include knowledge dissemination and promotion of CSA practices and technologies to farmers and products produced for consumers through communication channels [17,44,50,56].

Responses from the respective stakeholders from each UC were cited in the text using the code given to each stakeholder as a reference (the list of stakeholders with codes is shown in appendix A1). The coding here refers to each stakeholder in the supply chain, NL means Netherlands, ES is Spain and so forth, and then followed by a short name for the type of stakeholder proc = processor or two names if the specific stakeholder has two roles. This coding was made to avoid long names in the main text but at the same time to provide an indication of the type of stakeholder. The first and second authors of the paper coded the data by scheduling a meeting to discuss and reach a mutual understanding.

3. Results

This section is divided into four parts. First, the current and promising UC-level CSA initiatives as identified by stakeholders based on their knowledge and experience are described (addressing RQ1). The second and third parts presents the stakeholders' perception of drivers and barriers, respectively (together addressing RQ2). Based on these input, the interlinkage of the categorized themes on perceptions of drivers and barriers are presented in the fourth part (addressing RQ3).

3.1. *Suggested CSA initiatives put forward by stakeholders*

The stakeholders indicated CSA initiatives that they knew were currently being implemented. Table 1 summarizes the CSA practices along the value chain for each case study and this is followed by detailed descriptions of the stakeholders per case study. Stakeholders in the German organic dairy sector indicated that local production and protein feed supply, managing grasslands and using photovoltaics were identified current and promising CSA initiatives for the dairy sector. In the Lithuanian wheat sector, smart farming technologies, higher-yielding varieties, cover cropping, and organic fertilizers and residue composting were seen as CSA initiatives in wheat production. Local value chain development, smart irrigation, and using renewable energy are indicated as providing more efficient and climate-friendly production in the Spanish apple sector. Smart irrigation, improved varieties, and digitalized farming methods are some of the CSA initiatives indicated by onion and potato stakeholders in the Netherlands. Finally, renewable energy, hybrid ventilation, and efficient waste management techniques were stressed by stakeholders in the Danish pig sector as key CSA initiatives. More details on the CSA initiatives mentioned by stakeholders in the five UCs are given below.

3.1.1. *Organic dairy sector in Germany*

A total of 15 stakeholders, including main actors in the food supply chain were interviewed from the German organic dairy sector. Productivity aspects of CSA initiatives were mainly raised by the interviewees. One idea was to increase cow longevity to optimize lifelong output of milk and calves instead of focusing on milk production per year (DE-trad). At the field level, no-tillage during autumn and soil cover to avoid

Table 1

Summary of current and promising CSA practices and technologies suggested by stakeholders for the five case studies.

Organic dairy sector in Germany *	Wheat sector in Lithuania	Apple sector in Spain	Potato and Onion sector in the Netherlands	Pig production sector in Denmark
• Local production • Grassland management • Photovoltaics • Focusing on life-long production for cows • Local protein feed supply • Food waste recycling	• Smart farming technologies • Higher yielding and resistant varieties • Use of organic fertilizers • Inter-cropping, cover-cropping • Residue composting • Waste-free production	• Local production • Smart irrigation • Use of floral bands and cover crops • Use of renewable energy • Organic production • Energy efficient storage and cooling facilities	• Smart irrigation • Robust potato varieties • General digitalized farming • Site specific crop protection	• Renewable energy • Hybrid ventilation • Local feed production • Reduced feed waste • Slurry handing by acidification • Biogas production

Note: * Organic farming was categorized as a CSA practice because it prioritizes environmental sustainability, biodiversity and animal welfare [25].

erosion were suggested as well as adapted grazing (DE-farm1). One stakeholder mentioned local production and short distances for marketing as a promising initiative (DE-trad). Furthermore, creating a better market for calves from organic dairy cows was suggested (DE-coop-prod). Marketing of calves in organic production should be supported by inspiring customers to use only high-quality products (DE-trad). Local protein feed supply to avoid imported proteins was also addressed. In particular, protein from grass and Alfalfa was mentioned with local or on-farm grass drying facilities as well as feed production from grass and maize silage (DE-farm1, DE-proc and DE-mill). In addition, methane-reducing feed and plant extracts was also suggested (DE-feed-prod). To increase biodiversity, grassland management, planting hedges and insect-friendly mowing in the field was also suggested by three stakeholders (DE-coops. DE-advis, DE-farm1). In general, photovoltaics on farm roofs and using photovoltaic energy to dry hay was mentioned (DE-trad, DE-farm1, DE-farm2). Marketing of organic beef raised on pasture grazing was suggested but here there is a need for more “consumer education” to increase the consumption (DE-proc, DE-city-adv). Promoting organic certification and supporting organic inputs in kitchens and schools could also be a way forward (DE-gastro2, DE-city-adv). One solution was to establish specific kitchens focusing on organic food to supply schools (DE-city-adv). Waste reduction for reducing emissions from food systems was also highlighted by several stakeholders and use of leftovers from the food industry (DE-mill and DE-coop, DE-gastro1). Finally, it was suggested to promote seasonal and regional purchase of commodities, which needed to go hand-in-hand with a changed nutritional pattern within the population. Here seasonality was not the main CSA but a means to reduce costs to being able to purchase organic inputs (DE-city-adv).

In summary, the stakeholders in the organic dairy sector highlighted the importance of productivity aspects in CSA initiatives by suggesting increasing cow longevity for optimized lifelong output, implementing no-tillage and soil cover to prevent erosion, promoting local production and short marketing distances, creating a better market for organic dairy cow calves, ensuring local protein feed supply, implementing methane-reducing feed and plant extracts, enhancing grassland management, utilizing photovoltaics for energy generation, reducing waste, and utilizing leftovers.

3.1.2. Wheat sector in Lithuania

A total of 12 stakeholders from the wheat sector in Lithuania were interviewed. Digital tools and data management systems as well as a greater focus on automation in the supply chain were all regarded as promising CSA solutions in the wheat supply chain by several stakeholders (LT-log, LT-farm1, LT-farm2, and LT-sale). Smart fertilization equipment and micronutrient fertilizer practices with soil testing and automatic steering systems were also suggested to enable energy savings (LT-farm2, LT-farm1, LT-suppl-comp, LT-farm3). Soil improvement was recommended to increase productivity (LT-agtech.prov1, LT-farm3) and use of catch crops, minimum tillage and intercropping with legumes and other crops was recommended (LT-farm1, LT-farm2, LT-farm3). Local production of fertilizers should be promoted (LT-farm1) and the use of grain residues for composting and humus production was also suggested for soil improvement (LT-sale). Field mapping to reduce spraying (LT-farm3, LT-agtech-prov1, LT-suppl-comp) and robots on small farms were highlighted as sustainable solutions (LT-sale). A better utilization of existing and new machinery was also identified as CSAs (LT-farm3, LT-farm4). A better selection (breeding) of wheat with extensive roots could increase nutrient absorption (LT-agtech-prov1). Technologies to clean and dry grains without chemicals were also proposed (LT-sale). Water reduction and spraying with compression technologies were also recommended (LT-farm4). In this regard, energy efficiency was the primary pillar including use of solar panels and solar parks (LT-wholesale, LT-log). One stakeholder advocated for other packaging alternatives and better circular solutions (LT-log). Finally, it was suggested to introduce loyalty programs for farmers so that all sustainable farmers receive a discount after two to three years (LT-sale).

In summary, Lithuanian wheat stakeholders highlighted the potential of digital tools and data management systems in the supply chain, smart fertilization practices, soil improvement techniques like catch crops, minimum tillage, and intercropping, local fertilizer production, and grain residue composting. They also highlighted field mapping to reduce spraying, roots-rich wheat varieties, chemical-free grain cleaning and drying, water conservation, and solar panel energy efficiency.

3.1.3. Apple sector in Spain

In total, 12 stakeholders from the apple sector in Spain were interviewed. Local production and processing of organic apples and sales in differentiated and local markets was advocated with focus on seasonality to secure efficiency in the distribution (ES-prod-dist, ES-prod1, ES-prod-proc1, ES-wholesale1). Collective warehouses with refrigerated storage facility to reach a minimum volume sufficient to make storage efficient and sorting facilities were also mentioned (ES-prod2, ES-prod. process2). Solar panels for energy savings and reduce GHG emissions (ES-wholesale2, ES-prod3) and the optimization of water pumping and irrigation were recommended by several stakeholders (ES-prod1, ES-prod2, ES-prod-proc2, ES-prod-proc4) and using efficient machinery with GPS (ES-prod1). Anti-phytosanitary and anti-pest net treatments for fungi and pests were also recommended as sustainable solutions (ES-prod-proc2). Furthermore, grass-cutting, which leaves a central aisle in the field and serves as a reservoir for auxiliary fauna, was considered a sustainable practice (ES-prod2). Improved farm management and implementation of tools for crop planning (ES-prod-dist) and IT tools for order management (ES-prod-dist) stock control, and storage were recommended as well (ES-wholesal1).

Varieties to seek better agro-climatic adaptation and efficient use of resources were recommended like manure from livestock (ES-prod2, ES-prod4) and use of vegetation cover e.g. legumes (ES-prod4), and closed-cycle management of waste from apple tree pruning (ES-prod-proc5). To increase yields, more knowledge is required about pollination and its effect on the varieties used in the area (ES-prod-proc5), where specific solutions with bees to improve pollination were recommended (ES-prod-proc2). Finally, reuse of glass from bottles among cider producers (ES-prod-proc3), controlled atmosphere chambers to maintain apples longer and humidity- and respiration-controlled environment (ES-wholesal2) were also recommended. Cleaning water could be recirculated (ES-wholesal2), and better use of machines for separating pallots according to apple category were mentioned as well (ES-wholesale2). In addition compostable plastic in the packaging unit (ES-prod. proc4) and introduction of biodegradable cleaning products were recommended (ES-prod-dist). Initiatives to improve social sustainability such as long-term relationships in the supply chain, advanced payments, and wages for workers were also mentioned (ES-prod-proc4).

In summary, Spanish apple stakeholders highlighted local organic apple production and processing, local markets, and seasonal, efficient distribution. Collaborative warehouses with refrigerated storage, energy saving technologies, optimizing water pumping and irrigation, GPS-enabled machinery, anti-phytosanitary and anti-pest net treatments, farm management and IT tools, improved apple varieties, vegetation cover, closed-cycle waste management, and bee pollination were suggested CSA initiatives.

3.1.4. Potato and onion sector in the Netherlands

In total, 16 Dutch stakeholders from the potato and onion sector were interviewed. Reduced tillage combined with direct sowing was proposed as a CSA solution (NL-prod-proc) as well as strip cropping, and more mechanical weed control. Cultivation-free zones could be used to reduce pesticides in ditches (NL-env-fed). Robust potato varieties that are more resistant to drought with lower nitrogen inputs can enable climate-friendly production (NL-adv). Another suggestion was to enable long-term CO_2 storage, for example, in wood and fiber crops (NL-province, NL-crop-adv, NL-off-agri). Better water management, level-controlled drainage, and underground water storage were also discussed. Precision farming and robots were also considered in which many growers already use GPS on their tractors, enabling less driving and precise weeding (NL-province) and plant-specific treatment. Site-specific use of N, based on sensors and use of green manure also plays an important role. In addition, site-specific crop protection, mechanical weed control, and robot weeding were suggested as climate-smart crop protection technologies (NL-env-fed, NL-research, NL-found, NL-proc2act, NL-adv).

Several other initiatives regarding digital solutions and self-learning algorithms, such as hoeing, plant recognition, and footprint data valorization, were also suggested (NL-prod-proc, NL-proc2, NL-prod-proc). In addition, short links in the chain to reduce transportation and waste were mentioned (NL-found). Furthermore, solar panels in storage facilities and water supply could be more efficient, for example, by saving water during winter for use in the summer season and methods to reduce pollution (NL-proc1). Another initiative was to use tax reservations for weather extremes. (NL-adv).

In summary, stakeholders in the Dutch use case highlighted reduced tillage combined with direct sowing, strip cropping, and mechanical weed control to promote sustainable practices. The cultivation of robust potato varieties with lower nitrogen inputs and increased drought resistance was recommended for climate-friendly production. Improved water management through level-controlled drainage and underground water storage and precision farming with GPS were also suggested. In addition, robots for efficient and precise operations, mechanical weed control, shortening of supply chains, waste reduction and solar panels were suggested as initiatives to enhance sustainability in the sector.

3.1.5. Pig production sector in Denmark

In total, 14 Danish stakeholders from the pig sector were interviewed. Hybrid ventilation that combines natural ventilation and air cleaning with floor extraction could reduce energy use from the ventilation systems in pig production according to one stakeholder (DK-tec-prov1). Smart farm control systems, regulators and monitors of ventilation, heating and cooling on a central PC with hybrid ventilation could also provide a more stable indoor climate (DK-tec-prov1 DK-farm1). Likewise, frequent flushing of manure with less odor from the stable was recommended (DK-tech-prov1).

Separation of dry matter from slurry, which can be used for biogas (DK-soft-dev, DK-prod-man1) and technologies for cooling slurry in animal houses to reduce methane and ammonia emissions were also suggested (DK-tec-dev). Biogas can substitute natural gas for heating (DK-tec-prov2) and acidification of slurry reduces both methane and ammonia emissions from animal houses and slurry storage tanks (DK-tec-dev). It was further suggested to use software programs for handling logistics when moving slurry and to establish a cooperative to import sulfuric acid for acidification (DK-soft-dev). To engage in green action, it is necessary to have a reward system for example, by educating and creating climate ambassadors for employees (DK-retail). Use of precision agriculture (DK-farm3) such as spot spraying with field mapping to optimize crop production and improved irrigation/cultivation systems were also suggested (DK-prod-man2, DK-asso). Another stakeholder proposed setting aside marginal areas (DK-farm2). Several stakeholders focused on local production, including locally produced protein (DK-farm1, DK-farm2), and a short supply chain from farm to table (DK-farm4) minimizing feed waste (DK-farm2) and that residual product were better used for animal feed than for biogas (DK-farm4). At the retail level, reduction in food waste and meat consumption were suggested.

In summary, the Danish pig sector stakeholders highlighted hybrid ventilation systems and smart farm control systems to regulate and monitor ventilation, heating, and cooling for a stable indoor temperature. Separating dry matter from slurry, cooling it to reduce methane and ammonia emissions, heating with biogas instead of natural gas, and acidifying slurry and storage tanks were also indicated. Precision agriculture techniques like spot spraying with field mapping, optimized crop production, and improved irrigation and cultivation were also suggested.

3.2. Drivers fostering adoption of CSA practices and technologies

The interviewed stakeholders suggested a range of drivers that would foster the adoption of CSA technologies and practices. These drivers are categorized into six themes, as presented in Table 2 where each indicated driver under each theme was also summarized. We looked at general CSA adoption drivers in the five selected food supply chains by counting how many times each stakeholder gave that driver as an answer. Based on the percentage of driver's distributions among the themes, the most important drivers for adoption of CSA from the perspective of the interviewed stakeholders were economic, institutional and policy, as well as personal psychological factors (Fig. 2). CSA practice or technology-related aspects, social influence, and information dissemination are some of the other most common drivers for CSA adoption.

3.2.1. Personal drivers

Environmental concern, self-responsibility, knowledge about CSA, inspiration, commitment, and perceptions on CSA were suggested person-related drivers of CSA adoption (Table 2). These personal drivers were more focused on individual psychological aspects to adopt CSA that will, in turn, determine behavioural intentions towards CSA adoption. For instance, stakeholders in the Spanish apple sector indicated that adopting CSA practices requires an initial commitment of individuals to implement them (ES-wholesal1), as well as knowledge about CSA, like new ideas to improve day-to-day operations (ES-wholesal2). Furthermore, stakeholders in the Danish pig production sector expressed that individual psychological drivers can play a vital role in driving CSA implementation. Individual commitment from both supply and demand side is essential for driving the shift towards a climate smart food system. The idea was highlighted by interviewed stakeholders that the successful transition to a climate-smart food system relies on the strong commitment of producers to implement CSA practices and the willingness of consumers to consume food products

Table 2
Drivers for adoption of CSA practices and technologies by farmers from stakeholder perspectives grouped into 6 themes.

Personal drivers		Technological related drivers		Economic drivers		Social drivers		Institutional and policy drivers		Informational drivers	
Interest to implement CSA technology	5	Technical training and education on CSA technology	6	Bonus payment for CSA-based participation	2	Local support-societal influence	2	Subsidy schemes for implementation of CSA	7	Awareness on CSA technologies	11
Concern towards environmental benefits of CSA	4	Logistics improvement for climate-smart inputs including technologies	3	Premium price for CSA-based produce	7	Social norm regarding CSA-implementing farmers	5	CO_2 tax on use of practices and technologies that result in high emissions	3	Social media promotion on positive effects of using CSA	3
Intention towards adopting CSA practices and technologies	4	Demand for CSA technology/practice	3	Contractual motivations for CSA-based production	2	Complying to group who is implementing CSA	2	Rewarding system for those implementing greener action	2	Consumers campaign on consumption of CSA-based food products	2
Self-responsibility to contribute better environment	4	Availability of CSA technology	3	Certification of CSA-based food products	7	Society actions/ campaigns on climate change	2	Collaboration between farmer organizations and other institutions	2	Media and press promotion of implementing CSA as pro-environmental behaviour	6
Knowledge about CSA	6	Demonstration of the CSA technologies or practices	4	Membership of fair certification	3	Cooperation with communities/ farmers	5	Legislation and regulation on implementation of CSA	7	Demonstration of CSA practices and technologies	2
Personal pride on use of CSA technologies	2	Capacity development on implementation of CSA	3	Direct marketing for farmers	2	Positive feedback from peers on CSA	3	Guidelines for sustainable use of land, water, soil	3	Communication of innovation through education and advising	3
Inspiration by success stories of CSA practices	4	Efficiency of CSA technology	3	Financial incentive for CSA practice and technology adoption	11	Neighboring effect on CSA implementation	3	Incentive scheme for implementation of CSA	6	Disseminating knowledge by tour and exhibition	2
Commitment to implement CSA	2	The simplicity of CSA technology	4	Financial incentive to young and newly engaged farmers	4	Recognition for adoption of CSA practices and technologies	5	Availability of credit loans for CSA-based production	3	Workshops for farmers on how to implement CSA technologies	2
Intrinsic motivation in addressing climate change	6	Technical support from technology providers	5	Establishing a link with consumer demand	5	CSA knowledge sharing within group	3	Tax reduction for adopters of CSA practices and technologies	4		
Pro-environmental attitude	3	Compatibility of CSA technology	5	Compensation for opportunity costs of implementing CSA	8		5	Coordination along CSA-based food supply chain	2		
Perceptions on the CSA technology	7			Market development for CSA-based products	5			Support from governmental office on agricultural advisory services	4		

Note: The numbers in the table represent how frequently various stakeholders stated the respective drivers within the theme.

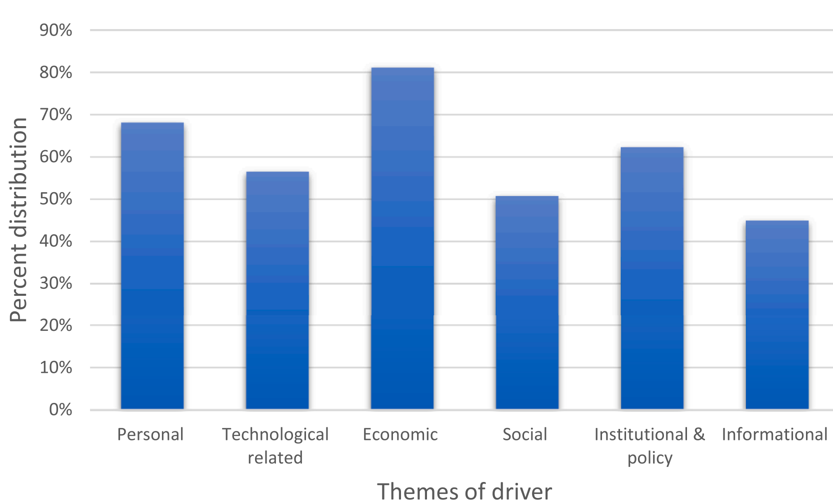

Fig. 2. Percent distribution of stakeholder opinions regarding drivers to CSA adoption in the five food supply chains studied.

that are based on CSA principles (DK-comm-dev, DK-retail, DK-farm4)

Emotion-related satisfaction with one's own work, the joy of succeeding, and professional pride (DK-farm4, DK-cat) were seen as drivers for adoption of CSA. The intrinsic motivation of farmers towards CSA implementation is another individual driver that determines adoption decision. For instance, Interviewed Danish pig production sector stakeholders indicated that farmers have a deep concern for the environment. This motivates them to comply with existing climate-friendly programs, whether they are from the national government or the EU (DK-prod-man1, DK-tec-prov2).

Another personal decision-making component that is essential for promoting the adoption of CSA practices and technologies is environmental consciousness. For instance, farmers who prioritize environmental sustainability for pig production strive to minimize emissions through various practices, such as regular flushing, floor extraction, enhanced ventilation, and thorough air cleaning (DK-tec-prov1). Furthermore, for wheat stakeholders, knowledge level, nudging and risk-averse and pro-environmental attitudes were suggested drivers supporting adoption of CSA (LT-agtech-prov2, LT-farm2, LT-supp-comp, LT-sale and LT-farm3). Finally, for organic dairy stakeholders, openness to new ideas and approaches, experience, motivation, risk awareness, and willingness to take risks were suggested drivers (DE-farm1, DE-research, DE-trad, DE-wholesale).

3.2.2. Technological drivers

Training in technology, logistics, availability of technology, demonstration of innovation, technical support, efficiency, perceived compatibility of technology with existing farming systems and ease to of CSA technologies are among range of technology-related mentioned drivers to spur CSA adoption (Table 2). The compatibility of practices and technology with the existing farming practices where if the technology fails to integrate with what farmers already have, the end users may be reluctant to accept it (DK-tec-prov1). The ease to use of technology which is reflected by how simple it is to understand and operate, is another factor in deciding whether to adopt it. Even though the technology has greater potential to achieve CSA outcomes, farmers may be discouraged from adopting a technology if it is too complicated and demands technical clarification (ES-prod3). Another technological driver is the availability of infrastructure and inputs, which can influence the adoption of climate-smart technologies. As noted in the stakeholder interviews, targeted aid for the acquisition of new machinery or infrastructure was mentioned as a driver of the Lithuanian wheat value chain (LT-prod-process2). Sharing climatic and agricultural data can enhance farmers' abilities to collect and analyze data and manage information, which can drive adoption (DK-tec.prov1, DE-farm2). Furthermore, improved monitoring and feedback systems that provide real-time information and feedback on the effectiveness of climate-smart farming practices could foster adoption (ES-prod1, DE-feed-prod).

3.2.3. Economic drivers

Financial incentives, compensation for opportunity costs, market development, short supply chains, contractual motivations and certification are indicated economic drivers of CSA adoption (Table 2). Farmers often estimate cost-benefit analysis based on the perceived economic benefits of adopting CSA practices or technologies by considering increased yield and reduced input costs such as water and fertilizer (DK-prod-man1, ES-prod-proc4, LT-farm1, LT-farm4, NL-prod, ES-prod-process5). For instance, stakeholders in the Danish pig production sector have indicated the viability of CSA practices or technologies to be adopted (DK-farm3, DE-farm1, DE-soft-dev.), which typically entails compensation for farmers' opportunity costs if it is not viable. The introduction of a bonus fee to farmers who have invested in climate-smart technologies, which leads to reduced greenhouse gas emissions, was suggested as an economic reward by Danish stakeholders (DK-tec-prov2). In this regard, food supply chain actors play a role in motivating producers by providing bonus fees. For instance, it was suggested that meat-producing companies can motivate livestock farmers to produce in a climate-friendly by introducing a bonus fee to the farmers (DK-prod-man1). Similarly, German organic dairy sector stakeholders indicated that the provision of monetary incentives to farmers could spur the adoption of CSA practices and technologies (DE-coop-prod, DE-feed-prod).

Marketing incentives are pointed out as another economic driver to motivate farmers' CSA adoption, as indicated by most stakeholders. For instance, German organic dairy sector participants indicated that if the marketing of organic products is efficient, more farmers will have a financial incentive to produce and benefit from fair partnerships (DE-coop-prod). Value addition aspect for sustainably wheat production along with new market development trends for cereals were indicated potential driver for adoption of CSA (LT-agrotech-provid, LT-farm2, LT-sup-comp). Financial aid to carry out climate-smart agricultural initiatives such as energy-saving farming technologies was indicated by Spanish apple supply chain stakeholder (ES-prod. process1). Similarly, several stakeholders have pointed toward the need for financial support to drive digital investments to enable climate-smart production (ES-wholesal1, ES-prod-proc1, ES-prod3, ES-prod-proc3). This could be provision of financial support to modifying existing cooling infrastructure, such as installing solar panels, replacing engines, or establishing networks capable of facilitating the sharing of cooling resources (ES-prod and distrib). The consumer demand and willingness to pay premium price for food products produced by CSA based practice and technologies could encourage more farmers to adopt CSA (ES-prod. proc1, ES-prod-proc5, NL-proc2, DE-research). In this regard, intervention to nudge consumers towards consumption of CSA products and value chain aspects like shortening supply chains, direct marketing and business modeling are also suggested some stakeholders (NL-proc2, NL-off-agri, DE-farm1).

3.2.4. Social drivers

Social norms and trust, cooperation with communities, neighboring effects, recognition for pro-environmental performance, and group knowledge sharing are indicated social drivers for adoption of CSA (Table 2). Farmers' adoption decisions are often influenced by their peers and community members (ES-prod4). Farmers are more inclined to adopt CSA approaches when they observe their fellow farmers effectively applying these strategies. The neighboring effect implies, that if there is a pioneer close by doing innovative practices, farmers are more likely to adopt them (DE-research). Community acceptance of the farm business model was also an essential motivation for implementing CSA, as these were popular measures that contributed to engaging with the community and increasing their acceptance of greenhouse gas expansion (DK-asso, DK-farm4). In this context, farmers will experience a sense of pleasure upon achieving success, coupled with a professional attitude of pride, which will serve as a motivating factor for adopting CSA (DK-farm4, DK-cat). Social norms, where farmers learn from farmers around them ongoing CSA practices and sometimes seek confirmation from the people around them, was indicated drivers for shaping an individual's adoption behaviour (NL-province). Peer-to-peer learning that could reflect obtaining knowledge from one farm to another when farmers come and see what they are doing in terms of implementing good practices (DE-research). A positive feedback loop that could be created by pro-environmental farmers may influence their neighbors and encouraging others to implement (DK-tec-prov1).

3.2.5. Institutional and policy drivers

The key institutional drivers indicated by interviewed stakeholders are subsidy schemes, CO_2 tax, partnership with other institutions, governmental regulation, transparency in the supply chain, support on agricultural advisory serves and coordination along the food chain (Table 2). Among the drivers, government policies and regulations are frequently indicated as having a significant role in promoting CSA technologies. Schemes for financial incentives, subsidies, tax, and regulatory frameworks can incentivize farmers to adopt technologies that reduce greenhouse gas emissions, improve resource efficiency, and enhance climate resilience (DE-mill, DK-farm1, DK-farm3). Financial support from the government and tax reductions are regarded as important drivers (LT-farm1, LT-sale, DK-farm1). Tax reduction for adopters of CSA could drive others to engage in such activities (LT-log, LT-agtech-prov1, LT-wholesal, LT-agtech-prov2). Similarly, the compensation for additional costs incurred by implementing CSA could drive adoption (LT-agtech-prov1). Increase in public subsidies for CSA adoption, such as aid for equipment and infrastructure (ES-prod-process1) and easier access to investment (ES-prod-proc2) also suggested drivers. Thus, it could enable more farmers to afford precision technology and motivates farmers to invest in climate smart solutions for agriculture (DK-prod-man2, DK-prod-man.1, DK-tec-prov2). Fair allocation of subsidies has also been mentioned (DK-tec-prov1) where financial support schemes from the EU or national governments for farmers who want to buy and install technology (DK-tec-dev).

A long-term policy commitment with a clear agricultural vision among policymakers to ensure stable long-term conditions for producers and processors to make investments is indicated driver for adoption of CSA by vegetable sector stakeholders from the Netherlands (NL-prod-proc). Politically, more actions could be taken to increase the organic share of food being consumed (DE-gastro1). In this regard, public procurement for public canteens and restaurants has much potential to increase the consumption of organic products (DE-trad, DE-proc). Advice for farmers is based on guidelines with practical scientific ideas that can promote adoption of CSA (DE-advis, DE-coop). In this regard, guidelines to estimate costs and benefits more precisely by estimating emissions from feed production, organic farming with grazing are suggested by stakeholders (DE-advis, DE-mill). Finally, support to the development of sustainable supply chains and certification systems can create market incentives to use these technologies (DE-coop). On the other hand, by pooling resources, negotiating with buyers, and exchanging knowledge and experiences among members, farmers' co-operatives and associations can, through collective action, foster the adoption of climate-smart technologies (DE-coop, LT-sup-comp).

3.2.6. Informational drivers

Social media and press promotion, consumer campaigns, demonstrations, education, workshops, and promoting innovation are the stakeholders indicated informational drivers of CSA adoption (Table 2). Increasing farmers' awareness of CSA encourages them to implement climate-friendly practices and technologies (DE-feed-prod). Awareness can be raised through extension services, workshops, and information campaigns. Education and advice for farmers (DE-coop), knowledge, education, and training (DE-farm2), including knowledge and information from universities (LT-farm4) are regarded as major drivers. However, demonstrations, on-farm trials, and field visits can provide hands-on experiences and build confidence in the effectiveness of a technology which in turn enhance adoption (LT-prod4). Furthermore, farmers need information about the long-term benefits of climate-smart technologies, such as their effects on soil health, farm sustainability, and food security, as well as environmental and ethical factors, such as reduced chemical inputs or improved soil and water quality, which can influence adoption, especially among environmentally conscious farmers [7,12,35]. Alternatively, it was suggested that awareness for consumers on sustainable food consumption through kitchen parties, where producers can meet guests and educate them (DE-gastro1, DE-city-adv). Furthermore, understanding climate-smart packaging, including labeling, has the potential to shift consumption behavior, allowing more farmers to participate in product production, hence driving CSA adoption. For instance, if consumers do not want vegetables produced by CSA-based practices, it is important to understand this and follow up on their preferences to find out their preferences (DE-city-adv).

3.3. Barriers to adoption of CSA practices and technologies from stakeholder perspectives

Although there are drivers that encourage the adoption of CSA, there are also numerous barriers that require further action to overcome. The personal, economic, institutional, social and informational are highlighted based on the themes of barriers. To provide a comprehensive general overview of themes it was presented in Fig. 3, while each indicated barrier under each theme from different stakeholders was summarized in Table 3. The percentage distribution of each theme was examined based on counting of how many times each stakeholder stated the barrier for adoption of CSA. Based on the percentage of theme-based barriers' distributions (Fig. 3), economic, technology-related, as well as institutional and policy factors, were the barriers most frequently indicated by the stakeholders interviewed. CSA practice- or technology-related aspects, social influence, and information dissemination are some of the most common barriers to CSA adoption.

3.3.1. Personal barriers

Barriers encompassed by this theme are individual behavior that can prevent farmers from implementing sustainable agricultural practices. Risk aversion attitudes, perceived lack of benefits from adopting CSA, low interest in implementation, prioritization of short-term benefits all bias against CSA adoption. Prior experience, resistance to change and lack of motivation are key personal barriers to adoption of CSA (Table 3). The risk-averse attitude of farmers due to fear of decreased yield or increased costs of implementing new technologies or practices could also limit adoption of CSA. If it is impossible to find payable financing, the risk of adopting CSA becomes too high (DK-farm4). Lack of willingness to invest was an indicated barrier by Lithuanian wheat sector stakeholders (LT-supply-comp). Farmers cognitive abilities determine the rate of adoption of sustainable agricultural practices and technologies [21,39,60]. The participant stakeholders indicated that the mindset among young farmer families is very entrepreneurial, and they have a high technology adoption intention; however, this is not true for all farmers (LT-sale). Another suggested "status quo bias", where farmers may resist change due to strong attachment to their existing practices, even if the promoted alternatives are more sustainable (LT-farm4). Lack of trust is also a barrier preventing producers from adopting CSA. For instance, a lack of trust in using autonomous systems, particularly regarding data security was indicated by a Lithuanian wheat supply chain stakeholder (LT-farm1).

3.3.2. Technological barriers

Lack of technical skills and knowledge to implement CSA, poor efficiency of some smart farming technologies, lack of technical support from technology providers in the required time, unavailability of demanded technologies and labor-intensive nature of CSA practices are the indicated key technological barriers by stakeholders (Table 3). For instance, Germany's dairy sector stakeholders indicated specific barriers mentioned like the challenge of processing sorghum due to unavailability of milling facilities (DE-feed-prod) and need for special technology for sorghum processing (DE-wholesal). This indicates that the accessibility of technology determines adoption behavior. More insect-friendly mowing methods incur high costs, and more workload is also considered a barrier (DE-farm1). In Lithuania, another barrier indicated by wheat supply chain stakeholders is finding specialized technical solutions that fulfil standards, can fit in with the production line and are profitable at the same time (LT-log). Furthermore, difficulty of obtaining expert knowledge on the best use of field and soil data (DK-farm1). There is also a need for equipment installers, as stated by one stakeholder: they simply do not keep up (DK-prod-man2). Another potential barrier to CSA adoption is the unavailability of raw materials in supply chains. For instance, the Netherlands stakeholders indicated that the unavailability of raw materials in the vegetable supply chain prevents the adoption of climate-smart potato production (NL-proc1).

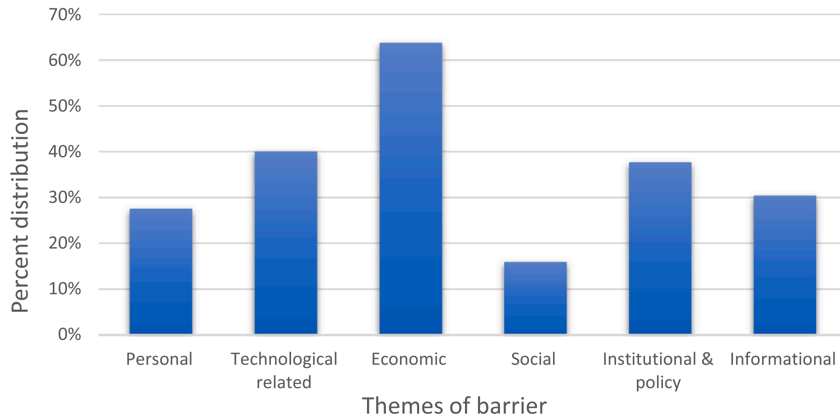

Fig. 3. Percent distribution of stakeholder opinions regarding barriers to CSA adoption in the five food supply chains studied.

Table 3
Barriers to adoption of CSA practices and technologies from stakeholder perspectives grouped into 6 themes.

Personal barriers		Technological or practice related barriers		Social barriers		Institutional and policy barriers		Economic barriers		Informational barriers	
Perceived lack of benefits from adopting CSA	3	Lack of technical skills and knowledge to implement	3	Mismatch in expectations and peer attitudes toward adopting CSA	3	Inadequate public financial support schemes for CSA practices and technologies	8	Lack of strong incentives to compensate for the cost of adopting CSA	12	Lack of awareness of CSA	3
Risk aversion attitude towards potential failure or financial losses of adopting CSA	6	Large investment cost of smart farming technologies	7	Social norm (looking at other people who are not interested)	4	Some ambitious regulations and legislation regarding some schemes	6	Low prices of climate-friendly produced foods	5	Absence of free scientific knowledge interchange with farmers	2
Low farmer interest in some CSA practices	2	Complexity of some smart farming technologies to implement	5	Culture-like local customs, values and traditions regarding CSA and other farming practices	2	Inadequate advice from governmental institutions	3	Profitability concern due to perceived cost of production	7	Need for additional skills and knowledge implementation of CSA technologies	6
Reluctance to change their current farming practices	2	Poor effectiveness of previously implemented smart farming technology	3	Fear of social disapproval for adopting new CSA practices and technologies	2	Lack of certification schemes for CSA-based production	2	Long supply chain for agricultural products	3	Inconsistency in information about CSA benefits across promoting channels	3
Confirmation bias of CSA pre-existing attitude	2	Lack of technical support from technology providers	3			Inadequate access to loans for some smart farming technologies	2	Low demand from consumers side to pay premium prices for climate-friendly products	9	Asymmetry in information along the CSA supply chain	3
Prioritization of short-term gains over long-term sustainability	3	Unavailability of demanded smart farming technologies	5			Lack of common objectives - different stakeholder objective prioritization	3	Budget limitations to implement smart farming technologies	4	Limited availability of knowledge and information regarding CSA benefits	4
Inadequate experience in CSA practices and technologies	2	The labor-intensive and costly nature of CSA practices	3			Poor rewarding system for reducing climate footprint	2	Farmer time preference focuses on the short-term benefit of adopting CSA	4		

Note: The numbers in the table represent how frequently various stakeholders stated the respective barriers within the theme.

3.3.3. *Economic barriers*

Lack of strong incentives to compensate for the cost of adopting CSA, lack of premium prices of climate-friendly produced foods, long supply chains of agricultural products, budget limitations to implementing smart farming technologies, and farmers time preference focusing on the short-term benefits are indicated barriers for adoption of CSA (Table 3). Lack of sufficient subsidies, incentives, and tax reductions was the predominant barrier indicated by stakeholders. Adopting CSA technologies require a large amount of investment in some cases, as farmers are more sensitive to the costs incurred, which impedes their attitudes towards using CSA technologies (LT-farm4). In this regard, the lack of a strong incentive to compensate for the costs incurred during the production process was indicated as the main barrier (LT-sale, LT-farm1 and LT-farm4). Stakeholders from the Netherlands also confirmed the lack of finance and high cost of implementing CSA initiatives (NL-province, NL-prod-proc). Likewise, stakeholders from the Danish pig production sector indicated a lack of subsidies as barriers to CSA adoption (DK-farm2, DK-prod-man1, DK-tec-dev, DK-com-dev). Most farmers do not invest in new technologies without a strong incentive (DK-tec-provider2). The current governmental subsidies are insufficient to cover the opportunity cost of implementing CSA, as one stakeholder mentioned (DK-farm3). Thus, there need to be a financial incentive that could at least cover the opportunity cost of implementing CSA.

The lack of premium price for CSA-based products and low farmer willingness to use CSA-based livestock feed were indicated barriers (DE-feed-prod). German stakeholders also indicated that many organic calves do not find a market because the rearing and fattening of organic cattle is not economically viable. Although it has been argued that premium prices are required to enable the production of organic food, which must be accompanied by consumer willingness to pay higher prices for climate-friendly products, some consumers may not be willing to pay a premium price (DE-city-adv, DE-coops). This was also confirmed by Lithuanian wheat sector stakeholders, indicating a low consumer willingness to pay a premium for CSA products (LT-suppl-comp). Several stakeholders in the Spanish apple supply chain also indicated lack of funding and investment capacity as barriers (ES-prod-proc2, ES-wholesale1, ES-wholesal1, ES-prod-dist). In addition, a lack of strong financial support and fair trade were indicated barriers (ES-prod1, ES-prod3, ES-wholesal2 and ES-prod-proc2). On the other hand, economic and health concerns were indicated individual psychological drivers by stakeholders from the vegetable sector (NL-env-fed, NL-prod, NL-proc2).

3.3.4. Social barriers

Looking at other farmers who were not interested in CSA, mismatches in expectations and peer attitudes toward adopting CSA, culture-like local customs, traditions regarding CSA and other farming practices, and fear of social disapproval for adopting new CSAs initiatives were some of the identified social barriers from this stakeholder interview (Table 3). For instance, in the Danish pig sector, neighbor effects are indicated as barriers, especially when farms grow more prominent, even though air cleaner applications are used and announced as part of the construction (DK-tec.prov1). Social norms can positively influence adoption behaviour, but confirmation bias is possible when farmers evaluate the information that reinforces their pre-existing beliefs [37]. In the context of CSA, if a farmer is surrounded by a social network that does not consider CSA practices, they may be less likely to explore new practices (ES-prod-proc5). Farmers may sometimes feel pressured if most of their neighbors do not adopt CSA practices, they may show reluctance to do so. Furthermore, farmers are less likely to implement CSA practices if technologies deviate from their social norms due to fear of social disapproval (ES-prod-proc5).

3.3.5. Institutional and policy barriers

The key institutional and policy-related barriers to adoption of CSA were inadequate public financial support schemes and regulation, inadequate advisory services from governmental institutions, lack of certification schemes for CSA-based production, insufficient access to loans for some smart farming technologies, lack of common strategies among different stakeholders, and lack of strong rewarding systems for reducing climate footprint (Table 3). Regarding regulation, how CO_2 tax is designed can act as both a barrier and a driver. For instance, for Danish pig production the national and EU framework conditions, including CO_2 tax, were regarded as barriers to production (DK-farm1). Similarly, the national government or EU implemented legislation as requirement for farmers to reduce their climate impact is seen as barrier (DK-prod.man1, DK-soft-dev). Barriers can also be related to subsidies and support scheme provision for selected practices and technologies (DK-tec-prov1).

Supply chain coordination can also influence farmer adoption decisions as indicated by German dairy sector stakeholders. It was mentioned that if the focus is only on GHG balance, higher efficiency will reduce GHG emissions per kilogram of milk (DE-advis, DE-research). However, it should be considered that dairy farming has a dual purpose: dairy cows also produce a lot of meat through their calves, which should also be reflected in the GHG balance to make it fairer and more realistic (DE-research). In addition, insufficient research on improving organic agriculture in a climate-smart manner was indicated as a barrier to CSA adoption (DE-advis). Governmental institutions were also viewed as barriers because they adhered to specific government programs (LT-cert-supp). Bureaucracy was described as a barrier by Spanish fruit supply chain stakeholders (ES-prod1, ES-prod3 and ES-prod.proc2).

3.3.6. Informational barriers

Lack of awareness, absence of free scientific knowledge, need for additional skills of CSA technologies, inconsistency in information about CSA benefits across promoting channels and asymmetry in information along the CSA supply chain were the key informational barriers to the adoption of CSA (Table 3). Regarding information and knowledge to implement CSA, young farmer families are often very entrepreneurial but this is not true for all farmers (LT-sale). There is a need to encourage farmers to be more active in joining cooperatives, and to participate in educational programs to see the bigger picture instead of only obtaining information from suppliers and salesmen (LT-farm2). To provide climate-smart solutions, it was further mentioned that educational activities on sustainable farming are needed (LT-cert-supp), since lack of specific education on climate smart solutions is a barrier to CSA adoption. In Spain, stakeholders cited that lack of specific knowledge about the value chain was a barrier to adoption (ES-prod-proc4) and insufficient technical knowledge creates a need for better understanding of initiatives and the implementation process (ES-prod4). For instance, in the German organic dairy sector, it was argued that the image of organic food is 'a bit dusty and old-fashioned' and that attempts have been made to change the image, but this is a barrier that takes time to erase (DE-gastro2). In addition, there is a lot of hype regarding vegan consumption, where people often think that it is good for the environment to stop eating meat and that veganism can compensate for this (DE-proc). Here, newspapers and journals promote this trend more often (DE-proc).

3.4. Interlinkages between drivers and barrier themes

The interlinkage between different drivers and barriers themes is important in the adoption process for CSAs in Europe because it reflects the complex and multifaceted nature of the process [38]. Fig. 4 illustrates the framework that represents the interlinkages between the main themes of drivers and barriers based on the results of the interviews. From the top three themes of drivers and barriers (see Figs. 2 and 3), we discussed four themes. The **personal theme** is influenced by the informational, economic, technological, social, and policy themes (see arrows b, d, e, f and k). The **economic theme** is influenced by institutional, technological and personal themes (see arrows f, i and j). The **institutional theme** is interlinked with the economic, social, personal and informational themes (see arrows c, b, h, i). While the **technological theme** is influenced by personal, economic and information themes (see arrows a, k, j).

These interlinkages demonstrate the complex relationships between the themes where addressing one theme can have ripple effects on other themes. For example, lack of awareness, skills, and information inconsistency across communication channels should be addressed by disseminating accurate information, whereas low engagement in social networks might be addressed by encouraging cooperation with communities and social networking activities. In this regards improving information dissemination (Informational Theme) can positively impact individual decision-making (Personal Theme), economic considerations (Economic Theme), and institutional policies (Institutional Theme). The technological complexity of implementation, lack of technical support, and the need for large investment can be addressed by providing training, demonstration, support, and substantial capital expenditure to promote CSA technologies. In this regard, the institutional theme as a driver plays a crucial role in facilitating the adoption of CSA. They provide the necessary support systems, such as extension services, training programs, and technical assistance, to help farmers understand and implement CSA practices and technologies effectively. Institutions can also create platforms for knowledge exchange and collaboration among stakeholders involved in technology development, testing, and dissemination. Institutions can provide financial support, subsidies and tax incentives, to encourage farmers to adopt climate-smart

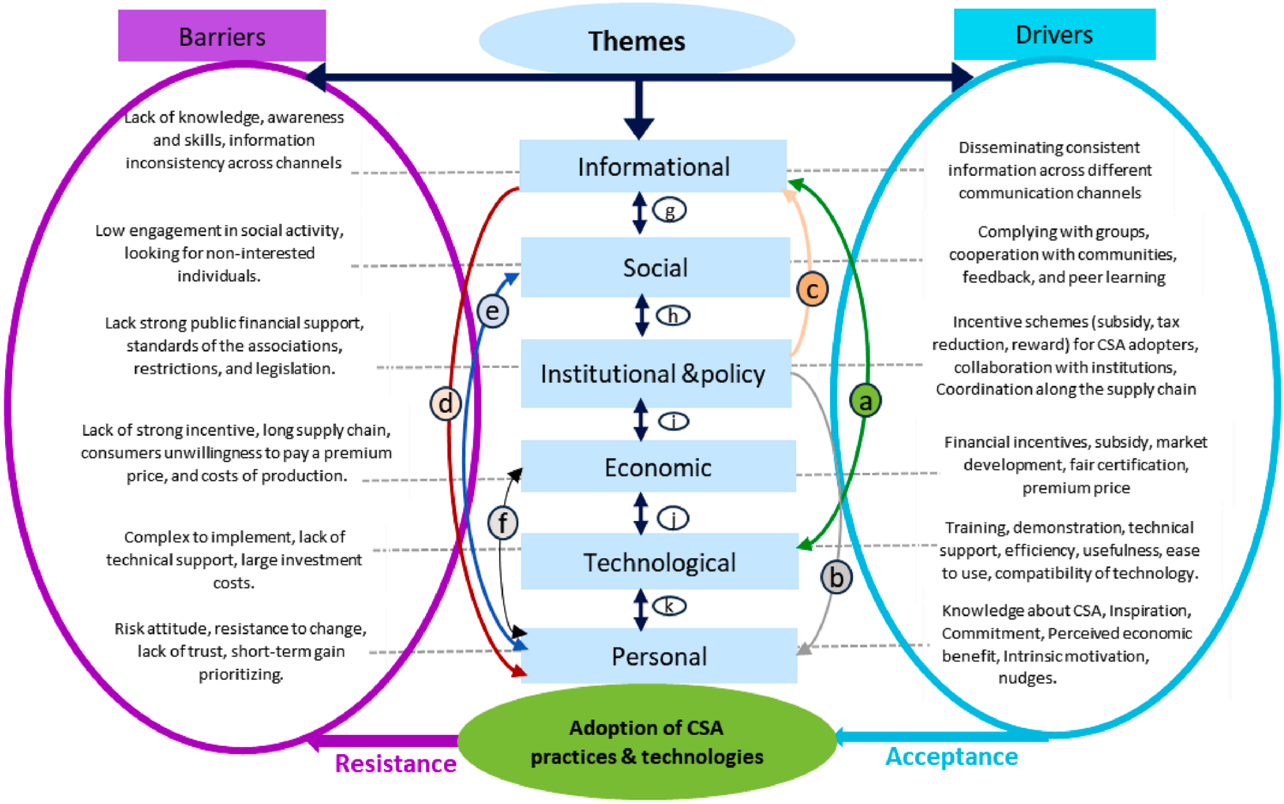

Fig. 4. Linkage between the drivers and barriers to CSA adoption and the overall themes classifying the views derived from the supply chain stakeholders.

technologies. These incentives can help overcome economic barriers and promote the widespread adoption of CSA. In this regard, institutions can design and implement incentive schemes that target specific technologies, regions, or groups of farmers to ensure equitable access and adoption. This interlinkage between the economic, institutional, technological, and informational themes underscores the interconnectedness of these themes along the CSA adoption process.

On the other hand, institutional and policy themes for CSA adopters require more collaboration with institutions, motivating consumers to purchase CSA products from demand side and facilitating food supply chain coordination which are more linked with the economic theme. This addresses the lack of promising economic incentives and market-demand issues, such as weak value chains. This is also linked to the informational theme because effective policy initiatives, and technology must be communicated to end users throughout the supply chain. Furthermore, the personal theme is essential, as it is the individual that implements the technology. In this regard, almost all themes are related to the personal theme, where individual-level opinions influence efficacy information, incentives, social networks and perceived costs and benefits of adopting CSA. Overall, the shift to a climate-resilient food system demands coordinated efforts from all stakeholders involved, items of interconnecting institutional, economic, individual psychological and technological aspects [58].

4. Discussion and conclusions

This study explored stakeholder perceptions on CSA initiatives, drivers and barriers to implementation in the primary production for five European food supply chains. The stakeholders in various agricultural sectors have identified specific CSA initiatives to promote climate smart food systems. In the dairy sector, stakeholder highlighted local production, protein feed supply, grassland management, and photovoltaics as potential CSA initiatives. Similarly, stakeholders in the wheat sector identified precision farming, higher-yielding varieties, cover cropping, organic fertilizers, and residue composting as key CSA initiatives. For the apple sector, stakeholders emphasized local value chain development, smart irrigation, and the use of renewable energy as climate-friendly production initiatives. Additionally, onion and potato sector stakeholders suggested smart irrigation, improved varieties, and precision farming as essential CSA initiatives. Lastly, stakeholders in the pig sector emphasized the significance of renewable energy, hybrid ventilation, and efficient waste management techniques as crucial CSA initiatives.

The drivers and barriers ranged from farm-specific changes to broader public initiatives. Financial incentives, technological support, and value-chain development were indicated as drivers for adoption of CSA. The need for advisory services that aim to raise awareness about CSA practices and technologies were indicated to unlock knowledge gaps. This is in line with Long et al. [38] who indicated adoption of climate-smart agricultural innovations, depends on farmer access to relevant and credible information. However, increasing farmer awareness of how consumers buy climate-smart agricultural products encourages them to implement climate-friendly practices and technologies. Economic factors are the most important drivers and at the same time they are barriers for adoption of CSA. For instance, consumer willingness to pay for climate-smart produced food products is a driving and impeding factor for CSA adoption, which is line with suggestions of World Economic Forum [61]. Economic barriers from both the supply side (i.e. subsidies, incentives, and tax reductions) and the demand side (i.e. market development) were the predominant barriers indicated by stakeholders, which is in line with findings of Guetschow et al. [31] . This indicates that there needs to be a financial incentive to implement CSA.

The premium prices for CSA-based commodities were also an identified adoption driver in this study. Consumer demand and willingness to pay premium prices are paramount to encourage farmer engagement in sustainable food production. Low demand from consumers' side to pay premium prices for climate-friendly products was one of the main identified barriers for low CSA adoption by interviewed stakeholders along the food chain. This aligns with the findings from Guetschow et al. [31], who highlighted that demand-side barriers impede adoption of sustainable agricultural practices. The type and accessibility of information regarding CSAs significantly affect the willingness of consumers to make decisions about purchasing climate-friendly food products [12, 35,43,45]. Consumer preferences and willingness to pay a premium for climate-friendly food products have been studied in Europe, even though they were not directly interviewed for this study. Previous research that focused on reducing the climate impacts of pig production suggests that consumers in Denmark, Germany, and the UK prioritize animal welfare aspects for paying a price premium [20]. A study by Chiripuci et al. [15] on the organic food preferences indicted that the trend among European consumers interest is particularly strong among young people, reflecting a growing recognition of the quality of organic products linked to sustainable development. Feucht and Zander [28] on the other hand indicated a significant barrier to climate-friendly food products purchase behaviour is a lack of awareness about the impact of food production and consumption on climate change. In this regard, climate-friendly labels can help in fostering the purchase behaviour, but they are only part of the solution, emphasizing the need for comprehensive information and education to promote climate-friendly food choices [28].

For instance, in the apple sector in Spain, a long supply chain between growers and buyers and low consumer interest was identified as a key barrier to climate-smart production. Thus, value chain development is suggested as a key driver to foster the adoption of the above initiatives. This is also true for the potato sector in the Netherlands and in line with Alexander et al. [3] and Bjarklev et al. [10]. The cost of implementing CSA practices was also identified as a key barrier that requires public finance subsidies to compensate for the opportunity costs of CSAs. Financial incentives like subsidy schemes were indicated key drivers, which is consistent with the findings of Guetschow et al. [31]. Difficulties of finding expert advice about specific data management systems for some smart agricultural technologies that require technical support from both technology providers and other responsible institutions was one of the indicated technological barriers. This is in accordance with previous findings [8,11,35,59]. Even though economic, institutional and individual behavioral factors were identified as the top three drivers in shaping CSA adoption behavior, social factors play a crucial role in the adoption of CSA. Social networks can serve as channels for CSA knowledge-sharing and peer learning [53] but they can also be barriers for adoption [4,37,38]. These barriers are often rooted in farmer perception of peer judgement regarding implementing CSA practices and technologies. In this regard, providing information to encourage adoption is crucial.

Addressing the key barriers to the adoption of CSA practices and technologies requires an integration of financial, institutional and policy support and capacity-building efforts to make these practices economically attractive. Consideration of farming system heterogeneity was also suggested, rather than fitting all of the CSA changes into one uniform policy prescription. Market development and price premiums for products produced by CSA, as well as governmental regulations and standards for climate-friendly practice implementation may boost adoption. To encourage adoption, this study suggests strengthening the incentive schemes for the implementation of climate-smart agricultural practices as an opportunity cost compensation, value chain development, and targeted dissemination of CSA-based product information to consumers. Finally, future interventions should focus on strengthening the identified drivers and addressing the identified barriers to motivate stakeholders towards CSA. Stakeholder involvement in the implementation of CSA could improve the adoption decision-making process by identifying lock-ins and levers through co-creation, which was also reported by Isakhanyan et al. [33]. The pace of transition requires coordination across multiple food supply chain system stakeholders, as they are interlinked and have a cumulative effect on shaping CSA adoption behaviour [42]. Thus, institutional initiatives such as incentive provisions, value chain development, and behavioral interventions are suggested. Given that the food sector is both affected by and contributing to climate change, from the farm to the plates of consumers, improved value chain coordination and tailored CSA communication strategies can help producers to implement CSA. Overall, this study suggests consideration of economic, institutional, and individual behavioural factors, as they are the top three identified drivers for the adoption of CSA. On top of economic and institutional factors, consideration of technological factors was suggested, as it is one of the three identified barriers to the adoption of CSA. The identified factors in this study for the adoption of CSA are interlinked with one another, highlighting the significance of considering combinations of factors for future behavioural economic experiment research to promote behavioural change towards a sustainable food system along the value chains.

4.1. Limitations and recommendations for future research

This study was the result of stakeholder interviews that focused on qualitative analyses. Although this study attempted to capture stakeholder views and perceptions in five European case studies, the sample size we obtained did not represent all possible stakeholders. Focus here has been on stakeholders from primary producers to retailers, with less focus on the final consumer. Even though consumers are only indirectly included in this study from retailers and catering stakeholders along the value chain, they play a major role in the farmer adoption of CSA since they are the buyers of food produced with CSA.

Although open-ended questions have a potential to significantly capture individual opinions on the subject matter, creating theme-based codes for further detailed investigation was carried out. The drivers and barriers described by stakeholders were placed into themes by grouping them according to context similarity. This study did not use direct transcripting from the stakeholder interviews, but instead consisted of summary reformulations. The study's findings may be subject to limitations due to potential language translation barriers that could introduce noise and affect the accuracy of information conveyed. As a result, future research should address the identified limitations throughout the research process.

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CRediT authorship contribution statement

Søren Marcus Pedersen: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Kassa Tarekegn Erekalo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tove Christensen:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation. **Sigrid Denver:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Conceptualization. **Marilena Gemtou:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Spyros Fountas:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Funding acquisition, Conceptualization. **Gohar Isakhanyan:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Funding acquisition, Conceptualization. **Arno Rosemarin:** Writing – review & editing, Validation, Methodology, Conceptualization. **Nelson Ekane:** Writing – review & editing, Validation, Methodology, Conceptualization. **LiseLotte Puggaard:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization. **Magdalena Nertinger:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization. **Harm Brinks:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization. **Diana Puško:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization. **Jon Bienzobas Adrián:** Writing – review & editing, Validation, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal ties that could influence the work disclosed in this study.

Data availability

The data that have been used are confidential.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.atech.2024.100478.

Appendix A1. List of interviewed stakeholders in each use case

Germany (DE)

1. Trader, selling animals to farmers (DE-trad)
2. A dairy cooperative (DE-coop)
3. Trader in gastronomy and catering (DE-gastro-cat)
4. Organic wholesaler (DE-wholesal)
5. Producer and processer of organic products (DE-proc)
6. Farmer (DE-farm1)
7. Farmer and producer of butter and cheese (DE-farm2).
8. Mix feed producer (DE-feed-prod)
9. City advisor that advises public institutions about providing food services (DE-city-adv)
10. Production cooperative (DE-coop-prod)
11. Gastronomy: Providing services to hotels, restaurants and events (DE-gastro1)
12. Research project (DE-research)
13. Gastronomy (DE-gastro2)
14. Advisor for organic agriculture (DE-advis)
15. Organic feed mill (DE-mill).

Lithuania (LT)

1. A primary production (LT-farm1)
2. A provider of agro-technology for primary producers (LT-agtech-prov1)
3. Provider of agro-technology for primary producers (LT-agtech-prov2)
4. Producer of eco-labels and certificates for sustainable farming (LT-cert-comp)
5. Logistics company that exports and connects producers and export companies (LT-log)
6. Primary producer (LT-farm2)
7. Company that sells fertilizers, seeds, agrochemicals, and grains (LT-sup-comp)
8. Company that sells different grain products - bread, flour, and others (LT-sale)
9. Primary producer (LT-farm3)
10. Primary producer (LT-farm4)
11. Online shop for the farmers (LT-shop)
12. Companies that buy from farmers and sell products to wholesalers and supermarkets (LT-wholesal).

Denmark (DK)

1. Producer and manufacturer (DK-prod-man1)
2. Producer and manufacturer (DK-prod-man2)
3. Primary producer (DK-farm1)
4. Primary producer (DK-farm2)
5. Primary producer (DK-farm3)
6. Primary producer (DK-farm4)
7. Retailer (DK-retail)
8. Technology provider (DK-tec.prov1)
9. Technology provider (DK-tec.prov2)
10. Private organic association (DK-asso)
11. Technology developer (DK-tec-dev)
12. Software developer (DK-soft-dev)
13. Restaurants, catering services (DK-cat)
14. The communication platform (DK-com-dev).

Spain (ES)

1. Producer of apples, cider and juice (ES-prod.proc1)
2. Apple producer (ES-prod1)
3. Primary production, distribution and marketing (ES-prod-dist)
4. Apple producer (ES-prod2)
5. Primary production and processing of apples (ES-prod-proc2)
6. Distribution of apples, vegetables and dry products (ES-wholesal1)
7. Primary producer and processor (ES-prod-proc3)
8. Distribution of products in large warehouses (ES-wholesal2)
9. Production, processing, and distribution to retailers and wholesalers (ES-prod.proc4)
10. Production of grapes and sweet apple (ES-prod3)
11. Apple producer (ES-prod4)
12. The production of apple and apple juice (ES-prod-proc5).

The Netherlands (NL)

1. A unit that supports social development and prosperity in a NL province (NL-province)
2. Environmental Federation (NL-env-fed)
3. Advisor that represents the interests and conditions between the grower and buyer (NL-adv)
4. Test on research farm (NL-research)
5. Food foundation network (NL-found)
6. Producers, processors and wholesalers of potatoes (NL-prod-proc)
7. Producer (NL-prod)
8. Potato processor selling frozen fries (NL-proc1)
9. Advisor in cultivation, soil and drainage (NL-crop-adv)
10. Producer of French fries and flakes (NL-proc2)
11. Advocate institution (NL-adv-inst)
12. Policy officer of agriculture and food (NL-off-agri)
13. Sustainability officer for agriculture and wholesale organization (NL-wholesal)
14. Advisor on crop variety introduction (NL-adv-breed)
15. Agricultural intermediary agency owner (NL-agen-own)
16. Owner transport company (NL-own-transp)

References

[1] A.K. Aare, S. Lund, H. Hauggaard-Nielsen, Exploring transitions towards sustainable farming practices through participatory research? The case of Danish

farmers? Use of species mixtures, Agric. Syst. 189 (2021), https://doi.org/10.1016/j.agsy.2021.103053.

[2] T.O. Akenroye, M. Dora, M. Kumar, J. Elbaz, S. Kah, F. Jebli, A taxonomy of barriers to the adoption of sustainable practices in the coffee farming process, J. Clean. Prod. 312 (2021) 127818, https://doi.org/10.1016/j.jclepro.2021.127818.

[3] K.S. Alexander, G. Greenhalgh, M. Moglia, M. Thephavanh, P. Sinavong, S. Larson, T. Jovanovic, P. Case, What is technology adoption? Exploring the agricultural research value chain for smallholder farmers in Lao PDR, Agric. Human. Value. 37 (1) (2020) 17–32, https://doi.org/10.1007/s10460-019-09957-8.

[4] E.P. Andrade, A. Bonmati, L.J. Esteller, A.A. Vallejo, Assessment of social aspects across Europe resulting from the insertion of technologies for nutrient recovery and recycling in agriculture, Sustain. Prod. Consum. 31 (2022) 52–66, https://doi.org/10.1016/j.spc.2022.01.025.

[5] N. Andrieu, F. Howland, I. Acosta-Alba, J.-F. Le Coq, A.M. Osorio-Garcia, D. Martinez-Baron, C. Gamba-Trimiño, A.M. Loboguerrero, E. Chia, Co-designing climate-smart farming systems with local stakeholders: a methodological framework for achieving large-scale change, Front. Sustain. Food Syst. 3 (2019) 37, https://doi.org/10.3389/fsufs.2019.00037.

[6] J.A. Aznar-Sánchez, J.F. Velasco-Muñoz, B. López-Felices, F Del Moral-Torres, Barriers and facilitators for adopting sustainable soil management practices in mediterranean olive groves, Agronomy 10 (4) (2020) 506, https://doi.org/10.3390/agronomy10040506.

[7] S.K. Balasundram, R.R. Shamshiri, S. Sridhara, N. Rizan, The role of digital agriculture in mitigating climate change and ensuring food security: an overview, Sustainability 15 (6) (2023) 5325, https://doi.org/10.3390/su15065325.

[8] P. Baur, When farmers are pulled in too many directions: comparing institutional drivers of food safety and environmental sustainability in California agriculture, in: G. Desa, X. Jia (Eds.), Social Innovation and Sustainability Transition, Springer Nature, Switzerland, 2022, pp. 241–260, https://doi.org/10.1007/978-3-031-18560-1_17.

[9] L. Bechini, C. Costamagna, L. Zavattaro, C. Grignani, J. Bijttebier, G. Ruysschaert, Drivers and barriers to adopt best management practices. Survey among Italian dairy farmers, J. Clean. Prod. 245 (2020) 118825, https://doi.org/10.1016/j.jclepro.2019.118825.

[10] A. Bjarklev, B. Kjærgård, E. Jelsøe, H. Haugaard-Nielsen, Fostering sustainability in new value chains for (Re)adopting underutilized crops, Eur. J. Sustain. Develop. 8 (1) (2019), https://doi.org/10.14207/ejsd.2019.v8n1p1.

[11] C. Brown, E. Kovács, I. Herzon, S. Villamayor-Tomas, A. Albizua, A. Galanaki, I. Grammatikopoulou, D. McCracken, J.A. Olsson, Y. Zinngrebe, Simplistic understandings of farmer motivations could undermine the environmental potential of the common agricultural policy, Land Use Policy 101 (2021) 105136, https://doi.org/10.1016/j.landusepol.2020.105136.

[12] F. Caffaro, M. Micheletti Cremasco, M. Roccato, E. Cavallo, Drivers of farmers' intention to adopt technological innovations in Italy: the role of information sources, perceived usefulness, and perceived ease of use, J. Rural. Stud. 76 (2020) 264–271, https://doi.org/10.1016/j.jrurstud.2020.04.028.

[13] G. Casimir, H. Tobi, P.A. Tamás, How to present the analysis of qualitative data within interdisciplinary studies for readers in the life and natural sciences, Qual. Quant. 56 (3) (2022) 967–984, https://doi.org/10.1007/s11135-021-01162-2.

[14] A.J. Challinor, L.N. Arenas-Calles, S. Whitfield, Measuring the effectiveness of climate-smart practices in the context of food systems: progress and challenges, Front. Sustain. Food Syst. 6 (2022) 853630, https://doi.org/10.3389/fsufs.2022.853630.

[15] B. Chiripuci, M.-F. Popescu, Bucharest University of Economic Studies, Bucharest, Romania, Constantin, M., & Bucharest University of Economic Studies, Bucharest, Romania, The European Consumers' Preferences for Organic Food in the Context of the European Green Deal, 24, 2022, p. 361, https://doi.org/10.24818/EA/2022/60/361. *Www.Amfiteatrueconomic.Ro*.

[16] C. Cholez, O. Pauly, M. Mahdad, S. Mehrabi, C. Giagnocavo, J. Bijman, Heterogeneity of inter-organizational collaborations in agrifood chain sustainability-oriented innovations, Agric. Syst. 212 (2023) 103774, https://doi.org/10.1016/j.agsy.2023.103774.

[17] P. David, C. Roemer, R. Anibaldi, S. Rundle-Thiele, Factors enabling and preventing farming practice change: an evidence review, J. Environ. Manage. 322 (2022) 115789, https://doi.org/10.1016/j.jenvman.2022.115789.

[18] M. Degieter, X. Gellynck, S. Goyal, M. Mattelin, J. De Wulf, D. Ott, H. De Steur, A mixed-methods approach to examine farmers' willingness to adopt protein crops, Outlook Agric. (2023), https://doi.org/10.1177/00307270231205924, 00307270231205924.

[19] S. Delmotte, V. Couderc, J.-C. Mouret, S. Lopez-Ridaura, J.-M. Barbier, L. Hossard, From stakeholders narratives to modelling plausible future agricultural systems. Integrated assessment of scenarios for Camargue, Southern France, Eur. J. Agron. 82 (2017) 292–307, https://doi.org/10.1016/j.eja.2016.09.009.

[20] S. Denver, T. Christensen, T.B. Lund, J.V. Olsen, P. Sandøe, Willingness-to-pay for reduced carbon footprint and other sustainability concerns relating to pork production – a comparison of consumers in China, Denmark, Germany and the UK, Livest. Sci. 276 (2023) 105337, https://doi.org/10.1016/j.livsci.2023.105337.

[21] F.J. Dessart, J. Barreiro-Hurlé, R. Van Bavel, Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review, Eur. Rev. Agricult. Econ. 46 (3) (2019) 417–471, https://doi.org/10.1093/erae/jbz019.

[22] I. Djekic, L. Batlle-Bayer, A. Bala, P. Fullana-i-Palmer, A.R. Jambrak, Role of the food supply chain stakeholders in achieving UN SDGs, Sustainability. 13 (16) (2021) 9095, https://doi.org/10.3390/su13169095.

[23] EEA, Transforming Europe's food System—Assessing the EU Policy Mix, European Environment Agency, 2023. https://www.eea.europa.eu/publications/transforming-europes-food-system.

[24] K. Eliasson, L. Wiréhn, T.-S. Neset, B.-O. Linnér, Transformations towards sustainable food systems: contrasting Swedish practitioner perspectives with the European Commission's Farm to Fork Strategy, Sustain. Sci. 17 (6) (2022) 2411–2425, https://doi.org/10.1007/s11625-022-01174-3.

[25] K.T. Erekalo, S.M. Pedersen, T. Christensen, S. Denver, M. Gemtou, S. Fountas, G. Isakhanyan, Review on the contribution of farming practices and technologies towards climate-smart agricultural outcomes in a European context, Smart Agricult. Technol. (2024) 100413, https://doi.org/10.1016/j.atech.2024.100413.

[26] D. Feliciano, Factors influencing the adoption of sustainable agricultural practices: the case of seven horticultural farms in the United Kingdom, Scott. Geograph. J. 138 (3–4) (2022) 291–320, https://doi.org/10.1080/14702541.2022.2151041.

[27] H. Ferreira, E. Pinto, M.W. Vasconcelos, Legumes as a cornerstone of the transition toward more sustainable agri-food systems and diets in Europe, Front. Sustain. Food Syst. 5 (2021) 694121, https://doi.org/10.3389/fsufs.2021.694121.

[28] Y. Feucht, K. Zander, Consumers' willingness to pay for climate-friendly food in European countries, in: Proceedings in Food System Dynamics, 2017, pp. 360–377, https://doi.org/10.18461/PFSD.2017.1738. Pages.

[29] G. Fusco, M. Melgiovanni, D. Porrini, T.M. Ricciardo, How to improve the diffusion of climate-smart agriculture: what the literature tells us, Sustainability. 12 (12) (2020) 5168, https://doi.org/10.3390/su12125168.

[30] M. Gemtou, K. Kakkavou, E. Anastasiou, S. Fountas, S.M. Pedersen, G. Isakhanyan, K.T. Erekalo, S. Pazos-Vidal, Farmers' transition to climate-smart agriculture: a systematic review of the decision-making factors affecting adoption, Sustainability 16 (7) (2024) 2828, https://doi.org/10.3390/su16072828.

[31] M. Guetschow, B. Bartkowski, M.R. Felipe-Lucia, Farmers' action space to adopt sustainable practices: a study of arable farming in Saxony, Reg. Environ. Change 21 (4) (2021), https://doi.org/10.1007/s10113-021-01848-1.

[32] A.S.M.M. Hasan, M.A. Kabir, M.T. Hoq, M.T. Johansson, P. Thollander, Drivers and barriers to the implementation of biogas technologies in Bangladesh, Biofuels 13 (5) (2022) 643–655, https://doi.org/10.1080/17597269.2020.1841362.

[33] G. Isakhanyan, C. Galgo Jr., M. Gemtou, S.M. Pedersen, Business strategies towards climate-smart agriculture in Europe: a literature review, Bus. Strategy. Environ. (2024) bse.3741, https://doi.org/10.1002/bse.3741.

[34] D. John, N. Hussin, M.S. Shahibi, M. Ahmad, H. Hashim, D.S. Ametefe, A systematic review on the factors governing precision agriculture adoption among small-scale farmers, Outlook Agric. (2023), https://doi.org/10.1177/00307270231205640, 00307270231205640.

[35] D. Johnson, M. Almaraz, J. Rudnick, L.E. Parker, S.M. Ostoja, S.D.S. Khalsa, Farmer adoption of climate-smart practices is driven by farm characteristics, information sources, and practice benefits and challenges, Sustainability 15 (10) (2023) 8083, https://doi.org/10.3390/su15108083.

[36] E. Karali, B. Brunner, R. Doherty, A. Hersperger, M. Rounsevell, Identifying the factors that influence farmer participation in environmental management practices in Switzerland, Hum. Ecol. 42 (6) (2014) 951–963, https://doi.org/10.1007/s10745-014-9701-5.

[37] P. Le Coent, R. Préget, S Thoyer, Farmers follow the herd: a theoretical model on social norms and payments for environmental services, Environ. Resour. Econ. 78 (2) (2021) 287–306, https://doi.org/10.1007/s10640-020-00532-y.

[38] T.B. Long, V. Blok, I. Coninx, Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy, J. Clean. Prod. 112 (2016) 9–21, https://doi.org/10.1016/j.jclepro.2015.06.044.

[39] A. Massfeller, M. Meraner, S. Hüttel, R. Uehleke, Farmers' acceptance of results-based agri-environmental schemes: a German perspective, Land Use Policy 120 (2022) 106281, https://doi.org/10.1016/j.landusepol.2022.106281.

[40] F. Matteoli, J. Schnetzer, H. Jacobs, Climate-smart agriculture (CSA): an integrated approach for climate change management in the agriculture sector, in: J.M. Luetz, D. Ayal (Eds.), Handbook of Climate Change Management, Springer International Publishing, 2021, pp. 409–437, https://doi.org/10.1007/978-3-030-57281-5_148.

[41] J. Mills, P. Gaskell, J. Ingram, J. Dwyer, M. Reed, C. Short, Engaging farmers in environmental management through a better understanding of behaviour, Agric. Human. Values. 34 (2) (2017) 283–299, https://doi.org/10.1007/s10460-016-9705-4.

[42] I.R. Moreira-Dantas, I. Martínez-Zarzoso, M.L.F. De Araujo, J. Evans, A. Foster, X. Wang, M. Thakur, S. Jafarzadeh, M.P. Martin, Multi-stakeholder initiatives and decarbonization in the European food supply chain, Front. Sustainab. 4 (2023) 1231684, https://doi.org/10.3389/frsus.2023.1231684.

[43] J. Mullins, J.G. Zivin, A. Cattaneo, A. Paolantonio, R. Cavatassi, The adoption of climate smart agriculture: the role of information and insurance under climate change, in: L. Lipper, N. McCarthy, D. Zilberman, S. Asfaw, G. Branca (Eds.), Climate Smart Agriculture, Springer International Publishing, 2018, pp. 353–383, https://doi.org/10.1007/978-3-319-61194-5_16. Vol. 52.

[44] M.R. Munaro, S.F. Tavares, A review on barriers, drivers, and stakeholders towards the circular economy: the construction sector perspective, Clean. Respons. Consumpt. 8 (2023) 100107, https://doi.org/10.1016/j.clrc.2023.100107.

[45] B. Nantongo, J. Ssekandi, A. Ngom, B. Dieng, N. Diouf, J. Diouf, K. Noba, Meteorological information utilization and adoption of climate-smart agricultural practices; modifying factors and mediating effect, Environ. Dev. 46 (2023) 100857, https://doi.org/10.1016/j.envdev.2023.100857.

[46] K. Nygaard, M. Graversgaard, T. Dalgaard, B.H. Jacobsen, S. Schaper, The role of stakeholder engagement in developing new technologies and innovation for nitrogen reduction in waters: a longitudinal study, Water (Basel) 13 (22) (2021) 3313, https://doi.org/10.3390/w13223313.

[47] P. Reidsma, F. Accatino, F. Appel, C. Gavrilescu, V. Krupin, G. Manevska Tasevska, M.P.M. Meuwissen, M. Peneva, S. Severini, B. Soriano, J. Urquhart, K. Zawalińska, C. Zinnanti, W. Paas, Alternative systems and strategies to improve future sustainability and resilience of farming systems across Europe: from adaptation to transformation, Land Use Policy 134 (2023) 106881, https://doi.org/10.1016/j.landusepol.2023.106881.
[48] Introduction: political economy of food system transformation, in: D. Resnick, J. Swinnen (Eds.), The Political Economy of Food System Transformation, 1st ed., Oxford University PressOxford, 2023, pp. 1–31, https://doi.org/10.1093/oso/9780198882121.003.0001.
[49] C. Ritter, J. Jansen, S. Roche, D.F. Kelton, C.L. Adams, K. Orsel, R.J. Erskine, G. Benedictus, T.J.G.M. Lam, H.W. Barkema, Invited review: determinants of farmers' adoption of management-based strategies for infectious disease prevention and control, J. Dairy Sci. 100 (5) (2017) 3329–3347, https://doi.org/10.3168/jds.2016-11977.
[50] J.M. Rodriguez, J.J. Molnar, R.A. Fazio, E. Sydnor, M.J. Lowe, Barriers to adoption of sustainable agriculture practices: change agent perspectives, Renew. Agricult. Food Syst. 24 (1) (2009) 60–71, https://doi.org/10.1017/S1742170508002421.
[51] G.F. Sassenrath, J.M. Halloran, D. Archer, R.L. Raper, J. Hendrickson, P. Vadas, J. Hanson, Drivers impacting the adoption of sustainable agricultural management practices and production systems of the northeast and southeast United States, J. Sustain. Agricult. 34 (6) (2010) 680–702, https://doi.org/10.1080/10440046.2010.493412.
[52] C. Schulze, B. Matzdorf, The institutional design of agri-environmental contracts—how stakeholder attitudes can inform policy making, Q. Open. 3 (1) (2023) qoad001, https://doi.org/10.1093/qopen/qoad001.
[53] W.J. Simon, T.J. Krupnik, N. Aguilar-Gallegos, L. Halbherr, J.C.J. Groot, Putting social networks to practical use: improving last-mile dissemination systems for climate and market information services in developing countries, Clim. Serv. 23 (2021) 100248, https://doi.org/10.1016/j.cliser.2021.100248.
[54] S. Stetkiewicz, J. Menary, A. Nair, M. Rufino, A.R.H. Fischer, M. Cornelissen, A. Guichaoua, P. Jorasch, S. Lemarié, A.K. Nanda, R. Wilhelm, J.A.C. Davies, Food system actor perspectives on future-proofing European food systems through plant breeding, Sci. Rep. 13 (1) (2023) 5444, https://doi.org/10.1038/s41598-023-32207-1.
[55] T.W. Tamirat, S.M. Pedersen, J.E. Ørum, S.H. Holm, Multi-stakeholder perspectives on field crop robots: lessons from four case areas in Europe, Smart Agricult. Technol. 4 (2023) 100143, https://doi.org/10.1016/j.atech.2022.100143.
[56] A.F. Tensi, F. Ang, H.J. Van Der Fels-Klerx, Behavioural drivers and barriers for adopting microbial applications in arable farms: evidence from the Netherlands and Germany, Technol. Forecast. Soc. Change 182 (2022) 121825, https://doi.org/10.1016/j.techfore.2022.121825.
[57] E. Torquebiau, C. Rosenzweig, A.M. Chatrchyan, N. Andrieu, R. Khosla, Identifying climate-smart agriculture research needs, Cahier. Agricult. 27 (2) (2018) 26001, https://doi.org/10.1051/cagri/2018010.
[58] UNEP, FAO and UNDP, Rethinking Our Food Systems: A Guide For Multi-Stakeholder Collaboration, UNEP, FAO, UNDP, Nairobi, Rome and New York, 2023, https://doi.org/10.4060/cc6325en.
[59] M. Van Asseldonk, E. Girvetz, H. Pamuk, C. Wattel, R. Ruben, Policy incentives for smallholder adoption of climate-smart agricultural practices, Front. Polit. Sci. 5 (2023) 1112311, https://doi.org/10.3389/fpos.2023.1112311.
[60] O. Westermann, W. Förch, P. Thornton, J. Körner, L. Cramer, B. Campbell, Scaling up agricultural interventions: case studies of climate-smart agriculture, Agric. Syst. 165 (2018) 283–293, https://doi.org/10.1016/j.agsy.2018.07.007.
[61] World Economic Forum, Transforming Food Systems With Farmers: A Pathway For the EU, World Economic Forum, 2022. https://www.weforum.org/reports/transforming-food-systems-with-farmers-a-pathway-for-the-eu/.
[62] Wreford, A., Ignaciuk, A., & Gruère, G. (2017). *Overcoming barriers to the adoption of climate-friendly practices in agriculture* (OECD Food, Agriculture and Fisheries Papers 101; OECD Food, Agriculture and Fisheries Papers, Vol. 101). https://doi.org/10.1787/97767de8-en.
[63] A. Zaharia, M.-C. Diaconeasa, N. Maehle, G. Szolnoki, R. Capitello, Developing sustainable food systems in Europe: National Policies and Stakeholder Perspectives in a Four-Country Analysis, Int. J. Environ. Res. Public Health 18 (14) (2021) 7701, https://doi.org/10.3390/ijerph18147701.
[64] Y. Zinngrebe, G. Pe'er, S. Schueler, J. Schmitt, J. Schmidt, S. Lakner, The EU's ecological focus areas – how experts explain farmers' choices in Germany, Land Use Policy 65 (2017) 93–108, https://doi.org/10.1016/j.landusepol.2017.03.027.