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# "We Could Be Much Further Ahead" -Multidimensional Drivers and Barriers for Agricultural Transition

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ABSTRACT

Agricultural transition toward sustainability is subject to individual and political constraints, spurring the need to understand system dynamics from both a psychological and a public policy angle; however, empirical data remains limited. The present paper empirically contributes to theoretical frameworks on sustainability transitions and analyzes multiple dimensions related to the success of agricultural transition. This investigation employed a multidisciplinary, multimethodological approach that combined two empirical studies. The first study focused on electrically driven field cultivation as one transition process to uncover potential drivers and barriers from an actor-centered perspective via semi-structured interviews with farmers and sectoral actors (N = 33). Next, study 2 validated and complemented the context conditions that emerged from the interviews as relevant to agricultural transitions through a fuzzy-set Qualitative Comparative Analysis (fsQCA) that uncovered configurations leading to agricultural transition in 38 OECD countries. Results show that for an agricultural transition, it is necessary to have a successful research and innovation policy. Furthermore, the inclusion of a green party in government is sufficient for an agricultural transition, whereas all other cases of agricultural transition are explained through a combination of different policy, polity, and politics factors. The results provide vital theoretical and practical implications for interdisciplinary research on agricultural transition processes and highlight the importance of regulative policies and political investments.

## 1. Introduction

The agricultural sector is experiencing an ongoing transition toward sustainability in response to climate policy objectives and consumer demands. Such transitions are long-term processes wherein socio-technical systems shift toward more sustainability along different dimensions, including institutional, political, economic, and socio-cultural (Markard et al., 2012, 2016). The variety of dimensions suggests that many factors potentially enforce or constrain agricultural transition and must be integrated to support sustainability transitions (Bazzan et al., 2022; Renting et al., 2009). One central factor is the increasing need for innovation (de Boon et al., 2022a; El Bilali and Allahyari, 2018), which the Organization for Economic Co-operation and Development (OECD, 2005) defined as the implementation of new or improved processes or products, as well as methodological or organizational methods in different institutions. Thus, the term "innovation"[1] goes beyond the innovative idea itself to encompass a diverse set of innovation activities (Läpple et al., 2016). In the agricultural sector, numerous innovations have recently emerged to shape sustainability trends (e.g., artificial products, drones, and big data; Herrero et al., 2020; Klerkx and Begemann, 2020). Notwithstanding the intended benefits, agricultural innovation processes require careful governing and a functioning interplay between institutions, political visions, and affected individuals, particularly farmers (Klerkx and Rose, 2020). As different disciplines focus on individual factors, their integration requires interdisciplinary research from various perspectives. This article combines a psychological perspective, focusing on the drivers and barriers shaping the agricultural transition according to actors, with a public policy research perspective that analyzes the policymaking processes and influence of political institutions and policy actors that comprise the

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[1] For simplicity, the term "(agricultural) innovation" is used to describe the overall implementation process of specific innovations (e.g., technological or non-technological).

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conditions for agricultural transition.

As critical as conceptualizing agricultural transition through different disciplinary lenses is the need to gather empirical data to cross-check the results from diverse research strands. Scholars have sought to understand the agri-food system and its interdependencies through frameworks and theories in order to explore complex changes within the system in light of ongoing sustainability transitions and derive implications and guidelines that can be used to support and ultimately bring about transitions (Daugbjerg and Feindt, 2017; de Boon et al., 2022a; Läpple et al., 2016; Turner et al., 2017). However, the need for empirical data to test and validate these frameworks likewise demands interdisciplinary research due to differences in data collection techniques and integrated perspectives (de Vries et al., 2021; Köhler et al., 2019). In particular, discerning connections between micro and macro levels, while occupying a central role in understanding the entire system, entails examining the relationships between individual-level and country-level data (de Vries et al., 2021; Pedersen et al., 2020; Swinnen, 2010), representing a critical research gap. Despite efforts to theoretically bridge the interplay between levels (e.g., Läpple et al., 2016; de Boon et al., 2022a), only a few authors have attempted to approach this gap empirically to the best of our knowledge. In addition to presenting conceptual work around a multi-level understanding of the agricultural system, scholars have proposed models for decision-making or food security (e.g., McGregor et al., 2001; Müller et al., 2020) that combine, for example, farm household responses on a micro level with macro-level data (e.g., soil type or climate). One empirical example is Aravindakshan et al.'s (2020) micro–meso–macro modeling of agrarian change, linking micro-level farm household variables (e.g., perceived soil fertility of the farm) to macro-level data (e.g., village population or cyclone severity index).

Our article contributes to this gap by drawing upon interdisciplinary research to holistically understand and explain agricultural transitions from different disciplinary angles. It applies relevant theoretical lenses, research methods, and empirical data at both the micro and macro levels rather than targeting only one dimension.

Our findings thus contribute to the literature by (1) further expanding the growing body of agricultural and food system transition research, (2) adding empirical evidence to explain systemic changes in the agricultural sector with qualitative and quantitative data, and (3) combining perspectives from psychology and public policy research to account for the micro and macro levels within the agricultural system.

This article seeks to answer the following question: What conditions (drivers and barriers) can be identified for successful agricultural transitional processes? Applying a mixed-method research design, we employed micro-level qualitative interview data and conducted systematic macro-level comparisons of generated data through Qualitative Comparative Analysis (QCA). The two studies in this article reflect a two-step procedure: We began by inductively gathering information on actors' understanding of the system (including micro, meso, and macro levels) to identify drivers and barriers related to agricultural transitions from a subjective perspective. Building on these results, we verified these identified conditions for a successful transition by performing a QCA of OECD countries to uncover complex explanatory patterns and contribute to sustainability transition research via in-depth investigation (Köhler et al., 2019). Therefore, we prioritized human-centeredness to ensure the inclusion of the social dimension in the agricultural sector (Rose et al., 2021) and connect the individual actor perspective (micro level) with a systematic comparison linking conditions to the outcome of agricultural transitions toward sustainability (macro level).

The article is structured as follows: the next section outlines relevant frameworks and theories within (agricultural) transition research that guided us in the methodological design for identifying (via interviews, study 1) and validating (via QCA, study 2) possible drivers and barriers related to a successful transition. Following our description of the methodological procedure for both studies, we present the results of the studies and discuss them jointly. Lastly, the article concludes by considering limitations and deriving practical and theoretical implications.

## 2. Frameworks for agricultural transition

Some scholars have sought to identify a variety of factors driving or hindering agricultural transition processes (Smith et al., 2005). One recently published comprehensive framework by de Boon et al. (2022a) depicts an extensive example of the successful integration of different established approaches, including the multi-level perspective (El Bilali, 2019; Geels, 2019), agricultural innovation systems (Klerkx and Begemann, 2020), and the theory of planned behavior (Ajzen, 1991), used to understand agricultural innovation and transition from a broad range of disciplines, such as psychology, economics, and political sciences, in one framework. The framework combines various characteristics that are necessary for sustainable, socially just and legitimate agricultural transition. It draws from different frameworks and complements them through the insight that "people" (Rose et al., 2021; Vanclay et al., 2013)—referring to capacity and actions at the individual level—play a key role in transitions. Specifically, this model presents several components and their interactions at multiple levels, picturing a variety of factors relevant to successful transitions. For example, the micro level includes psycho-social factors, such as different actors' attitudes and capacities to adapt to the transition. The meso level, which appears as the "immediate context," encompasses all actors and centers around the so-called agricultural innovation (and knowledge) systems. Lastly, the macro context and governance structures constitute the political, institutional, economic, and socio-economic factors that influence innovation processes. However, empirical evidence on the integration of these dimensions is lacking regarding the actual interplay between individual perceptions of relevant factors and macro-level differences in these factors between contexts as potential explanations for successful agricultural transitions. Thus, this article builds on this integration of theories to explain agricultural transition by adding empirical evidence to the interaction between individual-level factors and macro-level conditions from the perspectives of two disciplines: psychology and public policy research. Accordingly, the next section details the micro-level and macro-level factors that figure prominently in psychological and public policy research in order to offer a starting point for the subsequent two studies featured in this article.

### 2.1. Psychology: individual drivers and barriers to agricultural transitions (micro level)

Even though individuals' impacts on large transition processes are considered low, the actors' role is non-negligible in light of their interactions with technologies, processes, and institutions, among other factors (Fuenfschilling and Truffer, 2016). In fact, psychological research centers on individual actors. Several theories highlight the interplay of systems, humans, and technology (Darnhofer, 2015; Jørgensen and Jørgensen, 2009; Williams and Edge, 1996). Different actors can exert a considerable impact on innovation through their interaction and input within the process (see Läpple et al., 2016). Furthermore, individuals as change agents and boundary spanners help bridge between different fields, system levels, and multiple transition initiatives (Bögel et al., 2019).

Although the current literature outlines the promising role of different actors, relatively few empirical studies from an individual perspective have investigated impact factors on agricultural transition. One example is a stakeholder survey by Dinesh et al. (2021), which empirically validated Campbell et al.'s (2018) theory about transforming agriculture and food systems. The stakeholders' responses highlighted nine priorities for transition in food systems under the umbrella of climate change in different dimensions tailored to the study topic: micro (e.g. empowering farmer, women and youth); meso (strong farmer organizations, networking, and partnerships) and macro (enabling policy and institutions and existence of low-emission practices and technologies). Other studies focused on agricultural transition processes have been of qualitative nature. For example, Vermunt et al. (2020) illuminated transition dynamics in the agricultural sector through the lens of the multi-level perspective via in-depth interviews with experts in the Dutch dairy sector. In another qualitative study, Specht et al. (2015) investigated the early introduction phase of one specific process innovation and potential key factors for either hindering or promoting it. They identified multiple contextual factors (e.g. political context, market situation), actor-related factors (e.g. skills, expertise, attitude) and object-related factors (perceived benefits and risks, technological factors).

To sum up, these exemplary studies disclose the value of a variety of stakeholder perspectives on the agricultural system and the extensive diversity of impact factors on different dimensions. Therefore, it is particularly important to empirically focus on diverse actor groups in agriculture, particularly farmers. Accounting for the diverse understanding of the system, we aimed to uncover potential drivers and barriers by means of in-depth qualitative interviews for the transition process toward electrical field cultivation as a case example for a specific innovation in agriculture.

### 2.2. Public policy: policymaking for agricultural transitions (macro level)

Psychological research focuses on individual actors and their potential action to drive agricultural transitions or factors hindering them from acting. In contrast, public policy research scrutinizes the conditions under which transitions occur. These conditions can range from political institutions to policy actors and the adoption of policies (Öhlund et al., 2015). Thus, public policy research is often oriented towards different dimensions of politics, policy, and polity (Lindberg et al., 2019), which can yield necessary or sufficient conditions for agricultural transitions. In the polity dimension, the existing literature suggests that the outcomes of agricultural transitions can depend on the constraints that political systems may or may not impose on the governing actors to realize the latter's objectives. Accordingly, we assumed that federalism would make a difference as to whether agricultural transitions are successful, because policies could be tested at a subnational level prior to being implemented nationwide (Sheingate 2001).

In the political dimension, the government's ideological composition can be expected to have a substantial effect on transition processes. In the agricultural sector, in particular, green parties frequently emphasize enforcing sustainability (Tosun, 2017; Vogeler et al., 2020); thus, it could be assumed that the inclusion of green party members in the government would positively influence sustainability transitions in agriculture, resulting in reduced greenhouse gas emissions (GHG) while simultaneously increasing production. However, other interests could block these developments, especially the agricultural sector's workforce when faced with the need to innovate and change. A strong organization of such interests, which could be assumed if the relative workforce compared to others not working in the agricultural sector was large, was hypothesized to result in less developed innovation in agriculture.

Finally, public policy research starts from the perspective that policies affect outcomes. The literature on agricultural transition similarly calls for the consideration of governance factors—regulations, public funding, strategies to foster innovation processes, and sustainability-oriented policies—to explain and steer a sustainability transition (Melchior and Newig, 2021). In addition, multiple policy instruments are generally suitable—in theory, at least—to achieve successful sustainability transitions (Edmondson et al., 2019). Set at a national level, environmental subsidies, taxes, and other financial incentives presented to farmers and consumers who engage in and purchase sustainable agricultural products can promote a sustainability transition in agriculture. However, in addition to economic incentives, information campaigns and agreements represent soft policy instruments that can also contribute to the desired outcome (Metz et al., 2020), as well as hard policy instruments, such as permits, obligations, and prohibitions that complement the policy instrument mixes. The effectiveness of policy instruments also depends on the implementation context, for example, whether the federal or subnational government level is responsible for implementing a policy measure (Mavrot et al., 2019). Furthermore, the degree to which the government brings a sustainability orientation to its environmental policies and whether policies encourage research and innovation in the country should be crucial to successful agricultural transitions. These government attempts also include the quality of infrastructure, which should be essential for a successful transition process (Bohn and Dong, 2021).

## 3. Research design and method

The empirical research presented in this article aimed to answer the following question: *What conditions (drivers and barriers) can be identified in successful agricultural transition processes?* Since the current literature on the interplay of micro- and macro-level factors suggests that both dimensions play a central role, we considered these factors from the two perspectives of psychology and public policy. Study 1 deployed a human-centered perspective within agricultural transitions and built on the actors' understanding of the agricultural system and its change factors as a reflection of the system. Taking the example of electrically driven field cultivation, we asked: *What are potential drivers and barriers for the transition process of electrical field cultivation from an actor-centered point of view?* This question put individuals' perceptions at center stage and included context factors, which the interviewees found particularly relevant. Such context factors represent the core research object of public policy research. Next, building on the results of study 1, we conducted a QCA to analyze comparatively whether the subjectively perceived drivers and barriers related to agricultural transition held true empirically by connecting configurations of these conditions to the outcome of transition across countries. The inductively yielded context factors from study 1 were theorized as conditions under which agricultural transition potentially occurred, then tested for necessity or sufficiency. Therefore, in study 2, we ask: *Which of these factors, classified under the common heading of context alone or in combination with each other, contribute to agricultural sustainability transition?* The following sections provide details of the methodological procedure for the two studies, as illustrated in Fig. 1.

### 3.1. Study 1: Identifying barriers and drivers from an actor perspective

For the first psychological study, we selected electrically driven field cultivation as an example to visualize a single potential future-oriented transition within agriculture. This case is highly interesting because it simultaneously represents process innovation, involving new forms of maintaining and harvesting fields, and product innovation, with electrically driven agricultural machines (e.g., tractors, robots etc.). Furthermore, it poses both the need for system integration and intersection with other sectors and, as part of the energy transition, is interwoven in a wider political, social, and economic context (Sovacool et al., 2021). Due to its introduction of new processes and products, we defined the transition toward electrical field cultivation as one potential sustainability transition within agriculture.

Germany was chosen as the context for data collection to investigate the potential implementation of electrical field cultivation in a single agricultural system properly. Germany underlies both a problem pressure to transform due to continuously high $CO_2$ emissions and the dependency on fossil-fuel-based electricity production (Fraunhofer ISE, 2019) and reflects the ambitious goal of reducing climate change and contributing to sustainability transitions (Die Bundesregierung, 2019). New climate policies were implemented in 2021 (e.g., CO2 price mechanism), and Germany has engaged heavily in international efforts (e.g., Paris Agreement in 2015; Tosun and Peters, 2020).

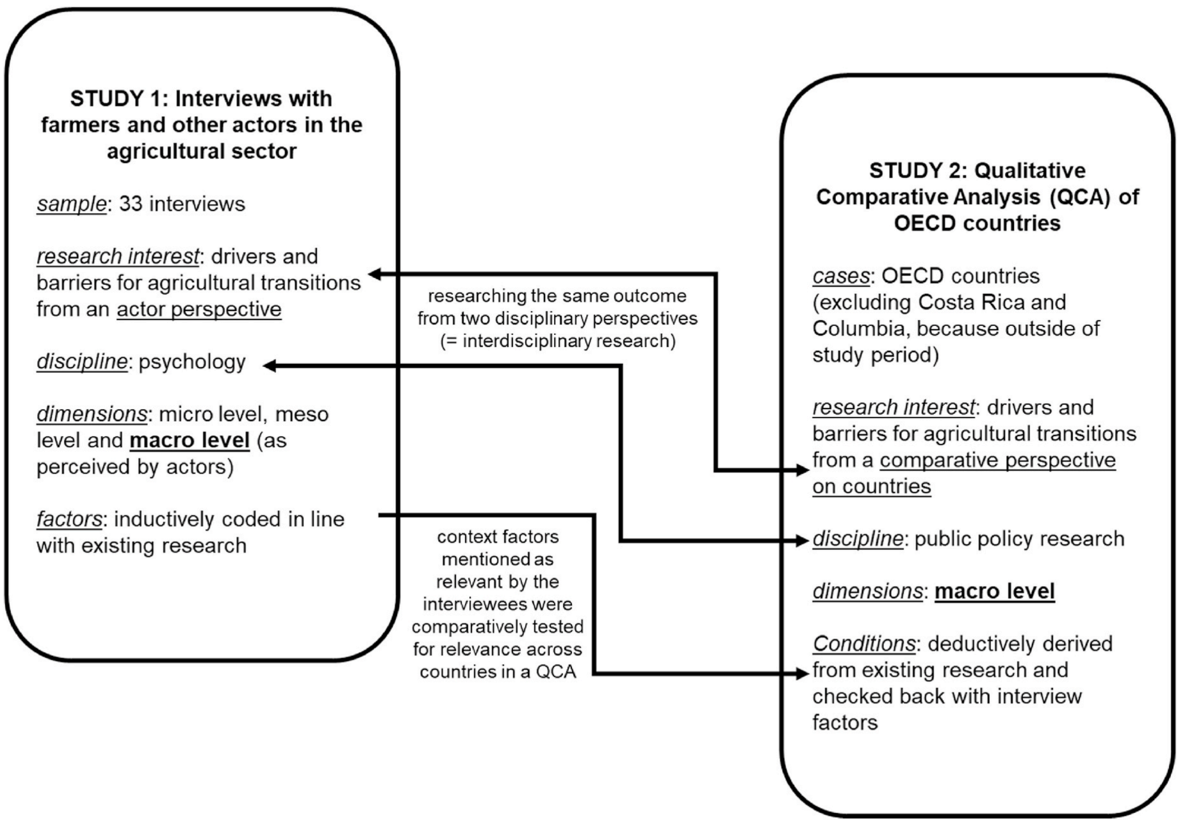


**Fig. 1.** Two-step procedure in present studies on successful agricultural transitions.

#### 3.1.1. Sample

In order to capture the high diversity of actors in the agricultural sector, we interviewed two groups while employing purposive sampling: farmers, as the main group affected by the transition, and various actors from public administration, research, and industry (PRI) in their role as transition process-shapers. Inclusion criteria for each interest group can be found in Appendix A1. Initially, invitation letters were sent out to representatives from each group (farmers and actors from PRI), starting with the project's local network. Complementary, the snowball principle was used to enlarge the overall sample and reach smaller and less accessible subgroups (e.g., female farmer or representatives from public administration). Recruitment and interviews took place from June 2020 to December 2020 and were mostly conducted online.

Prospectively, we aimed for a sample size of 26 interviewees after encountering repeated reports in the literature that 12–13 interviews per group of interest were found to yield thematic saturation (Guest et al., 2006; Hennink and Kaiser, 2022). To ensure that we would reach the point of saturation with our sample size, we retrospectively applied Guest et al.'s (2020) method for assessing thematic saturation[2] after 26 interviews with a threshold of 0% new information. First, we chose eight interviews (four from each group) as the base size number of interviews and summed the contained number of unique themes (=10) as base themes. Next, we calculated the number of new themes for the first "run" of the next three interviews in line (interviews 9, 10 and 11) and divided the base themes (=10) by the unique themes found in the "run" (=1) to calculate the saturation ratio (=0.10). This procedure was repeated until the ratio yielded 0 new themes acquired by further interviews. Consequently, thematic saturation emerged after the 13th interview. Due to the ongoing recruitment process, we conducted six more interviews than planned, which provided additional saturation.

Altogether, a sample of $N = 33$ interviewees in Germany was recruited. The sample of farmers ($n = 18$) primarily worked as plant managers, with their agricultural business as their main acquisition. The sample featured more farmers holding an academic degree (67%) than on average in Germany (cf. DESTATIS, 2020). Furthermore, the sample consisted of predominantly male farmers (87.5%, $n = 14$), reflecting the male dominance in this sector (see Padel, 2020). The farm types ranged from mixed farming ($n = 8$) to pure crop cultivation ($n = 9$) and one livestock holder. The interviewees' ages spanned from 22 to 67 years ($M = 39.77$ years, $SD = 13.92$ years). Further information about the sample can be found in Appendix A1.

#### 3.1.2. Design & Procedure

A pretest was conducted to test the comprehensibility and transparency of the interview questions. A semi-structured interview design was chosen for its flexibility and exploratory nature (Kallio et al., 2016). The innovation of interest (for this study, electrical field cultivation) was introduced by first presenting all interviewees with a sketch displaying a farm with fields managed by electric power along with a short description (see Appendix A2). Interviewees were asked directly about the drivers and barriers they perceived to be crucial in a successful transition. Interviewees were not limited to a specific number of drivers and barriers. Transcripts were anonymized, transferred to the qualitative data analysis program MAXQDA20 for further analysis, and analyzed by means of conventional qualitative content analysis (Hsieh and Shannon, 2005).

#### 3.1.3. Data analysis

The coding system in conventional qualitative content analysis is generally derived inductively. Therefore, the code system for different

[2] Further information on the procedure used in the method can be found in Guest et al. (2020).

drivers and barriers related to a successful transition toward electrical field cultivation was based on the transcribed interviewee responses to the core question, "What barriers (drivers) could hinder (promote) a successful transition toward electrical field cultivation?" Additionally, the frequency of mention for every factor across all interviews was noted, which provided a preliminary impression of the intensity of each reason to help assess its importance (Mayring P, 2014). Reasons repeatedly mentioned in a single interview were multiply coded but counted as 1 in the final frequency statement. Overall, Mayring's recommendations for qualitative criteria within qualitative content analysis (2014) were applied (reproducibility, stability, and construct validity). Internal reliability was further increased by double-coding 18% of the interviews, which yielded an inter-rater reliability of 0.93%. Additionally, trustworthiness, as the qualitative counterpart to validity, was promoted by using different verification strategies, for example, thick descriptive data and prolonged engagement (Hsieh and Shannon, 2005; Walby and Luscombe, 2016).

### 3.2. Study 2: Cross-nationally comparing conditions for agricultural transitions

Drawing from the state of the art in public policy research and study 1, the second study entailed performing a QCA[3] to investigate whether the context factors that the interview partners named as relevant held true when comparing these conditions and the outcomes of agricultural transitions across countries. The results from the study 1 interviews were taken as the starting point for the analysis and the choice of conditions. We particularly investigated the most frequently named factors and left out those that did not vary across countries (such as the required technical characteristics of machinery and the global market, which presents equal pressure in all of the included countries). Societal and consumer acceptance was not examined specifically in light of research demonstrating that social acceptance can be politically achieved through framing (Pleger et al., 2018).

The QCA method was originally proposed by Ragin (1987) to transcend the boundaries of qualitative and quantitative methods and focus on set-theoretical configurations of conditions to explain outcomes. The interviews in study 1 were conducted in Germany, raising the central question of the generalizability of their results. Thus, we sought to determine whether the conditions that individual sectoral actors deemed necessary for the successful introduction of an agricultural transition would prove relevant in a comparative study. Comparing Germany with countries that shared a similar economic and strategic outlook, which we defined as fellow member countries of the OECD, allowed us to evaluate the explanatory pattern of successful agricultural transition. The choice of QCA was based on the observation that the method has proven fruitful in earlier research performing comparative analyses of agricultural governance in OECD countries or climate action (Hornung, 2022; Popp et al., 2021).

One of the major challenges in analyzing the conditions for transitions is operationalizing the OUTCOME. Since innovation is a component of transition progress, a common and potentially highly valid measure in agriculture, as well as other contexts, is a nation's patent activity (Dziallas and Blind, 2019), although the use of composite indices is alternatively encouraged (Hagedoorn and Cloodt, 2003). Therefore, we used data from climate change adoption technologies in agriculture, forestry, and livestock or agricultural-alimentary production OECD Statistics (2021) to calculate the total patent activity in the agricultural sector per country from 2016 to 2018. We then divided this total by the country's population size to account for potential bias. Subsequently, we produced a combined indicator of agricultural transition to go beyond a unidimensional view on patents for agricultural transition and to account for other aspects of a successful transition, such as reduced emissions and increased productivity (Balafoutis et al., 2017; Valin et al., 2013; Velten et al., 2015). This indicator considered the percentage change in GHG emissions between 2016 and 2019 and the levels of livestock and crop production in 2018. Doing so resulted in very similar calibrations for the countries considered highly progressive, with Australia, Austria, Belgium, Canada, Israel, South Korea, Latvia, Luxembourg, the Netherlands, New Zealand, Switzerland, and the USA being identified as the OECD countries with the highest level of transition progress in agriculture.

At the polity level, the condition of federalism (FED) was coded with reference to the Comparative Political Data Set (CPDS; Armingeon et al., 2020) and supplementary sources. The polity condition was included in study 2's QCA only because it offered explanatory potential mainly in the comparison of countries, not within the same country. At the politics level, the data from the CPDS allowed for coding whether green parties had been present in government between 2016 and 2018. The condition of powerful interest organization of the agricultural workforce was calibrated according to the relative share of people working in the agricultural sector (EMPL). Additionally, we used sustainable nitrogen management (SNMI) performance as an indicator of the transition process and the problem pressure exerting influence at the political level (Environmental Performance Index, 2022). Regarding the policy level, the Bertelsmann Foundation's SGIs were used to capture the success of research and innovation policy (NEWRD), the extent to which sustainability goals were pursued in environmental policies (SGIENVPOL), and the quality of infrastructure (SGIINFR), as well as the levels of public investment in research and innovation (SGIRD) (Bertelsmann Stiftung, 2020e; 2020b; 2020c; 2020d). Public funding in agriculture was operationalized via the Agricultural Orientation Index (AOI). The existence of hierarchical policy instruments (OBLIEX) was coded following the OECD Database on Policy Instruments for the Environment. The details of the operationalization are displayed in Table 1.

## 4. Results: drivers and barriers for agricultural transitions—integrating the actor and public policy perspective

The inductive coding of the interviewees' responses led to three dimensions of drivers and barriers (individual, interpersonal, and context) and 14 unique (sub)factors, which described the subjectively perceived factors that might hamper or promote a transition toward electrical field cultivation in the future. Apart from "market situation" as only hindering and "consulting and support" as solely promoting successful agricultural transition, all subfactors occurred as both barriers and drivers (see Fig. 2).

Generally, as can be observed in Fig. 2, the context dimension was mentioned disproportionally more than the individual and interpersonal dimensions. The least mentions appeared in the interpersonal dimension. This outcome justifies the relevance of study 2 and the need to take a closer look at the macro-level factors in the cross-country comparison. A chi-square test confirmed a significant difference in the number of references between the assigned dimensions (2, $N = 202$) = 93.28, $p >$ .05; see Appendix 3a), whereby mentions of factors within one dimension did not differ between actor groups (farmers and sectoral actors) and their presence as drivers or barriers (see Appendix 3b). The following section provides an in-depth understanding of the factors displayed in Fig. 2.

### 4.1. Individual dimension

The individual dimension, representing the micro level, comprises factors that directly concern the individual within the transition as a far-reaching change process, including knowledge, attitude, beliefs, competencies, motivation, self-concept, and behavior on the individual level in social psychology research (e.g., Burton and Wilson, 2006; Montes de Oca Munguia et al., 2021). Empirically, the interviewees named two actor groups seen as critical within a successful transition toward

[3] Dataset can be obtained here.

**Table 1**
Operationalization, data sources, and calibration of conditions for successful agricultural transition.

| Dimension | Condition | Operationalization | Data Source | Calibration |
|---|---|---|---|---|
| ***Polity*** | Institutional Constraints for Policymaking | Federalism (FED) | Comparative Political Data Set (CPDS) Armingeon et al. (2020), Lijphart (2012) | dichotomous (existent or not) |
| ***Politics*** | Ideological Composition of Government | Green Parties in Cabinet (GOVGREEN) | CPDS, IPU (2022) | dichotomous: 0 (no green party in government); 1 (green party in government) |
| | Organized Interests | Agricultural Share in Employment (% of Active Work Force) (EMPL) | World Bank (2021) | fuzzy: 0 = < 1; 0.3 = <1–4; 0.7 = 4–10; 1 = > 10 |
| | Successful Nitrogen Management | Sustainable Nitrogen Management Index (SNMI) | Sustainable Development Report (2019) | fuzzy (0 = Major challenges remain, 0.3 = Significant challenges remain, 0.7 = Challenges remain, 1 = SDG achieved) |
| ***Policy*** | Quality of Infrastructure | Research, Innovation and Infrastructure (SGI Indicator) (SGIINFR) | Bertelsmann Stiftung (2020c) | dichotomous: 0 (<5), 1 (>5) |
| | Orientation Towards/ Investment in the Agricultural Sector | Agricultural Orientation Index (AOI) | FAO (2022) | dichotomous 0 = lower orientation by its central government to the agricultural sector relative to agriculture's economic contribution, 1 = higher orientation by its central government to the agricultural sector relative to agriculture's economic contribution |
| | Environmental Performance Indicator | Agriculture Issue Category (EPI.AGR) | Povitkina et al. (2021), Wendling et al. (2020) | fuzzy: 0 = > 60; 0.3 = < 60 > 50; 0.7 = < 50 > 40; 1 = < 40 |
| | Investment in Research and Innovation | SGI Public R&D Spending (SGI Indicator) (SGIRD) | Bertelsmann Stiftung (2020b) | fuzzy: 0 (1–2), 0.3 (3–5), 0.7 (6–8), 1 (9–10) |
| | Successful Environmental Policy | Environmental Policy (SGI Indicator) (SGIENVPOL) | Bertelsmann Stiftung (2020a) | fuzzy: 0 (1–2), 0.3 (3–5), 0.7 (6–8), 1 (9–10) |
| | Successful Research and Innovation Policy | R&I Policy (SGI Indicator) (NEWRD) | Bertelsmann Stiftung (2020d) | fuzzy: 0 (1–2), 0.3 (3–5), 0.7 (6–8), 1 (9–10) |
| | Policy Instrument: Obligations | Whether there exist hierarchical policy instruments to steer environmental policy (OBLIEX) | OECD (2022) | dichotomous: 0 = no, do not exist, 1 = yes, exist |
| ***Outcome*** | Agricultural Transition Progress | Combined Index of Patents, GHG emissions, and Production Index (OUTCOME) | | fuzzy (0, 0.3, 0.7, 1 – calculated from the rounded mean values of the three following conditions |
| | Patents in Agriculture | Sum of Patents (2016–2018), divided by population size | OECD Statistics (2021) | fuzzy: 0 = 0–0.48; 0.3 = 0.75–1.39; 0.7 = 1.65–1.82; 1 = 2.52–4.45 |
| | Production Index | Sum of Livestock and Crop Production (2018) | Valev (2022) | fuzzy: 0 = < −5; 0.3 = > −5 < 0; 0.7 = > 0 < 5 |
| | Greenhouse Gas Emissions | Percentual Change (2016–2019) | OECD Statistics (2022) | fuzzy: 0 = < −4; 0.3 = > −4 < 0; 0.7 = > 0 < 9; 1 = > 9 |

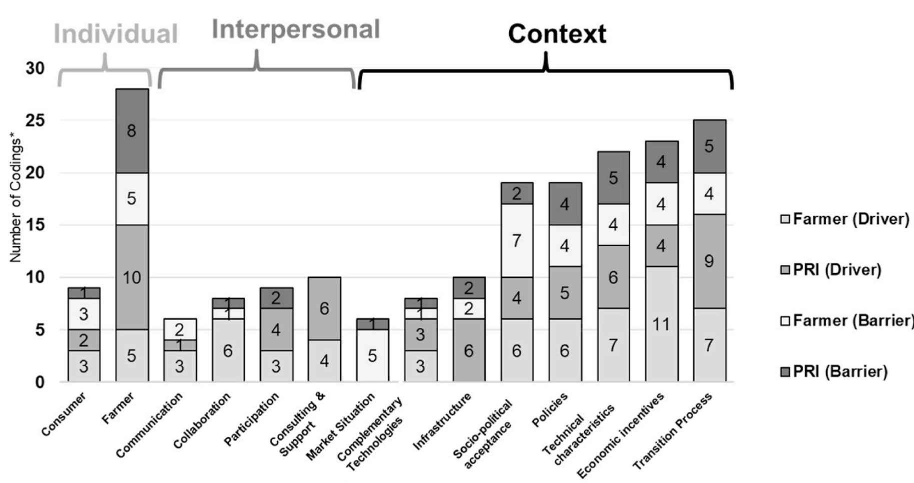


**Fig. 2.** Overview of drivers and barriers for electrical field cultivation ($N = 33$).
* Note. The frequency number indicates the number of interviewees who mentioned the subfactor. Notably, multiple factors per interview were coded. Therefore, the subcategories revealed more than 33 codes in total.

electrical field cultivation on an individual level: (1) *Civilians* as consumers and residents, in addition to (2) *farmers and employees* in the agricultural sector. Each group was mentioned as directive for a(n) (un) successful transition process according to their cognitive, affective, and behavioral response. It must be noted, however, that individual consumers and residents were differentiated from socio-political acceptability and acceptance as these concerned attitude and behavior from an individuum in comparison to socio-political acceptability as a concept on the national level (Busse and Siebert, 2018). Two interviewees mentioned that "consumer demands" (I33) were a necessary trigger for a change to occur, given that "long-term change in agriculture is inhibited by everyone's greed to pay for quality" (I13).

In total, 28 statements invoked farmers and employees, along with their attitude and abilities (e.g., willingness and competencies to change), as highly influential in facilitating a successful transition. The "willingness to think through fundamentally new things" (I21), break with the “culture of insistence” (I25), and “refrain from the mentality that ‘we have always done it that way’” (I28) were stated as necessary. In order to do so, interviewees listed the importance of positive experiences with new technologies, accompanied by possibilities to experience them, such as in living labs (see interpersonal dimension). Generally, the individual within the transition and the subsequent consequences (predominant new technologies) were described as double-edged. One farmer (I12) emphasized the individual feeling of “one’s farmer still being able to do his job” and maintain certain aspects of what makes them passionate about working in agriculture and “maintain intrinsic motivation” (I31). In contrast, an actor from PRI implied risk-taking, curiosity, and entrepreneurship as natural features of farmers’ daily business (I25), thereby implying ambiguous characteristics of the job. Additionally, competencies to adopt and apply electrical field cultivation in one’s business, as well as employees’ competencies, were mentioned as essential to “operate, adjust and repair applied technologies within the scenario [of electrical field cultivation]” (I6). In addition, the need for individual pioneers was mentioned as a noteworthy driver. One farmer described the effect simply as follows: “There are certain pioneers in the agricultural sector who quickly adopt new technologies. If it works, others will follow little by little” (I11). In particular, the young generation of farmers was mentioned in terms of representing promising adopters of new technologies in this context.

In summary, most of the individual factors (e.g., competencies and willingness to change) could be supported and developed within the interpersonal dimension, indicating the high degree of interconnection between these dimensions.

### 4.2. Interpersonal dimension

The interpersonal dimension encompasses such factors as interaction, relations, and events between two or more people or organizations. In total, the interpersonal dimension was relatively seldom mentioned, yielding a frequency of 33 statements. Therefore, and in light of the focus of this article on whether individually perceived drivers and barriers for agricultural transitions would prove relevant in a generalizable comparative analysis, we will only discuss them briefly here. Four drivers and barriers related to agricultural transition were identified: participation, cooperation, communication, and consultation connected to support. (1) *Communication*. A high level of transparency, active public relations work, and communication tailored to target groups were evaluated as favorable conditions, whereas a lack of information or poor-quality information about the transition and technology for actors and the public were assumed to act as barriers. (2) *Cooperation* was mentioned by eight interviewees and included any exchange and collaboration between different actors involved in the transition toward electrical field cultivation on various levels: national (between research institutes and industry), international, and local levels (between farmers). (3) *Participation* as the opportunity to enable stakeholders to take an active part in the transition process was seen as a driver for electrical field cultivation. (4) Ten sectoral actors and farmers mentioned *consulting and* support, such as tailored solutions for farmers and their business, training opportunities, and further education, which were seen as favorable for a successful transition toward electrical field cultivation and as a driver but never as a barrier.

### 4.3. Context dimension

The context dimension includes the political, economic, and societal context and is related to the macro level and governance system (cf. de Boon et al., 2021). This dimension had the most mentions in 132 statements. Two of the predominant factors here, mentioned by 26 interviewees, included *economic incentives* and other types of *policies* related to electrical field cultivation (see policies and economic incentives in Fig. 2). The category emphasized the importance of existing legal regulations in connection with agricultural policy. Accordingly, *economic incentives* referred to financial incentives to accelerate implementation, such as subsidies.

Besides the “temporary legislative periods” (I8) that were seen as one reason for the lack of necessary planning security for farmers, the policy dimension as a driver or barrier was heavily emphasized. Specifically, the German Renewable Energy Sources Act (EEG) was mentioned multiple times as having “significantly contributed to farmers’ investments in renewable energy sources” and “enabled earning money with photovoltaic or biofuel in the end. Accordingly, those innovations got off the ground” (I13). In this vein, “unified regulations” (I5) were repeatedly discussed. Interestingly, a sectoral actor emphasized legal provisions that completely hampered autonomous agriculture as one example of a specific innovation in the agricultural sector: “Only legal regulations keep us from, for example, having autonomous agriculture. We could be much further ahead” (I29). One interviewee underscored the importance of subsidies as “always helpful” (I19): “If you integrate it [electrical field cultivation] into an initiative that would be funded, that might significantly reduce the inhibition threshold. In response, one is more willing to invest.” In association with a highly “competitive pressure” within the agricultural sector, the *(global) market situation* was identified as solely a barrier to a successful transition in contrast to the other factors, which were recognized as having two sides (barrier and driver). Interviewees described Germany’s role in comparison to other countries and the necessity to stay competitive in the agricultural market. One farmer brought up the example of Russia and China as “superior” (I15) in the market and raised the concern that Germany might risk a decrease in its competitive ability if it strategically oriented toward electrical field cultivation. In total, 19 statements concerned *socio-political acceptance* as an equally favorable and hampering factor for the transition toward electrical field cultivation. One interviewee saw socio-political acceptance as the central factor: “I do not know where the journey will lead us, but in agriculture, there is so much attached to the degree to which society accepts it” (I7). Several references were made to the *technology* itself, with its design, characteristics, and development, along with the *complementary technologies* and their quality. One farmer claimed that the application of technology associated with electrical field cultivation would have to “smoothly function” (I2), and another noted that it must be applicable “without reading an entire book first” (I8). The interviewees had contrasting responses to advancing technology, seeing prematurely implemented technology with missing compatibility and poor range based on energy supply as hampering, while technological advances in other areas were noted as driving the transition. *Infrastructure* was mentioned by ten interviewees as essential for a transition toward electrical field cultivation. Infrastructure includes the availability of the internet and grids for the requisite energy supply. For example, one farmer (I6) elaborated on the difficulty of building high-voltage lines in rural areas under different conditions. In a similar vein, a major proportion of statements pinpointed the *transition process* and its design as hampering or supporting the development. On the one hand, a stepwise transition instead of a disruptive one was described as the right choice: “You should not replace the machines completely, but do it step by step. I envision the tractor in like 5 years; it’ll still look like it does today. [ …. ] the farmer can still operate it just the same” (I20). On the other hand, “overly hasty demands” would lead to the above-mentioned “immature technology” and “unforeseeable consequences” (I20). To avoid those consequences, one sectoral actor suggested following procedure: “expansion and installation in specific regions in order to explore electrical field cultivation” (I21), mirroring the idea of policy labs or experimental regions in decentralized political systems with high autonomy on the part of subnational governments.

Study 1 yielded an initial list of drivers and barriers for a successful agricultural transition from an actor perspective and revealed the substantial prominence of context factors. In practical terms, the identified factors are in line with those included in the major theoretical frameworks presented in the theoretical part and fit the three levels outlined therein. Therefore, we could confirm the multidimensional theoretical

**Table 2**
Sufficient conditions for agricultural transition progress.

| Configuration | Countries | inclS | PRI | covS |
|---|---|---|---|---|
| GOVGREEN | Australia, Latvia, Luxembourg | 0.775 | 0.710 | 0.197 |
| FED*EPI.AGR*SGIENVPOL | Belgium, Netherlands, Switzerland | 0.929 | 0.800 | 0.248 |
| AOI*SGIINFRA | Canada, Switzerland, Luxembourg | 0.900 | 0.889 | 0.172 |
| SGIINFRA*~EPI. AGR*~SGIENVPOL | Korea, USA | 1.000 | 1.000 | 0.242 |
| ~SGIINFRA*NEWRD*OBLIEX | Australia, Belgium, New Zealand | 1.000 | 1.000 | 0.153 |

Overall Solution Consistency: 0.874, Overall Solution PRI: 0.789, Overall Solution Coverage: 0.662.

**Table 3**
Sufficient conditions for unsuccessful agricultural transition progress.

| Configuration | Countries | inclS | PRI | covS |
|---|---|---|---|---|
| ~SGIINFRA*~EPI. AGR*~OBLIEX*~GOVGREEN | Hungary, Poland, Slovakia, Turkey, Lithuania, UK, Greece, Italy, Estonia, Czech Republic | 0.868 | 0.793 | 0.389 |
| FED*EPI. AGR*~GOVGREEN*~SGIENVPOL | Mexico, Spain | 1.000 | 1.000 | 0.143 |
| ~FED*EPI. AGR*~GOVGREEN*SGIENVPOL | Chile, Iceland, Ireland, Norway, Slovenia, Portugal | 1.000 | 1.000 | 0.325 |
| ~AOI*SGIINFRA*OBLIEX*SGIENVPOL | France | 1.000 | 1.000 | 0.049 |

Overall Solution Consistency: 0.929, Overall Solution PRI: 0.880, Overall Solution Coverage: 0.773.

conceptions proposed by prior investigations, such as de Boon and colleagues (2022). The existing literature, in particular, highlights the interplay between actors who significantly shape the phases of transition, as well as the institutional and macro-level opportunities and constraints within which they act (Feindt et al., 2020). Correspondingly, the overrepresentation of the context factors in the actors' minds called for validation of whether these factors would indeed favor transition in agriculture. Furthermore, the question arose as to which configurations of context conditions would favor or hinder agricultural transitions. The answer was provided by the second study, per the description in the next section.

### *4.4. Necessity and sufficiency of context conditions at the macro level*

A QCA starts by analyzing the conditions necessary for an outcome to occur.[4] A successful research and innovation policy, operationalized by means of the SGI data, is necessary for the outcome to occur. This result suggests that governments can actively steer agricultural transitions by supporting technological product and process innovation. The condition is necessary with a consistency value of 0.962 and a coverage value of 0.645, meaning that only 0.038% of countries with successful agricultural transitions lack a successful research and innovation policy at the same time.

The second step of the QCA entailed performing an analysis of the sufficiency of (configurations and) conditions by means of a truth table analysis (see Table 2). In the logic of QCA, this step is inspired by the results of the necessary conditions analysis, along with a trial-and-error procedure of identifying the conditions that alone or in combination with each other are sufficient for the outcome to occur. Therefore, whenever these conditions (or combinations thereof) are present, the outcome of successful agricultural transition is also present.

The results generally confirmed what was expected from the theoretical considerations: The conditions broadly referred to as "context" by the affected individuals, particularly farmers and sectoral actors, could be assigned to the dimensions of polity, politics, and policy and were relevant to the outcome. The most important and clearly visible condition was political: When there is a political will for transition in the agricultural sector because green parties are part of the government, agricultural transition occurs. Even if there is no green party in government, an agricultural orientation in terms of government investments can be successful in achieving agricultural transition—but only if the existing infrastructure is already in place to ensure the efficient use of these invested resources, as is particularly the case in Canada and Switzerland. These countries are also federalist countries, which in the polity dimension emerges as a condition that is part of configurations leading to a visible agricultural transition. In the cases of Belgium, the Netherlands, and Switzerland, such federalist structures, in conjunction with successful environmental policy and high levels of environmental performance indicators, are sufficient for the outcome. In contrast, South Korea represents a rather special case that does not fit into the explanatory patterns yielded by other countries. Korea has a comparatively well-developed infrastructure but lacks a sustainability orientation in its environmental policy and performance, just as the USA. These cases demonstrate that the provision of infrastructure can lead to high levels of innovation and sustainability transition if countries place less value on how these transitions are realized. Finally, the combination of a lack of infrastructure and a successful research and innovation policy combined with regulations equally explains the outcome in Australia and Belgium, as well as New Zealand.

The analysis of necessary and sufficient conditions was repeated for the negative outcome (i.e., the absence of a successful transition in agriculture) to support the formulation of conclusions explaining why Germany is not (yet) far ahead in its sustainability transition, adding further to the results of study 1. Among the necessary conditions for an unsuccessful agricultural transition, the absence of green parties in government (consistency value of 0.956, coverage value of 0.606), in particular, appeared to be necessary for the negative outcome to occur. This result generally supports the claim that green parties in a parliamentary political system exert the necessary influence to successfully govern agricultural transitions.

Enriching these results, the analysis of sufficient conditions revealed that the absence of green parties in government was also a part of configurations leading to an unsuccessful agricultural transition (see Table 3). If the environmental policy performance (EPI.AGR) was low and the infrastructure (SGIINFRA) was insufficient, the blocking of transition processes could be explained by the non-existence of green parties in government (GOVGREEN), in combination with the absence of "hard" policy instruments (OBLIEX). When environmental policy performance was high, the absence of green parties still resulted in unsuccessful agricultural transitions if, at the same time, either a successful environmental policy was lacking (in federal political systems) or if the systems were centralized, even if the environmental policy was considered successful. Furthermore, the configurations revealed that the processes of innovation and transition in agriculture were unsuccessful if good infrastructure (SGIINFRA), regulation (OBLIEX), and a successful environmental policy (SGIENVPOL) were not combined with economic incentives (AOI). However, this last configuration only explained the case of France and, therefore, could not be considered an explanatory

[4] The entire QCA was performed in R, using the packages of Dușa (2020) and Oana and Schneider (2018).

**Table 4**
Context factors (study 1) verified by study 2 for (un)successful agricultural transition.

| Study 1: Drivers and Barriers | Study 2: Conditions | Condition Shortcut | Study 2: Driver for successful agricultural transition when: | Study 2: Driver for unsuccessful agricultural transition when: |
|---|---|---|---|---|
| Infrastructure | Infrastructure Policy (***Policy***) | SGIINFRA | ✓/X | ✓/X |
| Economic Incentives | Agricultural Orientation Index (***Policy***) | AOI | ✓ | X |
| Policies | Successful Environmental Policy (***Policy***) | SGIENVPOL | ✓/X | ✓/X |
| | Successful Research and Development Policy (***Policy***) | NEWRD | ✓ | |
| | Policy Instrument: Obligations (***Policy***) | OBLIEX | ✓ | ✓/X |
| Political Structures | Federalism (***Polity***) | FED | ✓ | ✓/X |
| Transition Process | Green Party in Government (***Politics***) | GREENGOV | ✓ | X |
| | Environmental Performance in Agriculture (***Politics***) | EPI.AGR | ✓/X | ✓/X |

*Note. Interpersonal and individual dimensions from study 1 are not accounted for in study 2. See Table 1 for operationalization. Market situation, societal acceptance, and technical characteristics were excluded from the analysis because all countries face this challenge, i.e., they cannot be used to explain the outcome. Complementary technology was operationalized as part of the combined outcome through patent registrations.

pattern but rather a description of the French case.

## 5. Discussion

In summarizing the results of the two studies described in this article, our findings reveal that context factors at the macro level are perceived by different actors as crucial in enabling transitions; furthermore, study 2 largely confirmed this relevance across countries. Table 4 provides an overview of all context factors found in study 1, along with the extent to which study 2 found their presence or absence relevant to agricultural transition toward sustainability.

However, while the interviewees named certain factors as context conditions, the QCA went on to prove which factors were necessary or sufficient in leading up to the outcome of the transition. The classification according to the dimensions of polity, politics, and policy evolved into a useful tool: The polity dimension appears relevant in three configurations explaining the outcome: federalist structures one third (three of nine) of the configurations of conditions that are sufficient for successful agricultural transition. The politics dimension seems to be the most crucial in explaining the presence or absence of the outcome: Both the inclusion of a green party in government and environmental performance—either overall or specific to agriculture—are components of six sufficiency configurations (out of nine identified in the QCA). All sufficiency configurations include a combination of a polity condition

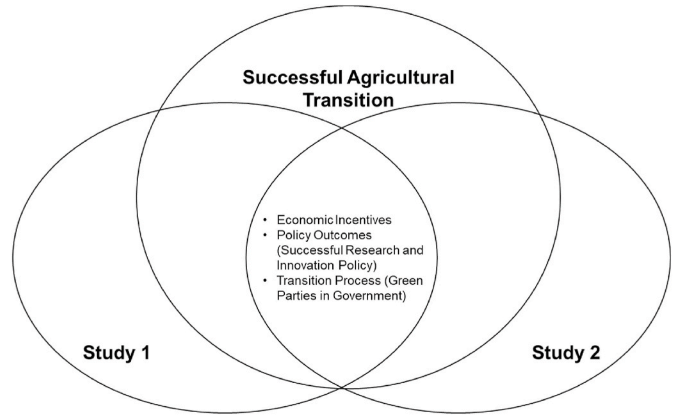


**Fig. 3.** Drivers and barriers for agricultural transitions confirmed by both studies.
* Own Illustration.

(infrastructure or federalism) and/or a policy condition (policy instrument, research and innovation policy, environmental policy, agricultural orientation) and/or a politics condition (green parties in government, environmental performance). As demonstrated by Table 4, certain conditions are sufficient or necessary for the presence or the absence of the outcome when being present (✓) or absent (x), depending on the configuration within which they find themselves.

In comparing the QCA results with those of study 1, it can be said that, in general, the factors named by interviewees as context-related drivers and barriers for agricultural transitions largely reveal a certain relevance to successful transitions, though less clearly as only a driver or barrier than the interviews might suggest. Only a few conditions are explicitly identified as drivers of successful agricultural transitions when present and as barriers (i.e., conducive to an unsuccessful agricultural transition) or irrelevant when absent. These conditions include green parties in government and financial investments in agriculture, as well as a successful research and innovation policy. Fig. 3 outlines these factors as the central implication of cross-checking the results.

The remaining conditions derived from the literature and the interviews reveal a complex interaction in the context of agricultural transitions. For example, infrastructure, environmental performance, and a successful environmental policy do not always contribute to agricultural transitions; sometimes, transitions occur especially because these factors are absent or when they interact with other conditions. Therefore, the individual perception of the success factors for agricultural transitions only partially corresponds to the empirical insights into the conditions that a comparative study of countries identified as contributing to agricultural transitions. Accordingly, actors who are involved in transition processes are urged to take into account the subjective perceptions of processes and should align strategies with research that sheds light on the decisive elements that underlie the success of agricultural transitions.

Altogether, this investigation contributes to the growing body of agricultural and food system transition research through its identification of various factors perceived by relevant actor groups, shedding light on the systemic understanding by individuals. Additionally, we developed empirical evidence via interviews (qualitative) and the QCA of qualitative and quantitative country-level data to empirically compare the individually perceived factors for successful transitions at a macro level across countries. In doing so, we combined perspectives from psychology and public policy research in highlighting the individual actor and inductively extracting their system understanding while applying policy research to further theorize and disentangle the system conditions. Thus, we identified necessary and sufficient conditions for the outcome of agricultural transition. The first study examined Germany as a case example; meanwhile, the second study clarified the results in showing that the country is not as far ahead as it could be given its clear ambitions toward a sustainability transition in agriculture. Along these lines, the comparative analysis explained why Germany lags somewhat in agricultural transitions, yielding results suggesting that the primary reasons include the low agricultural orientation in investments and decentralization of competencies.

As a theoretical implication, the study has made a case for the fruitfulness of interdisciplinary research in socio-technological transitions, in general, and agricultural transition, in particular. Combining insights from the two studies conducted from a psychological and policy research perspective helped illuminate the individual perception of system dynamics and the resulting success or failure of agricultural transitions. The QCA further highlighted the importance of political visions, policies, and institutions in transitions. Concerning cutting-edge psychological research, the use of QCA as a systematic method for analyzing small to medium-sized samples emerged as a promising approach. In the field of political science, the cognitive processes of actors in interacting with institutional factors should receive more attention and would profit from cross-fertilization with psychological theories and approaches (e.g., motivational theories, group identity, or social cognition). Drawing on perspectives and methodologies from psychology and public policy research and merging insights of the two thus offers potential benefit in advancing transition research.

The results contain practical implications for the governance of agricultural transitions that can be translated into recommendations for the actions of policy actors and farmers. At the political level, the results indicate that a combination of economic and regulative policy instruments oriented toward agricultural transitions is needed to ensure their success. These measures must be complemented by a political vision in addition to an effective allocation of competences at different levels of governance (Metz and Ingold, 2014). Since agricultural transitions appear particularly successful in decentralized countries that provide the necessary infrastructure, incentives, and regulation, shifting competences to regional levels should foster progression in agriculture, not least because challenges are best understood at the subsidiary level. Specifically, at the subjective level of the farmers, these challenges and opportunities must be reflected and translated into an awareness of the need for collaboration and individual engagement in such processes. Farmers should be open to agricultural transition but also taken seriously when they express skepticism because they are the change agents in this process. This two-way communication can be addressed by promoting empowerment through further education, consulting, and networking. In particular, the farmers' integration at the earliest phase of certain transitions must be promoted to foster legitimacy (de Boon et al., 2022b) and ensure social sustainability (Janker et al., 2019), among other issues.

This article adds an interdisciplinarity analysis of empirical data at the individual level (interviews) and the country level (institutions, policies, and processes) to the study of agricultural transition. However, the study also has some limitations to bear in mind when interpreting the results, which demonstrate the need for further research. For example, study 1 only presents the subjective and individual views of German sectoral actors concerning electrical field cultivation with an overrepresentation of academic actors, which may have resulted in a biased perception that overemphasizes some macro-level factors compared to others. However, the QCA results somewhat reduce concerns about bias by confirming the relevance of these conditions. In addition, the QCA only focused on macro-level factors (political institutions, policies, and processes) that were viewed as important at the micro level (farmers and sectoral actors). This limitation highlights the need for additional research projects to gather data types at different levels, such as interviews of individuals and aggregate data for countries and their subnational entities to integrate findings. The operationalization of the outcome of agricultural transition progress as an indicator of a successful transition within our study represents one of many possibilities and should be further validated. Mixed-method studies (for example, combining surveys, interviews, and focus groups) are highly encouraged. Accordingly, adding to in-depth investigations of farmers and sectoral actors, further actor groups such as the public should be included (see socio-political acceptance in the results section). Specifically, the meso level and its operationalization, such as via networks (Cofré-Bravo et al., 2019; Daugbjerg, 2018), should be subject to further studies, as well as the interaction between the individual perception of context factors (system understanding) and the actual influence of context factors on transitions. As a post-step of the presented QCA, cases that could not be explained by the presented pathways should be researched further, as should the mechanisms that link the pathways to the outcome. Lastly, we urge further integration of the psychological perspective within superordinate transition research at the intersection with political science.

## 6. Conclusion

Our studies reveal vital evidence on the interplay between micro- and macro-level factors that drive or impede agricultural transition progress toward sustainability. A central added value of interdisciplinarity lies in the explorative analysis of subjective and individual views on the conditions fostering successful agricultural transitions and their subsequent comparative and systematic verification across different country contexts. Thus, this investigation emphasizes incentives, institutions, and regulations, as well as the infrastructure-related factors mentioned by different actor groups. The comparative study reveals that these generally hold true in explaining successful agricultural transitions; nevertheless, characteristics of government and their strategies and foci as part of a transition process play an equal role. Further research is encouraged to add to these results by taking a closer look at in-depth country studies to provide complementary insights into micro and macro factors for successful transitions in many other fields in addition to agriculture.

## Author statement

**Madita Olvermann**: Data Curation, Formal analysis, Conceptualization, Methodology, Investigation, Validation, Project Administration, Writing – original draft, Writing – review & editing, Visualization, **Johanna Hornung**: Data Curation, Formal analysis, Methodology, Visualization, Validation, Writing – original draft **Simone Kauffeld**: Resources, Supervision, Funding acquisition, Validation.

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## Declaration of competing interest

The authors report no declarations of interest.

## Data availability

Data for study 1 is confidential because of personal information of interviewees, but can be made available in an anonymized format upon request. Data for study 2 is shared via an online repository.


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## Appendix

*A1. Sample Table*

* **criterion for farmers**: minimum of half-time employment in agriculture (general management of a farm was not a necessary criterion) * **criterion for actors from PRI**: minimum of half-time employment with direct relation to the agricultural sector in industry, public administration or science (e.g. agricultural engineering, agricultural chamber, or agricultural science).

| Code | Group of Actor | Type of Business/Profession | Type of interview (Live/Digital) |
|---|---|---|---|
| I1 | farmer | Crop cultivation | Digital |
| I2 | farmer | Livestock | Digital |
| I3 | farmer | Crop cultivation | Digital |
| I4 | farmer | Crop cultivation | Live |
| I5 | farmer | Mixed farming | Digital |
| I6 | farmer | Mixed farming | Digital |
| I7 | farmer | Crop cultivation | Digital |
| I8 | farmer | Crop cultivation | Live |
| I9 | farmer | Mixed farming | Digital |
| I10 | farmer | Mixed farming | Digital |
| I11 | farmer | Crop cultivation | Digital |
| I12 | farmer | Crop cultivation | Digital |
| I13 | farmer | Mixed farming | Digital |
| I14 | farmer | Mixed farming | Digital |
| I15 | farmer | Crop cultivation | Digital |
| I16 | farmer | Mixed farming | Digital |
| I17 | farmer | Mixed farming | Digital |
| I18 | farmer | Mixed farming | Digital |
| I19 | PRI | Science | Digital |
| I20 | PRI | Industry | Digital |
| I21 | PRI | Science | Digital |
| I22 | PRI | Science | Digital |
| I23 | PRI | Industry | Digital |
| I24 | PRI | Science | Digital |
| I25 | PRI | Public Administration | Digital |
| I26 | PRI | Public Administration | Digital |
| I27 | PRI | Science | Digital |
| I28 | PRI | Journalism | Digital |
| I29 | PRI | Public Administration | Digital |
| I30 | PRI | Science | Digital |
| I31 | PRI | Industry (Biogas installation/electrician) | Digital |
| I32 | PRI | Public Administration (fed. Government) | Digital |
| I33 | PRI | Science | Digital |

## A2. Interview Material

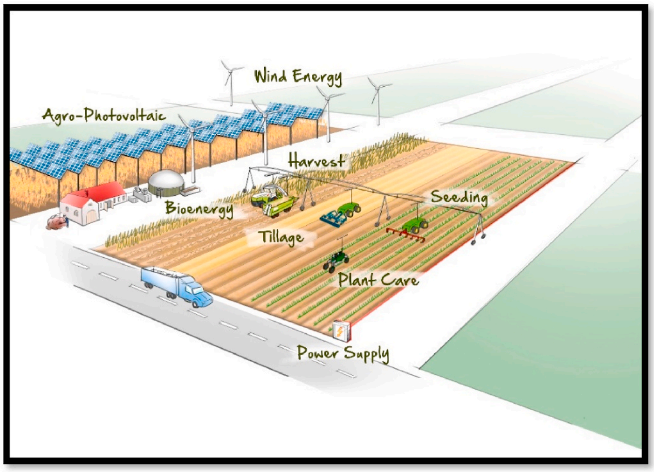


Illustration by Johanna Frerichs

**Explanation for Picture**: The picture shows a farm that cultivates its fields entirely without combustion engines. There are machines for harvesting, tillage and cultivation that are supplied, for example, via a power line. These machines are smaller than today's machines. There are also autonomous care robots for the field. At the edge of the field is a current transformer, which supplies the field with energy. The farm produces its own energy through biogas, agri-photovoltaic and wind energy, which can be used directly. This is meant to be an exemplary scenario. The impacts on humans and nature are not yet clearly visible here.

*A2a. Quantitative Analysis by Chi-Square for differences between actors*

| Dimension | Farmer (N = 18) | Sectoral Actors (N = 15) | total | p-value | $\chi^2$ |
|---|---|---|---|---|---|
| Context | 71 | 61 | 132 | .00 | 93.28 |
| Interpersonal | 19 | 14 | 33 | | |
| Individual | 16 | 21 | 37 | | |
| Total | 106 | 96 | | | |

*A2b. Quantitative Analysis by Chi-Square for differences between dimensions*

| Dimension | Farmers (N = 18) | Sectoral Actors (N = 15) | difference | p-value | $\chi^2$ |
|---|---|---|---|---|---|
| Context | 71 | 61 | 10 | .38 | 0.76 |
| Interpersonal | 19 | 14 | 5 | .38 | 0.76 |
| Individual | 16 | 21 | 5 | .41 | 0.68 |
| Total | 106 | 96 | | | |

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