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Drivers of Change: Experts' Perceptions of European Agri-Food and Livestock Farming Systems

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ABSTRACT

Transforming agri-food and livestock farming systems to increase their sustainability and climate resilience requires a clear understanding of what drives change and how driving forces are related. This study increases systems knowledge by identifying driving forces and actors that shape European agri-food and livestock farming systems, examining changes in experts' perceptions over a 5-year period, and exploring perceived relationships among the driving forces. We conducted semi-structured interviews and an expert workshop in two research phases and examined the collected data with a qualitative content analysis to identify driving forces, actors, and causal relationships. We then calculated three similarity coefficients to quantify the overlap between reported driving forces in these phases for each engaged organization and performed structural analyses of the empirically derived system diagram. In total, we identified 50 (79) driving forces for European agri-food (livestock farming) systems, 50%–71% of which were mentioned consistently in both phases. Four driving forces, namely the *European import of agricultural commodities, per-capita-meat demand, speed of agricultural technology development*, and *technology uptake*, were universally recognized as important by all participating experts in both phases. The study identified two additional promising drivers of change in livestock farming systems: *increasing political attention to climate change mitigation and adaptation* and *citizens' environmental awareness*. By integrating diverse perspectives, this study enhances our system-level understanding of drivers of change in European agri-food and livestock farming systems. This increased knowledge supports the alignment of agricultural and climate policies that can transform these systems, thus increasing their sustainability and climate resilience.

1 | Introduction

Agri-food systems, defined as the "range of actors and interlinked activities that add value in agricultural production and related off-farm activities" (FAO 2024, 1), are complex and develop rapidly and dynamically. In Europe, past developments have been shaped by productivity and efficiency paradigms characterized by high external inputs (e.g., synthetic pesticides, fertilizer, and energy), technological progress, reduced labor inputs, and structural and landscape change (Breustedt and Glauben 2007; Conti et al. 2021; McGreevy et al. 2022). A limited awareness of agricultural externalities, such as greenhouse gas emissions, soil degradation, species extinction, and the eutrophication of water bodies, combined with consumers' demand for cheap food, has largely favored intensive agricultural practices and specialization processes, as well as related business models, research, and development efforts (Conti et al. 2021). Recent developments reflect a shift in public discourse and social demands, indicating that the public has a greater interest in addressing pressing global challenges such as climate change and biodiversity loss (Obweger et al. 2024). These developments include changing demand patterns for food, feed, and bio-based materials (Aschemann-Witzel et al. 2021) and the implementation of impactful European strategies, regulations, and standards, including the European Green Deal, EU Biodiversity Strategy, and Nature Restoration Regulation. Multilateral trade agreements (e.g., with Mercosur) and technological advances, ranging from mechanization and digitalization to the introduction of artificial intelligence (King 2017; Asseng and Asche 2019; Sridhar et al. 2023; Vahdanjoo et al. 2025), are also reshaping agri-food systems. Specific developments relate to livestock farming systems (Van Zanten et al. 2019), not least due to their critically discussed impacts on environmental and human health (FAO 2006; Herrero et al. 2009; Leip et al. 2015; Poore and Nemecek 2018) and citizens' increasing demand for improved animal welfare standards (Grethe 2021; Birkle et al. 2022). These considerations are added to concerns about the large shares of (imported) cropland used for feed production (European Commission Joint Research Centre et al. 2024) and the fact that the livestock population exceeds the human population (Eurostat 2024), highlighting the social relevance of European livestock farming systems.

Driving forces and actors in past and recent developments (i.e., drivers of change) in agri-food and livestock farming systems, however, have not yet been systematically explored. Driving forces and actors shaping future developments are also inherently uncertain, and analyses have built on spatially explicit data and indicators. At the same time, the decisions of actors in agri-food and livestock farming systems are guided by their perceptions, experiences, and attitudes (Ajzen 1991; Ajzen 2020). For these reasons, we adopted a systemic approach toward gathering data on experts' perceptions and exploring drivers of change in European agri-food systems and the nested subsystem of European livestock farming. We investigated (i) driving forces and actors perceived by a diverse group of agri-food experts as influencing developments in European agri-food and livestock farming systems, (ii) how these perceptions changed over a period of 5 years, and (iii) causal relationships perceived by this group of experts among the identified driving forces of developments in European livestock farming systems.

Systematic analyses of driving forces are typically based on the general systems theory (Bertalanffy 1950; Von Bertalanffy 1972) and employ methods for identifying causal relationships in natural or human systems (Bürgi et al. 2005). According to the general systems theory, a system is defined by elements (i.e., driving forces and actors), functional relationships among these elements, a system boundary in spatial, temporal, and institutional scales, and interactions with other systems beyond defined boundaries (Bertalanffy 1950; Ossimitz et al. 2006). Previous research has examined driving forces of developments in specific subsystems of the agri-food system, such as the land use system or the mountain cattle farming system (García-Martínez et al. 2009; Jiménez-Olivencia et al. 2021). Investigations of driving forces have been conducted on a variety of scales, ranging from production units to nation states (spatial), months to decades (temporal), and groups of actors to nation states (institutional) (Bürgi et al. 2005). These studies have three limitations in common: (i) system and subsystem nesting (e.g., livestock farming systems being nested in agri-food systems) and cross-scale feedbacks were not consistently addressed, (ii) actors and their relationships to driving forces were under-represented, and (iii) driving forces were often assessed at a single timepoint (also in traditional futures and scenario exercises using an initial situation as a starting point; Wright et al. 2013; Mitter 2023). Few of these studies tracked how experts' perceptions changed over time (Plieninger et al. 2016; van Vliet et al. 2016).

Preferred methods for identifying driving forces of developments in agri-food systems often rely on the availability of spatially explicit data (e.g., satellite and aerial imagery) and target "proximate causes" (as compared to "underlying driving forces"; Meyer and Turner 1992; Geist and Lambin 2002). Proximate causes are defined as human activities or local actions having direct impacts on land use or production (Geist and Lambin 2002), such as urban and infrastructure development, agricultural expansion and intensification, and nature conservation (Plieninger et al. 2016). In comparison, underlying driving forces are fundamental processes motivating or enabling these activities and actions. These can include demographic trends, socio-cultural norms and consumer preferences, market and trade regimes (e.g., prices and costs), policy and institutional settings (e.g., payments under the Common Agricultural Policy CAP), and technological change (Geist and Lambin 2002). So far, most studies on driving forces of developments in agri-food systems have used quantitative methods (e.g., geospatial or statistical analysis and predictive modeling) to detect proximate causes in spatial or administrative datasets, based on data collected at one specific study site (Plieninger et al. 2016). Complementary literature reviews and meta-analyses have addressed specific topics, including the food system (Béné et al. 2019), agricultural land use change (van Vliet et al. 2015), tropical deforestation (Bernhard et al. 2024), grazing systems expansion and intensification (Godde et al. 2018), ecosystem services (IPBES 2019; Schirpke et al. 2023), and biodiversity loss (Isbell et al. 2023). Some authors have applied qualitative approaches, emphasizing context dependency and causal relationships between driving forces (Goertz and Mahoney 2012) at different scales (Plieninger et al. 2016; Bernhard et al. 2024). However, few studies have been conducted to systematically record experts' perceptions of driving forces in diverse types of organizations and pan-European region. Most research that has been conducted has examined the perceptions of farmers (Mohr et al. 2023), scientists (Kleemann et al. 2017), or actors in specific case study regions (Suškevičs et al. 2023). Few qualitative analyses of these data have been carried out, although these are equally important and should ideally be combined with quantitative data analyses, a consideration that underscores the need to conduct integrated research featuring different methods, scales, and perspectives (Bürgi et al. 2005; Mitter 2021).

Our study findings complement those of previous research and contribute to the literature in at least four ways:

First, we apply two philosophical frameworks in our study: *ontological relativism*, which holds that there is no single, objective reality independent of human perception, and *constructivist epistemology*, which holds that different individuals actively construct their own unique understandings based on experiences and prior knowledge. Previous research has generally applied either the framework of *ontological realism*, which holds that a single reality exists that can be measured and investigated, or that of *objectivist epistemology*, which holds that reality exists independent of consciousness, feelings, or wishes (Evely et al. 2008; Phoenix et al. 2013; Moon and Blackman 2014). In this study, we follow a perception-based approach and explore how experts with different backgrounds describe driving forces and causal relationships. Taking this qualitative approach enabled us to identify driving forces that may be difficult to quantify and allowed us to consider processes that go beyond administrative units commonly used in quantitative analyses.

Second, we focus on underlying driving forces and actors (i.e., drivers of change) that propagate change in European agri-food systems and the nested subsystems of livestock farming. Our study findings add to the literature on this topic, as previous studies have predominantly quantified selected proximate causes of change in subsystems at local to regional levels using spatial and administrative data while relevant actors were seldom analyzed explicitly. Few previous studies have examined the complexity of global agri-food systems in ways that enhance our understanding of the driving forces, including those by Ericksen (2008), HLPE (2017), and Béné et al. (2019). Here, we extend how agri-food systems are conceptualized by providing empirical, qualitative evidence from cross-national European experts that (i) reveals underlying driving forces in socio-economic, political, institutional, technological, and environmental contexts and (ii) identifies actors shaping European agri-food and livestock farming systems. We also build on forward-directed scenario exercises that have inventoried driving forces in European agri-food systems (Mitter et al. 2020; Nagesh et al. 2023) and contribute pan-European and actor-focused insights on the underlying driving forces to enrich these efforts.

Third, we examine changes over time by gathering data on the perceptions of experts from the same organizations 5 years apart, utilizing a panel-style research design rarely applied in this field. By examining changes in experts' perceptions over time, we broaden the general focus of preceding analyses conducted at a single point in time (Plieninger et al. 2016); this examination is of particular interest for the dynamically developing European agri-food system. The chosen 5-year interval was long enough for experts to register societal, market, and policy shifts, but short enough for us to track continuity in terms of system understanding. Methodologically, using this research design allowed us to quantify persistence and turnover in perceived driving forces and to identify emerging and fading issues. Substantively, it enabled us to uncover underlying driving forces seen as durable or volatile.

Fourth, we describe and quantify the structure of European livestock farming systems, a task that has rarely been tackled in perception-based approaches. We summarize structural characteristics of European livestock farming systems (e.g., density and centrality) and classify system elements as active, passive, critical, or buffering. While previous studies identified driving forces and discussed causal relationships without reporting structural metrics (Béné et al. 2019; Ericksen 2008; HLPE 2017; Mitter et al. 2020; Nagesh et al. 2023), our approach concisely characterizes the perceived structure of European livestock farming systems, helping us pinpoint levers of change and early warning signals for potential changes.

The article is structured as follows: in Section 2, we introduce the concepts of driving forces and actors, which informed the data collection in two empirical research phases and the data analysis. In Section 3, we present agri-food experts' perceptions of drivers of change of European agri-food and livestock farming systems, including changes over time and relationships among the driving forces. In Section 4, we discuss driving forces that share specific characteristics that we have identified as levers of change or early warning signals for potential changes. In Section 5, we draw conclusions for science-policy interaction and suggest future research steps.

2 | Materials and Methods

2.1 | Theoretical Concepts

Driving forces and actors are the main theoretical concepts directing empirical data collection and analysis. In agri-food and livestock farming systems, driving forces have been defined as factors, (recurring) events, or processes that exert an observable effect lasting a certain period of time and leading to considerable and enduring changes in or transformations of a system (Béné et al. 2019). These forces can emerge at various spatial, temporal, or institutional scales and may thus be internal (intrinsic and endogenous) or external (extrinsic and exogenous), depending on the system boundary of interest (Bürgi et al. 2005; Béné et al. 2019). Two or more driving forces may occur simultaneously and potentially affect each other (cross-effects); acute crises or sudden shock events are only considered driving forces if they have a persistent effect on the system of interest (Bürgi et al. 2005; Béné et al. 2019). For example, Béné et al. (2019) use the topical example of food price volatility to explain that a price shock with a limited duration resulting from a specific event does not qualify as a driving force, while the long-lasting effects of continuous price volatilities could be considered a driving force.

The literature includes the terms *proximate causes* and *underlying driving forces* and distinguishes between these: Proximate causes refer to human activities or immediate actions occurring at the local level, and underlying driving forces refer to fundamental socio-economic or environmental factors, (recurring) events, or processes that bring about change (Geist and Lambin 2002; van Vliet et al. 2016). The latter have been assigned to five thematic categories with reference to agri-food systems and related subsystems: *population and urbanization*; *economy*; *policies and institutions*; *technology*; and *environment and natural resources* (Mitter et al. 2020; Karner et al. 2024). Alternative categories have been suggested in the literature and are summarized in the Supporting File S1.

Actors may be individuals or collectives (Borgatti et al. 2018) who/that have the capacity to directly or indirectly influence the system of interest (Kok et al. 2006), drive gradual or abrupt change (Rotmans et al. 2000), or serve as moderators between underlying driving forces and proximate causes (van Vliet et al. 2016).

For example, governmental bodies at various levels, businesses, non-profit organizations, and scientists have been recognized as key actors, directly or indirectly influencing continuous processes of land use change and land degradation in the Mediterranean (Kok et al. 2006). Farmers have also been identified as important moderators between underlying driving forces and realized land use changes, which differ according to the farm type and farmers' attitudes, age, and motivation for farming (van Vliet et al. 2015; van Vliet et al. 2016).

Actors are often grouped into the following categories: industry entities and public enterprises representing the socio-economic domain; governmental bodies representing the political, administrative, and legal domain; media, advocacy groups, and non-profit organizations representing the socio-cultural domain; and academic institutions representing the educational domain (Etzkowitz and Leydesdorff 2000; Carayannis and Campbell 2009; Carayannis and Campbell 2012). For our research, we adopt a broad definition of actors representing the systems of interest in their entirety. Hence, this encompasses a spectrum of actors who operate at local to global levels, irrespective of their interests, objectives, responsibilities, legal status, or authority, but who (have the potential to) influence European agri-food and livestock farming systems.

2.2 | Data Collection

We conducted semi-structured interviews and a workshop with experts from European industry entities and public enterprises, governmental bodies, advocacy groups, non-profit organizations, and academic institutions. Our analysis of the empirical dataset collected in the interviews enabled us identify perceived drivers of change in European agri-food and livestock farming systems and how these perceptions changed over time. The collection of empirical data in the expert workshop enabled us to perform a structural analysis of experts' perceptions of European livestock farming systems. The interview partners and workshop participants were purposively sampled for maximum variation in (i) knowledge and expertise in agri-food and livestock farming systems, (ii) type of organization represented, and (iii) primary geographical scope of the organizations' activities. For descriptive purposes, we classified the participating organizations as "European" or "national" based on their primary geographical scope of operation (Table 1); however, all interview partners were asked to respond at the European level when answering the same core questions.

The interviews were conducted in two research phases (RPs) in 2018 and 2023 (Table 1 and Supporting File S2). In RP1 (2018), 49 organizational representatives participated: 20 from organizations with a European scope and 29 from those operating mainly at the national level. In RP2 (2023), we conducted 20 interviews with 23 experts. Of these experts, four represented organizations with a European scope and 19 represented those operating mainly at the national level. Representatives of seven organizations contributed to both RPs: one with a European scope and six with a primarily national scope. A set of core questions was asked in both RPs to identify perceived driving forces of developments in European agri-food systems (in general). We used our thematic categories of driving forces to structure the core questions into sub-questions in both RPs. The interview guide was complemented with questions about European livestock farming in RP2. In all interviews, sub-questions could be asked to encourage the interview partner and request more detail where needed. The interview guides for RP1 and RP2 are provided in the Supplementary Material (Supporting File S2).

In the second RP, we organized an expert workshop with 16 participants from governmental bodies and academic institutions. The goal of this workshop was to build a shared understanding of European livestock farming systems and to identify perceived causal relationships among driving forces. This workshop was held in person and comprised plenary sessions and a facilitated group activity. In the first plenary session, the research initiative, the workshop objectives and agenda, and the group activity were explained. The participants were then randomly assigned to three approximately equally sized groups and asked to engage in a four-step group activity. At each step, guiding questions and illustrations were provided on slides and printed posters to structure the discussion and interactions. The first and second steps were dedicated to identifying driving forces of developments in European livestock farming systems

TABLE 1 | Number of interviews by type of organization, primary geographical scope of the organizations' operation, and research phase.

	Research phase					
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Type of organization/Primary scope of operation	**Eur**	**Nat**	**Eur**	**Nat**	**Eur**	**Nat**
Industry entities and public enterprises	1	7	0	4	0	1
Governmental bodies	6	5	1	0	1	0
Advocacy groups	4	5	3	5	0	1
Non-profit organizations	7	6	0	4	0	3
Academic institutions	2	6	0	3	0	1
Total	**20**	**29**	**4**	**16**	**1**	**6**

Note 1: Primary geographical scope of the organizations' operation: Eur = European, Nat = National.
Note 2: The number of interview partners was lower in RP2 for two main reasons: First, some experts who we re-invited for an interview in RP2 had changed their affiliation or were not available for an interview, mostly due to the additional thematic focus on European livestock farming systems; second, the interviews were complemented by an expert workshop in RP2. Hence, we organized fewer interviews to reduce the time and effort required for the participants and in light of the limited project resources and research design; therefore, the interviews were conducted and the resulting data were analyzed before the expert workshop. In total, 36 participants engaged in RP2, taking part either in a semi-structured interview or in the expert workshop.

and to causal relationships among these. The third and fourth steps were dedicated to identifying actors shaping the European livestock farming systems and their interactions with the driving forces. The groups documented their discussions by developing a system diagram. Results were shared in a short plenary debrief, followed by concluding remarks and feedback. Four moderators supported the expert workshop: one per group to guide the process and a fourth to facilitate the plenary discussion, answer general questions, and for timekeeping. All interviews and the expert workshop were audio-recorded and transcribed. Automatic speech recognition supported the transcription. All AI-generated transcripts were manually checked and corrected word-for-word against the audio for accuracy, as their quality was insufficient. The system diagrams drawn during the expert workshop were digitized using yED Graph Editor. The workshop agenda, stepwise tasks, and guiding questions are provided in the Supplementary Material (Supporting File S2).

2.3 | Data Analysis

We analyzed the qualitative interview dataset in four steps. First, deductive coding was performed, guided by the theoretical concept of driving forces presented in Section 2.1. The five thematic categories of *population and urbanization*, *economy*, *policies and institutions*, *technology*, and *environment and natural resources* (as suggested by Mitter et al. 2020) were applied as primary codes to relevant passages in the interview transcripts. Based on the work of Mohr et al. (2023), we coded an expert's statement as a driving force when it (i) referred to a specific change in agri-food or livestock farming systems and (ii) ascribed a specific reason for or cause of that change. In addition, we used primary codes for actor groups in European agri-food and livestock farming systems, including the following domains: socio-economic; political, administrative and legal; socio-cultural; and educational.

Second, subcodes that reflected a specific driving force within one of the five thematic categories were iteratively and inductively developed based on the interview data coded in the first step, applying the principle of openness (Flick 2014). For instance, for the thematic category *population and urbanization* (i.e., primary code), the subcode *citizens' environmental awareness* was identified. The driving forces of developments in agri-food systems were derived from the findings of RP1 (Mitter et al. 2020) and complemented with agri-food and livestock farming system-specific findings from RP2. Third, we defined the primary codes and subcodes to ensure their consistent application to the empirical interview data throughout the research process, strengthen intra- and intercoder reliability, and facilitate clear and effective communication of the results (Miles et al. 2013). For instance, the subcode *citizens' environmental awareness* was defined as the "share of the European population that takes environmental considerations into account when fulfilling basic needs and taking related decisions." Fourth, we refined the codes to improve their fit with the interview data. We specified codes initially assigned to overly long text passages and discarded codes applicable only to small subsets of the interview dataset while maintaining a coherent code structure (Miles et al. 2013). In addition, we refined code definitions to capture the details observed in the interview data, which also enabled us to comprehensively analyze the identified themes. For instance, we added the examples of housing, mobility, and consumption to the definition of the *citizens' environmental awareness* subcode based on the collected data. Atlas.ti was used as a text analysis software in the data analysis process (Friese 2012).

To track changes in perceived driving forces over time, we compared the results from the seven organizations that contributed to RP1 and RP2, examining which driving forces they reported. We calculated three similarity coefficients (Özesmi and Özesmi 2004) based on the presence/absence of each driving force in the organizations' responses. The first similarity coefficient reports the overlap among driving forces mentioned in both RPs. This was 100% if the organization named exactly the same set of driving forces in RP1 and RP2, and 0% if no overlap was recognized. The second similarity coefficient reflects the overall consistency of the reported driving forces relative to the driving forces identified in RP1. This coefficient indicates how often (as a percentage of cases) the organization responded in the same way in both RPs (i.e., either mentioning a driving force in both RPs or not mentioning it in either RP), considering all driving forces identified in RP1 across all interviews. The third similarity coefficient reflects the consistent non-mention, relative to the driving forces identified in RP1. It provides the percentage of cases in which the organization did not mention a driving force in either RP1 or RP2, across all RP1 driving forces and all interviews. Interview partners could report or not report driving forces for different reasons. We strove to create similar interview settings in both RPs (as described in the previous section), and we carefully analyzed the collected interview data to identify mentioned driving forces and reasons why the participants considered them relevant at the time of the interview. However, two points should be considered: First, the interviews in RP2 had a broader focus (including livestock farming systems) than those in RP1, which may have influenced how individual driving forces were (not) reported; second, we were not able to determine why certain driving forces were not reported by the interview partners in any of the RPs.

Data on perceived relationships between driving forces and structural characteristics of European livestock farming systems were collected in the expert workshop in three steps. First, the workshop transcripts were analyzed qualitatively using protocol and causation coding (Miles et al. 2013; Saldaña 2016) and the text analysis software Atlas.ti. This software was used to code driving forces and relationships between them. The codes derived from the semi-structured interviews served as the recommended coding system (for reasons of consistency) and were applied to the workshop transcripts (i.e., protocol coding). Several new driving forces specific to European livestock farming systems were identified in the expert workshop and were added to the list of driving forces. Causation coding was used to detect perceived relationships between the driving forces by identifying when participants explicitly stated that one driving force influences another. We identified such causal statements in the workshop transcripts by recognizing specific types of causal clauses (i.e., causal, conditional, consecutive, concessive, final, and restrictive) and related signal words (e.g., because of, if – then, as a result of, even though – but, in order to; Karner and Mitter 2024; Bolkart 2025). For example, "stricter animal welfare standards are a result of public demand for higher animal welfare" was coded as a positive causal relationship between citizens' awareness of animal welfare and animal welfare standards. The causal relationships identified from the analysis of the workshop transcripts were cross-checked against the system diagrams produced in the expert workshop. Some adjustments were made to incorporate all details and ensure the consistent interpretation of these relationships.

Second, when possible, each causal relationship was assigned a positive (+) or negative (−) sign to reflect the direction of the perceived effect. A positive sign indicates a reinforcing effect (i.e., an increase in the sender tends to increase the receiver, or a decrease in the sender tends to decrease the receiver). A negative sign indicates the opposite effect (i.e., an increase in the sender tends to decrease the receiver or vice versa). The assignment of signs was based on the participants' verbal expressions. Where the direction of the effect was unclear or contingent, the causal relationship was recorded without a sign and noted as neutral in the coding process.

Third, the results of the qualitative analysis of the workshop material were transferred into a matrix. This lists the previously identified driving forces for the development of European livestock farming systems in the rows and the columns (i.e., a square matrix). The rows represent senders, and the columns represent the receivers of the respective causal relationships. In each cell, we recorded whether a direct causal relationship was identified between two driving forces: 1 denotes a direct causal relationship, and 0 denotes no direct causal relationship (i.e., a binary matrix). Bidirectional relationships are represented as two separate, directed entries where applicable (i.e., A → B and B → A occupy different cells in the matrix). Multiple causal relationships are represented as multiple non-zero entries. Indirect effects are considered conceptually (Levy et al. 2018), but only direct causal relationships were entered into the matrix to avoid counting items twice.

Fourth, the matrix served as a basis for the structural analysis of the European livestock farming systems. The structural characteristics include the size, density, and complexity of the system of interest. Size is the number of system elements (i.e., driving forces). Density is the proportion of identified direct causal relationships among all possible causal relationships. This value was calculated as the number of causal relationships documented in the matrix, divided by the maximum number of possible causal relationships (Harary and Hage 1984; Özesmi and Özesmi 2004). In practical terms, the density indicates the completeness of the system. Higher density indicates a more tightly coupled system with more pathways via which changes can propagate. Complexity is the ratio of the receiver to transmitter variables, where receiver variables were defined as driving forces with a positive indegree and an outdegree of zero, and transmitter variables were defined as driving forces with a positive outdegree and an indegree of zero (Özesmi and Özesmi 2004). A higher receiver-to-transmitter ratio suggests that the system has many potential outcomes shaped by comparatively few primary driving forces.

The outdegree and indegree are structural characteristics inherent to the individual driving forces. The outdegree is the number of driving forces influenced directly by a specific driving force (i.e., the row sum in the matrix developed in the third step). It indicates the cumulative strength of the relationships among the individual driving forces (Borgatti et al. 2018). The indegree is the number of driving forces exerting a direct influence on a specific driving force (i.e., the column sum in the matrix). It indicates the number of incoming relationships a specific driving force has (Borgatti et al. 2018). Put simply, a driving force with high outdegree can push change in many parts of the system, while a driving force with high indegree is strongly influenced by conditions elsewhere. The sum of the outdegree and indegree of a driving force reveals its interconnectedness within the system and is defined as centrality for this analysis (Özesmi and Özesmi 2004).

The outdegree and indegree were used to calculate two summary indices for each driving force, namely the interaction and activity indices, which are depicted in the influence matrix. The interaction index demonstrates indirect effects and is calculated as outdegree times indegree. A high interaction index indicates strong interconnectedness; the specific driving force strongly influences others and is strongly influenced by others (i.e., it sends and receives many influences and can be considered a central element where indirect effects can accumulate and cascade). The activity index demonstrates direct effects and is calculated by dividing the outdegree of a specific driving force by its indegree. An activity index >1 indicates a driving force that exerts more influence than it receives. An activity index <1 indicates a driving force that is more influenced than influential. For example, a driving force assigned to the thematic category *policies and institutions*, such as a carbon price may influence many other driving forces (e.g., *variable costs of livestock production* and *prices of animal-based food products*), while being influenced by a low number of other driving forces. This would result in an activity index above 1 and suggest leverage for instigating change. Conversely, a driving force such as *farmers' average income* may be shaped by many driving forces, but directly influence only a few system elements. This would result in an activity index below 1, signaling higher sensitivity to change.

The influence matrix was used to identify and document active, passive, critical, and buffering elements. Active elements have a high activity index and can serve as levers for change because they exert significant effects on other driving forces. By strategically focusing on these active elements, challenges may be effectively managed, and desirable change may be initiated. Passive elements have a low activity index. They may exert a limited amount of influence on their own, but are primarily useful as sensitive indicators of shifts in system dynamics. While they may not be the primary drivers of change, their responses to environmental variations provide valuable insights and serve as early warning signals for potential systemic changes or disruptions. Monitoring these passive elements may help to predict and prepare for future developments. Critical elements are highly interconnected (having high centrality and often a high interaction index) and are essential for system behavior and functionality. Changes or disruptions in critical elements tend to send ripple effects throughout the system due to their interconnectedness. Buffering elements stabilize the system by absorbing fluctuations, dampening responses to disturbances, and thereby delaying potentially harmful or beneficial effects.

3 | Results

3.1 | Perceived Driving Forces of Developments in European Agri-Food Systems and Their Changes Over Time

The perceived driving forces shaping the European agri-food systems were assigned to five thematic categories: *population and urbanization* (P&U); *economy* (E); *policies and institutions* (P&I); *technology* (T); and *environment and natural resources* (E&N). Table 2 shows the 50 driving forces identified in RP1 and found again in RP2. Economic driving forces (E) were the most numerous ($n = 20$), followed by P&I ($n = 13$), P&U ($n = 11$), T ($n = 3$), and E&N ($n = 3$). Table 2 shows that all 50 driving forces were addressed in both RPs, with more total mentions in RP2. This pattern aligns with the interview partners' perception that agri-food systems are becoming more complex and interconnected. However, the interview partners in both RPs emphasized regional differences between driving forces and related changes in the agri-food systems. Ten driving forces were reported by exactly the same interviewed organizations in both RPs, indicating that these remained relevant over time: *average educational level of society* (8P&U), *economic growth rate* (14E), *European import/export of agricultural commodities* (16E/17E), *meat demand per capita* (21E), *amount of food waste per capita* (24E), *public payments for investments or technology development* (44P&I), *speed of agricultural technology development* (45T), *technology uptake in agriculture* (46T), and *technology acceptance by producers and consumers* (47T). Of these, four driving forces were mentioned by all interview partners in both RPs, reflecting strong agreement on their importance, namely *European import of agricultural commodities* (16E), *meat demand per capita* (21E), *speed of agricultural technology development* (45T), and *technology uptake in agriculture* (46T) (see Table 7 in the Supporting File S1).

To analyze the continuity and change in perceived driving forces at the organization level, we compared data from seven organizations that participated in both RPs using three similarity coefficients (described in Section 2.3). First, 50%–71% of the driving forces mentioned by an organization in either RP were also mentioned by the same organization in both RP1 and RP2. This overlap highlights driving forces regarded by each organization as important in both periods. Second, considering a set of driving forces identified in RP1 in all interviews and used as a common reference, 60%–78% were treated consistently by each organization (i.e., either mentioned (or not) in both RPs), indicating a substantial stability in organizational perspectives over time. The share of repeatedly reported driving forces per thematic category differs according to the type of organization. When compared to the other types of organizations, this share is highest for P&U for the academic institution and advocacy group; for E and T for the industry entities and public enterprises, and the non-profit organizations; and for P&I for the governmental body. All types of organizations have approximately the same share of driving forces from the thematic category E&N. Third, individual organizations did not mention 16%–40% of the RP1 set of driving forces in either RP. Five interview partners (IP1, 3–4, and 6–7) provided more detailed responses in RP2 than in RP1, while two interview partners (IP2 and 5) were more concise, which suggests that the variety of driving forces mentioned can also differ depending on the interview setting and individual context. The exact matches are provided in Table 8 in the Supporting File S1.

In RP1, nine driving forces were mentioned by at least six of the seven interview partners. In RP2, this number doubled, including the nine driving forces mentioned in RP1, with two driving forces mentioned substantially more often (at least three more mentions) in RP2 than in RP1. The strong level of agreement between the interview partners regarding specific driving forces may underscore their relevance. For example, *citizens' environmental awareness* (7 P&U), *European import/export of agricultural commodities* (16E/17E), *meat demand per capita* (21E), *agri-environmental payments* (42 P), *speed of agricultural technology development* (45 T), *technology acceptance* (47 T) and *uptake in agriculture* (46 T), as well as *resource depletion* (48E&N) were widely cited in RP1 and continued to be cited frequently in RP2 (see Table 9 in the Supporting File S1). Two economic driving forces, namely *European trade of agricultural inputs* (15E) and *diversity of agricultural supply chains* (18E), were mentioned substantially more often in RP2 than in RP1. The interview partners linked 15E and 18E to recent, concrete developments they expected to have lasting effects, including supply chain disruptions during the pandemic and major shipping incidents, as well as civil efforts to shorten and diversify supply chains, in particular under the European Commission's Farm to Fork Strategy.

In all thematic categories, the interview partners provided more specific information in RP2 than in RP1. In P&U, *citizens' environmental awareness* (7 P&U) was addressed in both RPs. In RP2, it was complemented by explicit references to *citizens' awareness of health and animal welfare*, as reflected in the addition of related driving forces in all thematic categories. Regarding the demand-related driving forces (E), respondents contrasted the rising demand for quality products – often defined by citing attributes such as health and animal welfare – with the continued demand for highly processed food products. Regarding standards (P&I), *animal welfare standards* were discussed along with *environmental and food standards*. In *technology* (T), the interview partners emphasized food technology development, and especially the development of plant-based food products, in addition to agricultural technology development.

The following examples of associations were recorded for the first time in RP2, addressing individual driving forces: *Population size* (1 P&U) with migration flows; *individual farmers' social status in society* (9 P&U) with the appreciation of agricultural work by consumers, which was frequently mentioned during the 2023 farmer protests; the *European trade of agricultural inputs* (15E) with the EU Regulation on Deforestation-free Products (published in 2023); *political stability* (32 P&I) with Brexit (January 2020) and the Russian invasion of Ukraine (February 2022). One particularly interesting "first-time" example is that of the *socio-environmental focus of agri-food*

TABLE 2 | Driving forces of developments in European agri-food systems perceived by interviewed experts from the same organizations (IP) in the two research phases (1 and 2).

	Research phase	**1**							**2**						
ID	**Driving force** **IP**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1 P&U	Population size	x	/	x	/	x	/	x	x	/	x	x	x	x	x
2 P&U	Percentage of people living in urban areas	/	x	/	/	x	/	x	x	/	/	/	/	x	/
3 P&U	Pace of urbanization	/	x	/	/	/	/	/	x	/	/	/	/	/	/
4 P&U	Infrastructure development in rural areas	x	x	/	/	/	/	/	x	/	/	/	/	/	/
5 P&U	Urban-rural linkages	x	x	x	/	x	/	x	x	x	x	x	/	/	x
6 P&U	Levels of social tension and conflict	/	x	x	/	/	/	/	/	/	/	x	/	x	/
7 P&U	Citizens' environmental awareness	x	x	x	/	x	x	x	x	x	x	x	x	x	x
8 P&U	Average educational level of society	x	/	/	/	/	/	x	x	/	/	/	/	/	x
9 P&U	Individual farmers' social status in society	x	x	/	/	x	/	x	x	x	/	/	/	x	x
10 P&U	Average age of farming population	/	/	x	/	x	/	/	x	/	x	x	/	x	x
11 P&U	Average educational level of the farming population	x	/	/	/	x	/	x	x	/	x	/	/	/	x
12 E	Market integration	x	/	/	/	x	x	x	x	/	x	/	/	x	x
13 E	Market concentration in the up- and downstream sector	x	/	/	/	x	/	x	x	/	/	x	/	x	x
14 E	Economic growth rate (GDP-PPP)	/	/	x	/	/	/	x		/	x	/	/	/	x
15 E	European trade of agricultural inputs	/		x	/	/	x	/	x	/	x	x	x	x	x
16 E	European import of agricultural commodities	x	x	x	x	x	x	x	x	x	x	x	x	x	x
17 E	European export of agricultural commodities	x	x	x	x	x	x	/	x	x	x	x	x	x	/
18 E	Diversity of agricultural supply chains	x	/	/	x	x	/	x	x	x	x	x	x	x	x
19 E	Pace of structural change in agriculture	x	x	x	x	/	/	x	x	x	x	x	/	x	x
20 E	Demand for non-food agricultural commodities	/	/	x	x	x	/	/	x	/	/	x	/	/	/
21 E	Meat demand per capita	x	x	x	x	x	x	x	x	x	x	x	x	x	x
22 E	Demand for feed	/	/	x	x	x	x	/	x	x	x	x	x	/	/
23 E	Demand for regulation and cultural services from the agricultural sector	x	x	x	x	x	/	/	x	/	x	x	x	/	x
24 E	Amount of food waste per capita	/	x	/	/	x	/	/	/	x	/	/	x	/	/
25 E	Relative prices for agricultural inputs	/	/	/	/	x	x	/	x	/	/	x	x	x	/
26 E	Relative prices for natural resources	/	/	x	/	/	/	/	/	/		x	/	/	/
27 E	Labor supply in agriculture	/	/	/	/	x	/	/	/	/	x	x	/	x	/
28 E	Required skills and knowledge of agricultural labor	x	x	/	/	x	/	x	x	x	x	x	/	x	x
29 E	Labor productivity	x	x	/	x	x	/	/	x	x	x	/	/	/	/
30 E	Land productivity	x	/	/	/	/	/	x	/	/	x	/	x	/	x
31 E	Relative prices of agricultural commodities	x	x	x	x	x	/	/	x	/	/	x	x	x	x
32 P&I	Political stability	x	/	x	/	x	x	x	x	/	x	x	x	x	x
33 P&I	Effectiveness of European institutions	/	x	x	/	x	/	x	x	/	x	/	/	/	x
34 P&I	Multilevel cooperation	/	x	x	/	x	/	x	x	/	x	/	/	/	x
35 P&I	Societal participation	/	/	/	/	x	/	x	/	/	/	x	/	/	x
36 P&I	International trade agreements	x	x	x	/	x	x	/	x	/	x	/	x	x	x
37 P&I	Relative importance of European agri-food policy	x	x	x	x	/	x	/	x	x	x	x	x	x	
38 P&I	Socio-environmental focus of agri-food policies	x		x	x	x	/	x	x	/	x	x	x	x	x
39 P&I	Environmental standards	/	/	/	x	x	x	x	/	x	x	x	x	x	x
40 P&I	Food standards	/	/	x	/	/	x	x	x	/	x	/	/	x	x
41 P&I	Direct payments	/	/	x	/	x	x	/	x	/	x	/	/	/	x
42 P&I	Agri-environmental payments	x	x	x	x	x	x	/	x	x	x	x	/	x	x
43 P&I	Public payments for rural development and less-favored areas	x	x	x	/	/	/	/	x	/	x	/	/	/	x

(Continues)

TABLE 2 | (Continued)

	Research phase	1							2						
ID	**Driving force** **IP**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
44 P&I	Public payments for investments or technology development	/	/	x	/	/	/	/	/	/	x	/	/	/	/
45 T	Speed of agricultural technology development	x	x	x	x	x	x	x	x	x	x	x	x	x	x
46 T	Technology uptake in agriculture	x	x	x	x	x	x	x	x	x	x	x	x	x	x
47 T	Technology acceptance by producers and consumers	x	x	x	x	x		x	x	x	x	x	x		x
48 E&N	Resource depletion	x	x	x	x	x	x	/	x	x	x	x	x	x	x
49 E&N	Resource use efficiency	x	x	x	/	x	x	/	x	x	x	/	/	/	x
50 E&N	Occurrence of invasive species	x		/	/	x	/	/	x	/	x	/	x	/	/
Total count of "x"		**31**	**27**	**32**	**18**	**37**	**19**	**26**	**41**	**20**	**37**	**30**	**23**	**28**	**35**

Note: The ID provides a consecutive count of the driving forces, which are assigned to the five thematic categories of population and urbanization (P&U); economy (E); policies and institutions (P&I); technology (T); and environment and natural resources (E&N). An "x" indicates that the interview partners stated the driving force in the respective research phase. A slash "/" indicates that the interview partners did not state the driving force in the respective research phase.

policies (38 P&I), which was associated with the European Green Deal (approved in 2020), its Farm to Fork Strategy and its Biodiversity Strategy for 2030, the Nature Restoration Regulation (entering into force in 2024 as a key element of the EU Biodiversity Strategy), the European Protein Strategy resolution (adopted by the European Parliament in 2023), and the Eco-schemes (introduced in the CAP period 2023–2027).

3.2 | Perceived Driving Forces of Developments in European Livestock Farming Systems and Their Relationships

The participating experts described 79 driving forces that they perceived as shaping European livestock farming systems, including driving forces of developments in European agri-food systems (Table 3). Most driving forces were assigned to the thematic category of E ($n = 28$), followed by P&I ($n = 18$), T ($n = 15$), P&U ($n = 11$), and E&N ($n = 7$). Of these driving forces, 16 reflect those of the European agri-food systems suggested in RP1 (indicated by the prefix AFS-RP1 in Table 3). The emphasis on the pertinence of driving forces for both European agri-food and livestock farming systems underlines their interconnectedness.

Another 22 driving forces assigned to the categories of P&U, E, P&I, and T specify driving forces of developments in European agri-food systems, which also stresses the nested nature of agri-food and livestock farming systems. For instance, the new driving force *food literacy of consumers* (05 P&U) specifies the *average educational level of society* (8 P&U in Table 2), while the *European export of animal-based food products* (14E) and *European export of animal feed* (15E) specify the *European export of agricultural commodities* (17E in Table 2). Other examples refer to *technology uptake in agriculture* (46 T in Table 2) and *speed of agricultural technology development* (45 T in Table 2). The first is specified with *degree of automatization in livestock farming systems* (63 T), *use of climate-friendly technologies for fertilizer application* (65 T), *use of fossil-fuel based machinery* (66 T), and *use of technologies for animal health* (67 T). The second is specified with *interoperability of technologies* (69 T), *climate-adaptive breeding* (70 T), and *animal feed efficiency* (71 T). For a full overview, the interested reader is referred to Table 10 in the Supporting File S1. The remaining 33 driving forces were newly identified and, in part, specific to European livestock farming systems, such as *regional manure trading systems* (39E), *manure management efficiency* (72 T), and *availability and quality of organic fertilizers* (78E&N).

The perceived causal relationships among the driving forces of developments in European livestock farming systems are recorded in a square matrix (see Supporting File S3), which provides the basis for calculating the structural characteristics of the system and its driving forces, as summarized in Table 4. The size of the system is 79. A total of 327 causal relationships were reported by the participants, yielding an average of 4.1 relationships per driving force. The density describes the system's connectivity, and it is 0.053 in our analysis, that is, 5.3% of the possible total relationships (100%) are present. In addition, we find one transmitter, six receivers, and 72 ordinary variables for the European livestock farming system. The transmitter variable is *citizens' average income* (20E), and the receiver variables are *European export of animal feed* (15E), *labor supply in agriculture* (24E), *per capita demand for highly processed food products* (29E), *relative prices of livestock breeding technology* (36E), *international standards for carbon sequestration* (44 P&I), and *speed of technology development for plant-based food products* (59 T). The low number of transmitter variables (i.e., 1) reflects a conception of the system without pronounced hierarchies, and the low number of receiver variables (i.e., 6) underlines the focus on driving forces. Similarly, the low calculated complexity indicates the power of the primary driving forces.

With respect to the structural characteristics specific to the driving forces, Figure 1 shows the driving forces with the highest outdegrees (min. 7) and the highest indegrees (min. 6). Two driving forces in each of the categories of *population and urbanization* and *policies and institutions* (02 P&U, 07 P&U, 40 P&I, and 48 P&I) are perceived as exerting the highest influence on other driving forces (i.e., highest outdegrees). Three economic driving forces (31E, 32E, and 35E), however, are perceived as influenced by the highest number of other driving forces (i.e., the highest indegrees). Hence, *citizens' environmental awareness* (02 P&U), *social pressure for sustainable livestock farming systems* (07 P&U), *environmental standards*

TABLE 3 | Perceived driving forces of developments in European livestock farming systems.

ID	Driving force	Outdegree	Indegree	Centrality	Activity index	Interaction index
01 P&U	AFS-RP1: Urban-rural linkages	1	1	2	1.0	1
02 P&U	AFS-RP1: Citizens' environmental awareness	15	2	17	7.5	30
03 P&U	Citizens' awareness of animal welfare	7	4	11	1.8	28
04 P&U	AFS-RP1: Individual farmers' social status in society	5	4	9	1.3	20
05 P&U	Food literacy of consumers	10	4	14	2.5	40
06 P&U	Consumers' attention to ecolabels	3	6	9	0.5	18
07 P&U	Societal pressure for sustainable livestock farming systems	13	5	18	2.6	65
08 P&U	Attractiveness of circular farming for farmers and citizens	4	7	11	0.6	28
09 P&U	Living standards of farmers and agricultural labor	2	5	7	0.4	10
10 P&U	Farmers' intrinsic motivation for farming	7	5	12	1.4	35
11 P&U	Farmers' technology expertise	4	5	9	0.8	20
12E	AFS-RP1: Market integration	10	3	13	3.3	30
13E	AFS-RP1: Diversity of agricultural supply chains	3	6	9	0.5	18
14E	European export of animal-based food products	1	6	7	0.2	6
15E	European export of animal feed	0	4	4	0.0	0
16E	European import of animal-based food products	1	7	8	0.1	7
17E	European import of animal feed	1	4	5	0.3	4
18E	AFS-RP1: Pace of structural change in agriculture	4	3	7	1.3	12
19E	Working conditions of farmers and agricultural labor	5	6	11	0.8	30
20E	Citizens' average income	10	0	10	NA	0
21E	Farmers' average income	3	2	5	1.5	6
22E	Agricultural laborers' average income	5	3	8	1.7	15
23E	Income equality	1	6	7	0.2	6
24E	AFS-RP1: Labor supply in agriculture	0	4	4	0.0	0
25E	Demand for biogenic resources for biogas production	1	3	4	0.3	3
26E	Per capita demand for animal welfare products	3	5	8	0.6	15
27E	Per capita demand for conventional animal-based food products	3	6	9	0.5	18
28E	Per capita demand for cultivated animal-based food products	1	6	7	0.2	6
29E	Per capita demand for highly processed food products	0	3	3	0.0	0
30E	Per capita demand for plant-based food products	2	7	9	0.3	14
31E	Variable costs of livestock production	9	10	19	0.9	90
32E	Fixed costs of livestock production	1	8	9	0.1	8

(Continues)

TABLE 3 | (Continued)

ID	Driving force	Outdegree	Indegree	Centrality	Activity index	Interaction index
33E	Private investment volume in animal welfare	3	7	10	0.4	21
34E	Public investment volume in animal welfare	4	5	9	0.8	20
35E	Relative prices of animal-based food products	7	8	15	0.9	56
36E	Relative prices of livestock breeding technology	0	4	4	0.0	0
37E	Relative prices of synthetic fertilizers	3	4	7	0.8	12
38E	AFS-RP1: Land productivity	1	3	4	0.3	3
39E	Regional manure trading system	3	6	9	0.5	18
40 P&I	AFS-RP1: Environmental standards	11	3	14	3.7	33
41 P&I	AFS-RP1: Food standards	4	3	7	1.3	12
42 P&I	Animal welfare standards	8	3	11	2.7	24
43 P&I	Traceability standards for agricultural commodities	5	5	10	1.0	25
44 P&I	International standards for carbon sequestration	0	3	3	0.0	0
45 P&I	Carbon budget for livestock farming systems	7	4	11	1.8	28
46 P&I	Carbon credits in agriculture	2	2	4	1.0	4
47 P&I	Carbon price	6	3	9	2.0	18
48 P&I	AFS-RP1: International trade agreements	11	3	14	3.7	33
49 P&I	AFS-RP1: Multilevel cooperation	3	1	4	3.0	3
50 P&I	Regional collaborations between farmers	4	5	9	0.8	20
51 P&I	Knowledge exchange between actors in livestock farming systems	5	4	9	1.3	20
52 P&I	Accessibility of agricultural extension services (public or private)	4	3	7	1.3	12
53 P&I	AFS-RP1: Socio-environmental focus of agri-food policies	3	3	6	1.0	9
54 P&I	Political attention to climate change mitigation and adaptation in livestock farming systems	10	1	11	10.0	10
55 P&I	Political attention for internalizing external costs of livestock farming systems	3	2	5	1.5	6
56 P&I	Land use regulation for prioritizing plant-based food production	3	3	6	1.0	9
57 P&I	Public investment volume in education and food literacy	6	3	9	2.0	18
58 T	AFS-RP1: Speed of agricultural technology development	9	5	14	1.8	45
59 T	Speed of technology development for plant-based food products	0	5	5	0.0	0
60 T	Speed of certification and accreditation of new technologies	3	6	9	0.5	18
61 T	AFS-RP1: Technology acceptance by producers and consumers	6	5	11	1.2	30
62 T	AFS-RP1: Technology uptake in agriculture	5	4	9	1.3	20
63 T	Degree of automatization in livestock farming systems	1	4	5	0.3	4

(Continues)

TABLE 3 | (Continued)

ID	Driving force	Outdegree	Indegree	Centrality	Activity index	Interaction index
64 T	Degree of digitalization of livestock farming systems	7	3	10	2.3	21
65 T	Use of climate-friendly technologies for fertilizer application	3	4	7	0.8	12
66 T	Use of fossil-fuel based machinery	3	4	7	0.8	12
67 T	Use of technologies for animal health	1	5	6	0.2	5
68 T	Use of technologies for greenhouse gas emission monitoring	1	4	5	0.3	4
69 T	Interoperability of technologies	5	3	8	1.7	15
70 T	Climate-adaptive breeding	2	3	5	0.7	6
71 T	Animal feed efficiency	1	2	3	0.5	2
72 T	Manure management efficiency	3	5	8	0.6	15
73E&N	Global land availability for animal nutrition and husbandry	7	4	11	1.8	28
74E&N	Availability of agricultural land	4	3	7	1.3	12
75E&N	Share of agricultural land with cultivation restrictions resulting from nature protection	3	4	7	0.8	12
76E&N	Availability and quality of organic fertilizers	3	5	8	0.6	15
77E&N	Biodiversity (genetic and species and ecosystem diversity)	4	2	6	2.0	8
78E&N	Recurring occurrence of communicable zoonotic diseases	1	2	3	0.5	2
79E&N	Animal health	4	4	8	1.0	16

TABLE 4 | Structural characteristics of the European livestock farming system.

Structural characteristic	Value
Size	79
Number of relationships	327
Average number of relationships per driving force	4.1 (327/79)
Density	0.053 (327 actual out of 6162 possible edges)
Number of transmitter variables	1 (i.e., 20E)
Number of receiver variables	6 (i.e., 15E, 24E, 29E, 36E, 44 P&I, and 59 T)
Number of ordinary variables	72
Complexity (ratio of receiver to transmitter variables)	6

(40 P&I), and *international trade agreements* (48 P&I) represent the most influential driving forces. The driving forces that were considered to be the most strongly influenced by others are *variable costs* and *fixed costs of livestock production* (31E and 32E), as well as *relative prices of animal-based food products* (35E).

Lowest outdegrees are reported for specific driving forces in the categories of E, P&I, and T, and lowest indegrees are reported for driving forces in the categories of P&U, E, and P&I. In particular, driving forces that are perceived as having a low level of influence on the other driving forces (i.e., low outdegrees) are *European export of animal feed* (15E), *labor supply in agriculture* (24E), *per capita demand for highly processed food products* (29E), *relative prices of livestock breeding technology* (36E), *international standards for carbon sequestration* (44 P&I), and *speed of technology development for plant-based food products* (59 T). Driving forces that are perceived as only slightly (if at all) influenced by others (i.e., low indegrees) are *urban-rural linkages* (01 P&U), *citizens' average income* (20E), *multilevel cooperation* (49 P&I), and *political attention to climate change mitigation and adaptation in livestock farming systems* (54 P&I).

The centrality of the driving forces (i.e., the cumulative strengths of their relationships) ranges from two to 19 (Table 3), with the total relationships being lowest for *urban-rural linkages* (01 P&U) and highest for *variable costs of livestock production* (31E). Low centrality reveals driving forces with only few relationships and may be considered least important in the system. By contrast, the driving force with highest centrality is perceived as most important in the system, together with *societal pressure for sustainable livestock farming systems* (07 P&U) and *citizens' environmental awareness* (02 P&U).

The activity index is above 1 for a total of 31 driving forces, suggesting that they influence more than they are influenced. It is particularly high (> 3) for the five driving forces: *Political attention to climate change mitigation and adaptation in livestock farming systems* (54 P&I), *citizens' environmental awareness* (02 P&U), *environmental standards* (40 P&I), *international trade agreements* (48 P&I), and *market integration* (12E). Interestingly, four of these five driving forces are also identified as driving forces for European agri-food systems in RPs 1 and 2. Driving forces with a low activity index are perceived as easily influenced but have only a minor or no influence on other driving forces. We detected a low activity index (≤ 0.2) for *European import/export of animal-based food products* (16E/14E), *fixed costs of livestock production* (32E), *income equality* (23E), *per capita demand for cultivated animal-based food products* (28E), and *use of technologies for animal health* (67 T).

The interaction index is high for driving forces perceived as strongly influencing other driving forces and as easy to influence. We identified a high interaction index for *variable costs of livestock production* (31E), *societal pressure for sustainable livestock farming systems* (07 P&U), *relative prices of animal-based food products* (35E), *speed of agricultural technology development* (58 T), and *food literacy of consumers* (05 P&U). In comparison, a low interaction index indicates driving forces with a small influence and which are themselves only weakly influenced. Our analysis enabled us to identify several of these driving forces with no outdegrees (i.e., 15E, 24E, 29E, 36E, 44 P&I, and 59 T), as well as *urban-rural linkages* (01 P&U), *animal feed efficiency* (71 T), *recurring occurrence of communicable zoonotic diseases* (78E&N), *demand for biogenic resources for biogas production* (25E), *land productivity* (38E), and *multilevel cooperation* (49 P&I).

The interaction matrix in Figure 2 shows the activity and interaction indices and reveals active, passive, critical, and buffering elements. We identified two active elements, that is, *political attention to climate change mitigation* and *adaptation in livestock farming systems* (54 P&I) and *citizens' environmental awareness* (02 P&U) as potential levers of change. The passive elements of *societal pressure for sustainable livestock farming systems* (07 P&U), *variable costs of livestock production* (31E), and *relative prices of animal-based food products* (35E) may serve as early warnings for changes in livestock farming systems. The large number of identified buffering elements can be regarded as constants in the system, having a stabilizing or retarding effect.

3.3 | Actors Shaping the European Agri-Food and Livestock Farming Systems

The interview partners identified various actors with distinct interests and responsibilities who shape European agri-food systems. These are presented in Table 5, categorized into the socio-economic, political, administrative and legal, socio-cultural, and educational domains. With respect to the socio-economic domain, the interview partners referred to main actors in the agri-food value chain, such as agricultural input suppliers, farmers and farmer cooperatives, processors, distributors, and retailers, and provided several examples. Additionally, they considered agriculture investors, consultants, and advertising agencies to be relevant actors. Where appropriate, they also mentioned different levels of operation (local to multinational) and different ownership structures (private or public). Most actors named by the interview partners belong to the political, administrative and legal domain. They include international organizations, prominent global political actors (e.g., China and USA), key institutions of the European Union

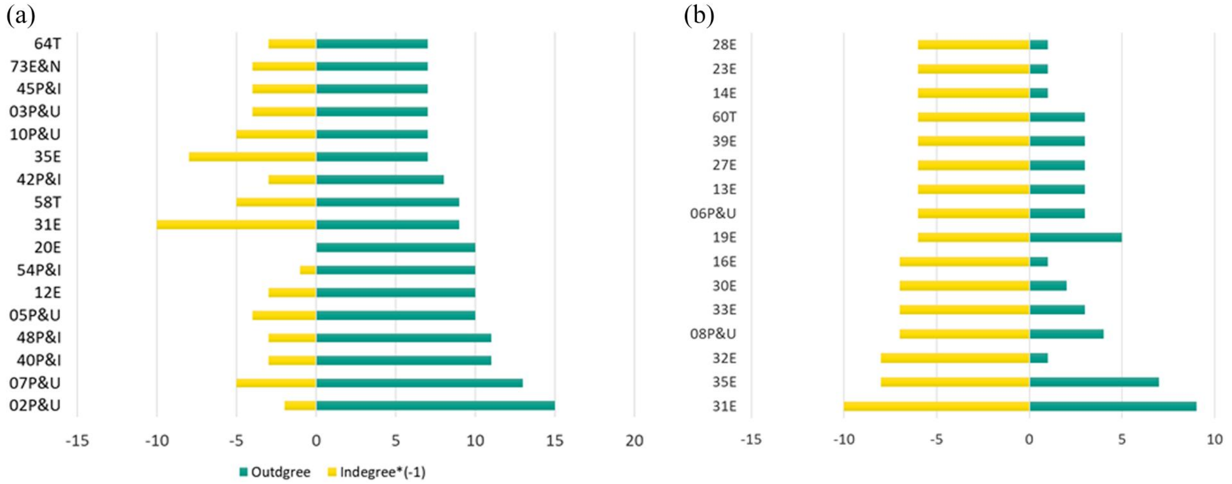

FIGURE 1 | Driving forces of developments in European livestock farming systems with an outdegree ≥ 7 (a) or an indegree ≥ 6 (b).

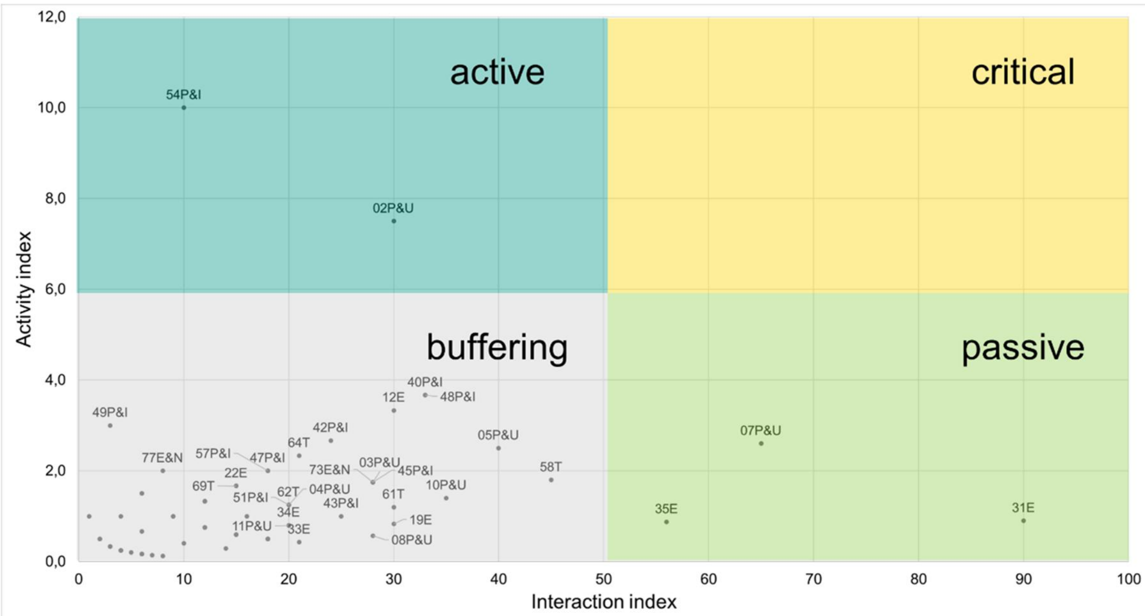

FIGURE 2 | Interaction matrix.

(e.g., the European Commission, European Parliament, Council of the European Union, and European Court of Auditors), governmental bodies of EU member states (e.g., selected Ministers of Agriculture and national parliaments and governments), as well as non-governmental organizations (NGOs) and advocacy groups. Regarding the EU member states, the interview partners differentiated between their accession status, population size, economic performance, spatial location, and regional interests. The NGOs were described as animal welfare and environmental campaigners. The advocacy groups were mentioned in the context of new technologies and novel food, and the interview partners linked them to legislation and policymaking at the European level. The socio-cultural domain is represented by civil society with its specific subgroups, by public institutions, influencers, and farmer-citizen movements that advocate for socio-cultural interests, and by conventional and social media. The interview partners described civil society as both consumers of agricultural commodities and taxpayers who provide, for instance, money for the CAP. They highlighted the voices of specific countries, interest groups, or individuals that enjoy trust or popularity and are, for instance, organized in movements or public institutions. In the educational domain, educational levels mentioned include academic and non-academic organizations. Finally, the cooperation between the actors was described as stimulating development or having an impact in agri-food and livestock farming systems.

4 | Discussion

Our results show that agri-food experts perceive a range of driving forces related to population and urbanization, economy, policies and institutions, technology, and environment and natural resources as being important for the development of European agri-food and livestock farming systems. The highest number of reported driving forces is in the economic realm,

TABLE 5 | Actor categories shaping the European agri-food and livestock farming systems and respective examples from the expert interviews.

Actor category	Examples from the expert interviews
Socio-economic domain	
Suppliers of agricultural inputs	Agri-tech companies providing seeds, mineral fertilizer, pesticides, and animal breeds
Farmers and farmer cooperatives	Industrial farmers and smallholder farmers and producer cooperatives, input purchasing cooperatives, and direct marketing cooperatives
Processors, food, and feed industries	Multinational companies and cooperative industries processing food and drinks; producers of novel food
Distributors	Logistics companies
Retailers, gastronomy, and catering	Supermarkets, canteens, and fast food restaurants
Agriculture investors	Private investment companies or banks
Consultants	Public extension services and private consulting agencies
Advertising agencies	Poster designers and promotional videographers
Political, administrative, and legal domain	
International organizations	Food and Agriculture Organization of the United Nations (FAO)
Global political actors	China and USA
European Commission	Commissioner for Agriculture and Food, Commissioner for Environment, and Head and Executive Head of the European Commission
European Parliament	Political parties represented in the European Parliament
The Council of the European Union	--
European Court of Auditors	Control systems
European authorities	The European Food Safety Authority
EU Member States	Current, former, and potential new EU Member States
Ministers of Agriculture	German Minister of Agriculture
National governments	Political parties represented in the national governments and policymakers
Parliaments of nation states	Legislators
Non-governmental organizations	Advocates for environmental protection or animal welfare
Advocacy groups	Farmers' associations and farm interest groups
Socio-cultural domain	
Civil society, networks, and specific sub-groups	Consumers and taxpayers; networks of young farmers and networks of animal welfarists; and rural and urban citizens, young generation, and intellectuals
Public institutions	Future commission
Role models	Famous people (such as TV cooks) or countries (such as Austria for organic production)
Farmer and citizen movements	Farmer protests and activists
Media	Magazines, commercials, and social media
Educational domain	
Academic organizations	Universities, colleges, and academies of science
Educational organizations	Schools and centers for continuing education

followed by policies and institutions in the agri-food and livestock farming systems and in the two RPs. Similarly, economic driving forces are predominant in participatory scenario development processes, whereas complementary social, political, technological, and environmental factors have been less frequently considered (O'Brien 2004). In comparison, a systematic synthesis of landscape field studies by Plieninger et al. (2016) identified policies and institutions, environment and natural resources, and population and urbanization as the dominant driving forces of landscape change across Europe. This study also suggests that the relevance assigned to driving forces differs regionally and indicates that landscape change typically results from a combination of driving forces. These results are in line with our interviewed experts' views, who stressed regional differences – especially between Northern, Southern, Eastern, and Western European countries or regions – and who identified driving forces for at least four of the five thematic categories.

Our analysis of data collected over a 5-year study period reveals that four driving forces – two from the economic and two from the technology realm – were described as important by all experts interviewed in both RPs. This finding indicates that these experts are strongly aware of and agree that changes in agri-food systems are driven by the forces of the *European import of agricultural commodities* (16E), *meat demand per capita* (21E), *speed of agricultural technology development* (45 T), and *technology uptake in agriculture* (46 T). These experts' perceptions are supported by scientific theory and the results of empirical analyses. For instance, technology and innovation are central concepts in economic theory that are used to explain changes in the system of interest (Nordhaus 1969; Romer 1990). Furthermore, several empirical and modeling studies have argued for prioritizing improvements in agricultural technologies and management, dietary change, and reductions in food loss and waste to promote change in agri-food systems and improve their sustainability and climate resilience (Springmann et al. 2018; Gerten et al. 2020; Ivanova et al. 2020). Others have suggested that technological progress may disrupt agri-food systems (King 2017; Walter et al. 2017; Asseng and Asche 2019; Vahdanjoo et al. 2025).

Our findings also reveal that experts use similar argumentation tactics when explaining changes in the European agri-food systems in both RPs; the interview partners also stressed recent advancements and supported their arguments by citing the latest developments and examples. For instance, the driving forces of *citizens' environmental awareness* (7 P&U), *European import/export of agricultural commodities* (16E/17E), *meat demand per capita* (21E), *agri-environmental payments* (42 P), *speed of agricultural technology development* (45 T), *technology acceptance* (47 T), and *uptake in agriculture* (46 T), as well as *resource depletion* (48E&N) were prominently recognized in RP1 and remained a core focus of the interviews in RP2. Two other economic driving forces, namely *European trade of agricultural inputs* (15E) and *diversity of agricultural supply chains* (18E), were highlighted more frequently in RP2 than in RP1. Here, the interview partners associated these forces with recent developments they predicted would have persistent effects, such as recurring global supply chain disruptions or emerging grassroot initiatives aiming to shorten and diversify supply chains.

Previous study authors have noted that life experiences and current challenges and concerns influence research participants' responses (O'Brien 2004). Referring to topical events or latest developments may be related to so-called *recency error* or *availability bias*. Recency error refers to the observation that individuals' perceptions are distorted in light of recent experiences or most recently received facts or impressions (American Psychological Association 2025). Availability bias refers to the observation that the perceived likelihood of occurrence is higher if related information becomes more easily available, accessible, and pertinent (Tversky and Kahneman 1982). Empirical research on agri-food systems has reported such findings in the contexts of risk management (Huseynov et al. 2024), experienced shocks (Lee 2026) and enduring challenges such as climate change (Le Dang et al. 2014; Mitter et al. 2019). Furthermore, the outcome of our analysis shows that agri-food experts generally reported a higher number and more nuanced driving forces in RP2. These reports reflect the general notion that agri-food systems are becoming steadily more complex, which may increase their vulnerability to unexpected or unintended effects (Conti et al. 2024). Due to this (growing) complexity, the resilience of these systems must be enhanced to guarantee system functions (Meuwissen et al. 2019).

In both reporting periods, the interview partners discussed price volatilities and climate change. We chose not, however, to include them in the list of driving forces based on the argument of Béné et al. (2019), who suggest that, for a process to be regarded as a driving force, its effects must persist over a defined period of time, thus ensuring that it changes or influences the system consistently and in a lasting manner. The interview partners tended to describe the price volatilities discussed as crises or shock events, but did not specify effects that could be considered as continuous. Béné et al. (2019) also argue that climate change is too vague to clearly describe durable effects on agri-food systems, while acknowledging that it has repeatedly been identified as a driving force (Ericksen 2008; HLPE 2017). Recurring extreme events could, however, become a driving force if actors adapt, thereby changing agri-food systems.

European livestock farming systems are nested within agri-food systems, as evidenced by the driving forces considered important for both systems. We identified two active and three passive system elements for the European livestock farming systems. The active elements may be interpreted as potential levers of change, comprising *political attention to climate change mitigation and adaptation in livestock farming systems* (54 P&I) and *citizens' environmental awareness* (02 P&U). The call for livestock-related policies that support and promote sustainability and climate resilience is not new. However, the statuses of national and European implementation differ (Mehrabi et al. 2020), subsidies for coupled livestock production remain in place (SAPEA 2023), and the amount of public funds spent on increasing animal welfare is still comparably low (Grethe 2021). Citizens' environmental awareness may have an effect on policy orientation and individual behavior. Policy design is considered to be at least partly responsive to societal demands. The connection between policymaking and society is evident in the European Commission's use of the "public goods subframe" to legitimize payments and communicate the societal benefits of the CAP. This connection is further reinforced by the environmental coalition's demand that the CAP design align with the needs and expectations of citizens (Obweger et al. 2024; Loacker et al. 2025). Individuals are more likely to act in pro-environmental ways if they endorse biospheric (i.e., ecocentric) values and adopt a pro-environmental attitude (De Groot and Steg 2009; Steg 2016). However, research has shown that individuals' pro-environmental attitudes do not necessarily reflect pro-environmental behavior, a phenomenon referred to as the *attitude-behavior gap* (Kollmuss and Agyeman 2002; Farjam et al. 2019).

The three passive system elements we identified for the European livestock farming systems are *societal pressure for sustainable livestock farming systems* (07 P&U), *variable costs of livestock production* (31E), and *relative prices of animal-based food products* (35E). A previous analysis suggested that public acceptance of livestock husbandry systems is low (Birkle et al. 2022), which may signal that changes are occurring or expected in livestock farming systems. Variable costs of livestock production have been shown to decrease with market integration (Deppermann et al. 2018), feed efficiency

(Keogh et al. 2024), genetic advancements (Goddard 2012), and farm size (Yilmaz et al. 2016). Alternatively, another study shows that more comprehensive environmental regulations generally increase variable costs (Martín-Hernández et al. 2022). The real prices of animal-based food products (i.e., nominal deflated world prices) were high in recent years but are expected to continuously drop toward their long-term trend levels (OECD and FAO 2024); hence, these are not a strong signal for change. If external costs for climate change, soil degradation, and water pollution were considered, however, the prices for beef, pork, lamb, and poultry would have to increase on a global average between 19% and 56% (Funke et al. 2022; Mitter et al. 2022).

Actors from the socio-economic, political, administrative and legal, socio-cultural, and educational domains have been assumed to have the capacity to effect or influence change in European agri-food and livestock farming systems. The list of reported actors is comprehensive and extends beyond those addressed in the triple and quadruple helix models (Etzkowitz and Leydesdorff 2000; Carayannis and Campbell 2009; Carayannis and Campbell 2012; Ranga and Etzkowitz 2013). In the socio-economic domain, this list includes not only classical actors from the value chain but also agriculture investors, consultants, and advertising agencies. Our study participants did not mention actors specialized in agricultural storage and waste management, although storage capacities are becoming increasingly important, for instance, because they offset yield variabilities that are increasing in response to climate change (Ray et al. 2015; Hu et al. 2024) and regional supply shocks (Mitter et al. 2022). Handling waste is receiving increased attention, not least due to the increasing application of the circular economy concept and related policy targets (Morseletto 2020). In the political domain, our study participants consider national, European, and international actors to be powerful and influential in the development of European agri-food systems. This reflects the interplay between local to global actors (institutional scale dimension, Bürgi et al. 2005) and the long history of the CAP, which allows for national specifications. The socio-cultural and educational domains directly link to the driving forces category of *population and urbanization*. For instance, the establishment and maintenance of educational institutions are a prerequisite for maintaining or increasing society's average educational level. Finally, the interview partners in RP2 raised the question of when artificial intelligence would be considered a driving force – a question that would be useful to discuss in interdisciplinary forums.

5 | Conclusion

In this study, we investigated agri-food experts' perceptions of driving forces underlying change in European agri-food and livestock farming systems. Our findings support the value of coordinating and targeting economic, agricultural, and climate policies on European import of agricultural commodities, reducing per capita meat demand, and accelerating the speed of agricultural technology development and its uptake. These driving forces were consistently perceived and reported as important by the experts interviewed in the two RPs, indicating a widespread and enduring consensus that these forces promote change in agri-food systems. However, the agri-food experts perceived an increase in the system's interconnectedness in recent years, which may suggest that the requirements for successful policy design and implementation have increased recently.

With respect to European livestock farming systems, we identified the driving forces of *political attention to climate change mitigation and adaptation* and *citizens' environmental awareness* as potential levers of change. The first force implies a clear commitment of actors of the political, administrative and legal domains to mitigate and adapt to climate change (i.e., enhance climate resilience). The second force is more comprehensive in that it addresses actors in the socio-economic, socio-cultural, and educational domains. Three additional driving forces, namely *societal pressure for sustainable livestock farming systems*, *variable costs of livestock production*, and *relative prices of animal-based food products*, are sensitive to change in system dynamics. Hence, regularly monitoring these forces, as well as their relationships and effects, may enhance our knowledge of these system dynamics, potentially informing the timing of specific policies or interventions.

The results of our analysis of agri-food experts' perceptions complement the results of research that has examined spatially explicit data to trace historical developments in the systems of interest. By recording these perceptions, we have increased our system understanding (i.e., systems knowledge) and identified several potential levers of change (i.e., transformation knowledge). However, our analysis primarily focused on European agri-food and livestock farming systems, and only limited attention was paid to detecting regional heterogeneities and global linkages. We examined how perceptions of driving forces have evolved over a 5-year period, while also recognizing the challenges inherent in distinguishing among these driving forces and their impacts. Furthermore, our findings are based on data collected from carefully selected agri-food experts, which facilitates our ability to make analytical generalizations but does not support statistical generalizations. Overall, the importance of our work for broader application lies in its capacity to connect theoretical system analysis with practical decision-making, helping shape the future of European agri-food and livestock farming systems. Our findings thereby provide a roadmap for managing change in these systems to support and enhance their sustainability and resilience.

Future research may build on our findings. We would like to suggest that future researchers (i) use the identified driving forces to inform scenario development at the European level, (ii) apply a weighting procedure to gain a more detailed understanding of the relationships among the driving forces as presented in the interaction matrix, and (ii) analyze actors with respect to their responsibilities, engagement, and cooperation in order to identify agents of change.

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Policy on Using ChatGPT and Similar AI Tools

During the preparation of this work Hermine Mitter used https://unigpt.uni-graz.at/chat to improve language and readability. After using this tool, Hermine Mitter reviewed, verified, and, where necessary, edited the content for appropriateness and accuracy and takes full responsibility for the content. Katrin Karner used https://boku.academic-ai.at/general-chat/ for grammar, spelling, refining wording, clarifying paraphrases, and improving readability. Katrin Karner reviewed, verified, and, where necessary, edited the text for accuracy and appropriateness and takes full responsibility for the final content. Automatic speech recognition supported the transcription in the second research phase. All AI-generated transcripts were manually checked and corrected against the audio for accuracy by a team of researchers, including Christina Bolkart, Bernadette Kropf, Judith Fischer, Hermine Mitter, Carina Auzinger, and Christina Roder.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data supporting the findings of this study are not publicly available for reasons of data privacy or ethical considerations.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.
Supporting File 1: ffo270050-sup-0001-02b_Appendix_v0_hm1_R1.docx.
Supporting File 2: ffo270050-sup-0002-SM_I_S_1.DOC.
Supporting File 3: ffo270050-sup-0003-SM_II_Square_matrix_R1.xlsx.