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Social network analysis among German farmers reveals potentials to overcome the production–conservation dichotomy in land use

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Abstract

1. For agriculture to become more sustainable, farming needs to incorporate biodiversity conservation practices. However, farmers must largely choose between agricultural production and biodiversity conservation in their land-use decisions, and accordingly, seek knowledge and support for either of these goals. A better understanding of knowledge exchange and support in farmers' social networks could highlight how biodiversity conservation may be integrated with agricultural production.
2. We conducted structured interviews with 70 farmers in northwest Saxony, Germany. We asked farmers about basic farm characteristics, their participation in agri-environmental schemes (AES), with whom they exchange knowledge and how those contacts support them in reaching their agricultural or conservation goals. This information was used for social network analysis, including network autocorrelation modelling.
3. We found that the knowledge-exchange network related to biodiversity conservation was centralized, with non-profit organizations as central knowledge providers. The knowledge exchange network related to agricultural production was decentral, with private companies having a central role. The farmers' support networks for achieving conservation and agricultural goals were largely overlapping. Peer support was the most important mechanism for farmers to participate in AES. Participation of large-scale farmers was associated with the level of AES participation of other large-scale farmers in their network. However, large-scale farmers did not influence small-scale farmers.
4. Arable-crop farmers maintained ties to large, private companies while participating in the fewest AES. If non-profit organizations engaged in advice for agricultural production, they might reach arable-crop farmers. Large-scale farmers who have comprehensive experience in both agricultural production and participation in AES play a central role in both knowledge exchange and support networks. Together

with non-profit organizations, they might be important for breaking down the dichotomy of production and conservation, if they can more widely communicate their contextual, experiential knowledge of implementing AES.

5. *Policy implications*. Public and non-profit advisory services should be empowered in their ability to provide both agronomic and biodiversity conservation information to support a less dichotomous land use. Promoting mutual support among farmers may effectively facilitate AES participation. Large-scale farmers should be encouraged to share knowledge regarding biodiversity conservation, particularly with small-scale farmers who operate within different economic contexts.

KEYWORDS
agri-environmental schemes, biodiversity conservation, farmer survey, human-environment research, network autocorrelation models, sustainable agriculture

1 | INTRODUCTION

Biodiversity conservation across agricultural landscapes is possible if farming becomes more sustainable (Kremen & Merenlender, 2018). In Europe, the Common Agricultural Policy (CAP) is designed to address society's need for affordable food while simultaneously supporting farmers in achieving diverse goals such as maintaining vibrant rural areas, mitigating climate change or preserving landscapes and biodiversity (European Commission, 2024). Farmers receive subsidies for their productive activities (e.g. area of land they manage) and also for their landscape management and biodiversity conservation by following good farming practices that are encoded in agri-environmental schemes (AES), including 'ecoschemes' in the latest CAP iteration. However, studies have shown that despite their ambitions, such measures have not been successful in conserving biodiversity across Europe (Pe'er et al., 2014, 2022). In Germany, ecological focus areas, cover crops and diverse rotations have been some of the most ubiquitously applied AES (Baaken, 2022; Zinngrebe et al., 2017), but there has nevertheless been a substantial decline in different species (e.g. flying insect biomass and diversity: Hallmann et al., 2017). So, understanding the factors that determine farmers' engagement in biodiversity conservation, particularly their participation in AES, is imperative to making sustainable land use more widespread.

A potential hurdle to more sustainable farming is the artificial segregation of biodiversity conservation and agricultural production from each other (Lécuyer et al., 2021; Mattison & Norris, 2005). For millenia, traditional farming practices had created cultural landscapes in Central Europe which supported a diverse flora and fauna. In fact, the maximum level of biodiversity, which was reached in the early 19th century, was the consequence of agricultural land use by humans (Bignal & McCracken, 2000). It was only after the industrialization of agriculture in the second half of the 20th century that agricultural production became unsupportive for biodiversity and led to strong species declines (Stoate et al., 2001). In recent decades, farmers have often been pressed to choose between focusing on intensifying production or on conservation when making decisions for their land, and seek advice for either of these goals. These goals are not considered as attainable simultaneously (Gabel, Home, Stolze, Birrer, et al., 2018; Ingram & Mills, 2019), largely due to the separation of regulatory frameworks and of governmental institutions, funding and research (Simoncini et al., 2019). Relationships between actors associated with agricultural production and those associated with biodiversity conservation will thus be essential to breaking down the dichotomies between these two goals, allowing farming to become more sustainable. Farmers make up a group of actors that are involved in both activities, but whether they communicate differently with their social networks for these different goals is unclear. As such, understanding how farmers' social networks may affect how agricultural production and biodiversity conservation are perceived will be key to gaining insight to how biodiversity loss can be mitigated and thereby support farm sustainability (Albizua et al., 2021; Nyantakyi-Frimpong et al., 2019).

Social networks are shaped by communication, knowledge exchange, and support. Studying how biodiversity conservation in farming may become more widespread has thus emerged as a challenge of understanding communication and knowledge exchange among actors in the farming community, more than a challenge that can be solved with the natural sciences (Bennett et al., 2017). It appears established that the social networks in which farmers are embedded are a major determinant of their involvement in biodiversity conservation (Brown et al., 2021; Lastra-Bravo et al., 2015; Schaub et al., 2023). However, this relation cannot be described simply by the phenomenon of social networking increasing AES participation, as the mechanisms behind social network effects remain rather elusive (Lastra-Bravo et al., 2015; Schaub et al., 2023).

Although social network analysis (SNA) has been widely used to understand the adoption of certain technologies or farming practices, such as laser land levelling (Magnan et al., 2015), no-till farming (Skaalsveen et al., 2020), agroforestry (Lin et al., 2021; Nyantakyi-Frimpong et al., 2019) or the use of fertilizer (Matous & Bodin, 2024), the role of social networks for participation in

AES remains understudied. There are differences between the adoption of a new technology or farming practice with the aim of enhancing productivity or resilience and the participation in AES to promote biodiversity or ecosystem services. In the first case, we may assume an intrinsic motivation of the farmer to enhance or ensure income. Thus, farmers who find a new farming practice beneficial often stick to this practice in the future and apply it to their entire farmland (Hidayat et al., 2024; Mekonnen et al., 2018; Skaalsveen et al., 2020). In contrast, AES offer financial compensation for a farming practice or conservation measure that would otherwise decrease farmers' income. The AES offered in EU countries oblige farmers to perform certain management measures only in 1 year (eco-schemes, I pillar) or a couple of years (regional rural development programs, II pillar) and potentially on very small parts of their land (Sächsischen Staatsministeriums für Energie, Klimaschutz, Umwelt und Landwirtschaft (SMEKUL), 2023). Thus, farmers must make yearly decisions about whether and where to implement AES (Wittstock et al., 2022). Moreover, farmers who have adopted a new farming practice to enhance or maintain productivity often identify with each other and view themselves as a separate community (e.g. agroforestry: Nyantakyi-Frimpong et al., 2019; no-till practices: Skaalsveen et al., 2020; greenhouse farming: Hidayat et al., 2024). Whether this is true for farmers who participate in certain AES is uncertain, given that AES represent a whole bunch of very different conservation measures, and the motivation of farmers to participate in AES is often not driven by idealism but by financial incentives and considerations about whether or how an AES fits into their usual operating procedure (Gabel, Home, Stolze, Pfiffner, et al., 2018; Wittstock et al., 2022). There is thus an explicit need to study how social networks affect participation in AES.

In theory, three types of network effects on farmers' engagement in biodiversity conservation can be distinguished (Kreft et al., 2023; Manski, 2000): endogenous network effects, exogenous network effects and correlated effects. An endogenous network effect is operative if a farmer's behaviour is influenced by the behaviour of their peers. It may be the expression of different mechanisms such as a social norm, a herd effect, or social learning (Keil et al., 2017; Manski, 2000; Matuschke & Qaim, 2009). For instance, if farmers are surrounded by other farmers who already participate in AES, they might feel a certain social pressure to take up measures as well (Hauck et al., 2016; Kreft et al., 2024; van Dijk et al., 2015). Thus, if participating in certain AES becomes the social norm, defining what makes a 'good farmer' (Burton, 2004), this might specifically motivate farmers who previously were reluctant to implement these measures (Calvet et al., 2019; Cusworth, 2020; Kreft et al., 2024). If, however, AES participation is not the social norm, social networks might even inhibit participation in AES, because farmers fear being exposed to the judgement and criticism of their peers (Lastra-Bravo et al., 2015). Also, social learning, that is, information flow among peers, might express itself in an endogenous network effect. There seems to be broad agreement that social learning may facilitate certain farming practices, including environmental management (Mathijs, 2003; Moschitz et al., 2015; Schneider et al., 2009). It is, however, less clear whether and under which conditions social learning takes place. Concerning the spread of new farming practices, perceived benefit appears to be an important factor (Magnan et al., 2015). Thus, a farmer is more likely to adopt a new farming practice if there is a peer in their social network who has had a good experience with this new practice (Ataei et al., 2019; Hidayat et al., 2024). Farmers showing signs of being successful with a new farming practice are often consulted by other farmers and hold central positions in the social network (Albizua et al., 2021; Lin et al., 2021; Nyantakyi-Frimpong et al., 2019). However, in terms of AES, the economic and agronomic benefit is often not clear to farmers (Bianchi et al., 2013). As such, it is unclear to which extent social learning promotes participation in AES.

Another example of an endogenous network effect is the dominance of certain farmers in the community, whose behaviour influences the land-use decisions of other farmers. For instance, in highly centralized networks among smallholder cocoa farmers in Indonesia, farmers' decision whether to apply fertilizers is disproportionately influenced by a small number of high-status opinion leaders (Matous & Bodin, 2024). In Navarre, Spain, intensive irrigation practices used among modern farmers were spread among the social network due to the dominance of these farmers (Albizua et al., 2020). Concerning participation in AES, we know that large farms in Saxony, Germany, are those that implement the most AES (Wittstock et al., 2022). However, whether such large farms simultaneously have a leader position in the farmers' community and thus promote participation in AES through their social networks remains to be studied.

Exogenous network effects are operative if a farmer's behaviour is associated with some external characteristics of their peers (e.g. age, education, knowledge) rather than by their peers' behaviour (Keil et al., 2017; Kreft et al., 2023; Manski, 2000; Varshney et al., 2022). Given that having knowledgeable farmers in the network is the prerequisite for social learning, social learning can also be considered an exogenous network effect (Kreft et al., 2023). Another peer characteristic that might be beneficial for farmers' engagement in biodiversity conservation is the support they provide for implementing conservation measures. For instance, being a member of an environmental cooperative gives farmers in the Netherlands the feeling of being capable of carrying out meadow bird management and thus promotes their intention to participate in the corresponding AES (van Dijk et al., 2015). Moreover, feeling supported by an environmental cooperative enhanced these farmers' willingness to perform additional, unsubsidised conservation measures (van Dijk et al., 2016).

Finally, correlated effects occur if peers behave similarly because they are exposed to the same environment, for instance because they have contact with the same external advisors, such as authorities, NGOs or private companies (Kreft et al., 2023; Manski, 2000). Receiving professional advice from external sources has been found to be as or even more important for the adoption and diffusion of new technologies or farming practices as learning from peers (Genius et al., 2014; Mekonnen et al., 2018; Vishnu et al., 2019).

Also, AES participation appears to be more likely if farmers receive professional advice (Gabel, Home, Stolze, Birrer, et al., 2018; Sutherland et al., 2013). However, the source of advice is likely to influence whether or not a farmer behaves environmentally friendly (Schaub et al., 2023). For instance, Wuepper et al. (2021) showed that farmers advised by public extension services were more likely to use non-chemical, preventive measures against pest infestation, whereas farmers advised by private extension services were more likely to use synthetic pesticides.

Although the literature suggests multiple social network mechanisms that are potentially important for facilitating AES participation, there is little consensus on which network structures and interactions within networks benefit or hinder farmers' engagement in biodiversity conservation. We therefore need social network analyses of real-world farmer communities in a biodiversity conservation context. Insights into interactions within such networks in this context could help dissolve the dichotomy between agricultural production and biodiversity conservation by encouraging dialogue across sectors (e.g. Bundesamt für Naturschutz, 2023). Developing a common narrative between actors through frequent communication can help mitigate conflicts (Koch et al., 2023). This will be increasingly important for facilitating collaboration between several farmers and other actors at the local scale for implementing landscape-scale measures.

Here, our aim was to elucidate how farmers' knowledge-exchange and support networks related to biodiversity conservation and agricultural production influence their participation in AES. We used social network analysis and focused on a farming community in northwest Saxony, Germany, to test the following hypotheses:

> **H1.** Farmers' social networks related to biodiversity conservation are distinct from those related to agricultural production. Specifically, we hypothesize the following:

a. Farmers exchange knowledge on topics related to biodiversity conservation with other people than those with whom they exchange knowledge on agricultural production.
b. Farmers ask other people for support to achieve their conservation goals than those whom they ask for support to achieve their agricultural goals.

> **H2.** Farmers' level of participating in AES is associated with their relations to certain actor groups. Specifically, we hypothesize the following:

a. Farmers having relations to peers who participate in AES participate in AES themselves (general endogenous network effect).
b. Farmers having relations to managers of large-scale farms will mimic their level of AES participation (specific endogenous network effect through the dominance of large-scale farms).
c. Farmers having relations to peers with a propensity to share their knowledge on topics related to biodiversity conservation show a higher level of participating in AES (exogenous network effect through social learning).
d. Farmers receiving support from peers to achieve their conservation goals show a higher level of participating in AES (exogenous network effect through peer support).
e. Farmers receiving information from advisory non-profit organizations show a higher level of participating in AES (correlated effect through exposure to the same institutional environment).
f. Farmers receiving information from private companies show a lower level of participating in AES (correlated effect through exposure to the same company environment).

2 | METHODS

2.1 | Study region and its landcare association

The study was conducted in the 'Altkreis Delitzsch' (N 51.51°, E 12.48°), a former administrative district in northwest Saxony, Germany, with a total area of 861 km^2 (Figure S1). The multifunctional landscape is used for agriculture (56.7% cultivated crops, 13.7% grassland), while the rest entails forest (17.4%), urban areas (6.4%), water bodies (2.6%) and wetlands (3.4%) (Hölting et al., 2020). Grasslands are concentrated on the floodplain of the Mulde River in the east of the region and are used as pastureland. Arable crops are dominated by field fodder and cereals. Agri-environmental schemes (AES) are applied on 9.7% of the cropland and on 8.6% of the grassland area (Sächsisches Staatsministerium für Energie, Klimaschutz, Umwelt und Landwirtschaft (SMEKUL), 2022). Typical AES on cropland aim to promote wildflowers in fields and along field edges and to increase the amount of floral resources for insects. Typical AES on grassland aim to promote species-rich grassland communities.

The study region corresponds to the management area of the regional landcare association, the Landschaftspflegeverband Nordwestsachsen e.V. (LPV). The LPV is a non-governmental organization with the objective of maintaining a diverse cultural landscape, including its habitats for threatened wild-living plants and animals. Their main tasks include the consultation of farmers concerning the integration of biodiversity conservation measures into farming practices, the implementation of biodiversity conservation measures, as well as environmental education. Decision-making processes within the LPV involve three stakeholder groups with different interests, that is, representatives of farmers, nature conservation groups and members of regional councils, who all have an equal voice. Several of the authors work for the LPV.

2.2 | Farmer interviews

The LPV contacted about half of the farmers in the region (140 farmers), as these farmers were in contact with the LPV. The results of this study are therefore not representative of the whole farmer community in the region, but only for those who either have a basic interest in implementing conservation measures or farm in protected areas, and therefore are in contact with the LPV. Seventy of these farmers (50%) agreed to be interviewed. These farmers are the subject of the research conducted here.

The structured interviews followed a questionnaire with several sections (Appendix S1). First, we asked the farmers to provide information on themselves and their farm, which was used to identify groups of farmers (Section 2.3). Second, we asked the farmers in which AES they are participating. A list of all AES mentioned by the farmers and considered here is provided in Table S1. Third, we asked the farmers to nominate up to five persons with whom they have regular contact to exchange knowledge about (a) topics related to biodiversity conservation and/or (b) topics related to agricultural production. These contact persons could be other farmers, but also representatives of private companies or non-profit organizations, including public authorities and non-governmental organizations (like the LPV). For each contact person and knowledge type, we wanted to know whether the farmer receives or provides knowledge or both. This information was used to create knowledge exchange networks (Section 2.4). Furthermore, we asked the farmers to indicate whether they consider each contact person important to achieve (a) their conservation goals and (b) their agricultural goals. This information was used to create support networks (Section 2.4).

2.3 | Farmer clusters

Assuming that the networking behaviour might differ among different types of farmers, we used Hierarchical Cluster Analysis (HCA) to find clusters of farmers with a similar farming system. We implemented this with the R function hclust (R Core Team, 2023) using the Ward method, minimizing the variance within clusters and resulting in homogeneous groups. We considered farmers' age (years), experience in agriculture (years), farm size (ha), the proportion of rented area (%), land-use system (three categories: arable land, grassland or both), crop types grown (each as a binary variable: cereals, maize, oilseed rape, beets, field fodder) and the number of crop types grown.

2.4 | Social network analysis

2.4.1 | Network creation

To test our first hypothesis and its components, we modelled the farmers' social networks with four graphs based on the farmers' responses. Nodes represented actors, that is, farmers and their contact persons including representatives of private companies or non-profit organizations. Edges between nodes represented ties between actors. All actors, including contact persons that we had not interviewed, themselves were indexed so that each actor represented a single node in the graph and was eventually connected to multiple farmers. In the first two graphs, edges reflected the exchange of knowledge on topics related to biodiversity conservation and agricultural reproduction, respectively. In the other two graphs, edges reflected support for the interviewed farmers to achieve their conservation and agricultural goals, respectively. All four networks were modelled as directed graphs with incoming and outgoing ties representing the reception and provision, respectively, of knowledge or support. While ties could point both from farmers to contact persons and from contact persons to farmers in knowledge-exchange networks, ties could only point towards farmers in the support networks.

2.4.2 | Network characteristics

For each network, we calculated network characteristics both at the node level and at the network level. Given the relatively high proportion of missing data (50% of the farmers did not respond, Section 2.2), we restricted these network characteristics to those that are most robust to missing data and would provide reliable estimates even under the given circumstances (Smith & Moody, 2013). Furthermore, the aim of our study was not to assess networks on an absolute scale (i.e. to compare their characteristics with networks in other studies), but to compare multiple networks with each other, of which each consisted of the same group of actors but different ties. Thus, any (presumably) biased network characteristics should still provide a reliable picture of how the knowledge exchange and support networks differ for certain kinds of knowledge or support. Characteristics at the node level comprised two measures of centrality. In-degree centrality corresponds to the number of incoming edges and measures an actor's activity in asking other people for advice or support. Out-degree centrality corresponds to the number of outgoing edges and measures an actor's activity in providing advice or support for others. For all networks and node-level centrality measures, we calculated mean values for all actor groups to assess their centrality in exchanging knowledge and providing support. Network-level characteristics included graph size, that is, the number of edges in the graph, the number of farmers connected to at least one other actor, and centralization, a network-level measure of centrality based on node-level out-degree centrality. We normalized centralization by its theoretical maximum value (as achieved in a star graph) to make it comparable among networks (between 0 and 1). All graphs were created and analysed with the R package igraph (Csárdi & Nepusz, 2006).

2.4.3 | Group-to-group knowledge exchange

To elucidate from which actor groups farmers receive their knowledge on biodiversity conservation and agricultural production topics (H1a), we calculated group-to-group exchange scores. These corresponded to the total number of edges pointing from actors of one group to any actors of another group. To test whether farmers select persons at random within the network to ask for information, or whether they purposefully choose certain actor groups, we compared the observed knowledge exchange scores with expected ones (Crona & Bodin, 2006). However, the standard procedure to do this, that is, relational contingency table analysis (Hanneman & Riddle, 2005), was not applicable in our case given the asymmetric nature of our data. Here, we were solely interested in knowledge flow towards farmers, but not in knowledge flow from farmers to any other actors such as private companies or non-profit organizations. Therefore, we had to adjust the procedure of generating random graphs for the estimation of expected knowledge exchange scores. Specifically, we removed any edges from the knowledge exchange graphs pointing towards unknown farmers or organizations. This was to ensure that in random graph generation, no edges were created among unknown farmers or organizations. Random graphs were generated by permuting the entries in the corresponding binary adjacency matrix so that column totals (in-degrees) and zeros in the diagonal were fixed. This means that during random graph generation, the number of persons that individual farmers ask for knowledge was fixed, while it was open whom they ask for this knowledge. Expected knowledge exchange scores corresponded to mean values over 1000 random graphs. The ratio of observed over expected knowledge exchange scores was used to assess an actor group's importance as a knowledge provider for the different farmer clusters, with ratios >1 and <1 indicating that farmers select for and against a given actor group, respectively (Crona & Bodin, 2006). To decide whether a ratio significantly deviates from 1, we calculated *p*-values as the probability that a random exchange score is smaller or larger than the observed one (two-sided test). For this purpose, we divided the number of graphs (random and observed) for which the exchange score was as extreme or more extreme than in the observed graph by the total number of graphs (random + observed).

2.4.4 | Network congruency

To assess in how far the farmers' knowledge exchange and support networks related to biodiversity conservation are congruent with the networks related to agricultural production, we calculated quadratic assignment procedure (QAP) correlations (Borgatti et al., 2018). This allowed us to evaluate in how far farmers ask the same actors for knowledge or support concerning each of the topics (H1a, H1b). Given the asymmetric nature of our data, we had to adjust the underlying permutation procedure similarly as explained in the previous subsection, that is, we maintained column totals (in-degrees) in the adjacency matrices during permutation. The QAP correlation tests were based on 1000 permutations.

2.5 | Network effects on farmers' participation in AES

We used network autocorrelation models to test our second hypothesis and its components. Network autocorrelation models (NAM) were developed for quantifying and testing for social influence on individual behaviour (Dittrich et al., 2020). They take the non-independence of actors in a network into account when modelling actors' behaviour as a function of actor attributes (Leenders, 2002). In our case, we wanted to test how far farmers being in contact with each other are more likely to show a similar level of participation in AES.

We used simple first-order NAMs to test H2a and H2c to H2f. The general formula is as follows:

$$y = \rho W y + X\beta + \varepsilon \quad (1)$$

where y is the dependent variable, that is, the level of participating in AES, ρ is the network autocorrelation parameter, W is a weight matrix that defines which actors potentially influence each actor in the network, X is a standard design matrix that includes predictor variables as used in common regression models, β is a vector of regression coefficients corresponding to the predictor variables in X and ε are the residuals. As a measure for the response variable y, we used the number of different agri-environmental schemes in which a farmer declared participation (#AES). This variable represents count data and was therefore modelled using either a negative binomial model or a Poisson model (depending on the degree of overdispersion) with log link.

The weight matrix W is directly derived from the adjacency matrix of a network. Here, this network corresponded to a general farmer network that comprised all interviewed farmers and their relations modelled as undirected ties. All non-interviewed actors had to be excluded for this purpose. To account for differences in individual network sizes among farmers, we row-standardized W as recommended so that all rows sum to 1 (Dittrich et al., 2020; Leenders, 2002). This implies that the term Wy represents a vector of each farmer's peers' average level of AES participation. Therefore, the autocorrelation parameter ρ quantifies the influence of a farmer's peers' AES participation on their own AES participation. With only one weight matrix and a single autocorrelation parameter, we assume that a single network process is at work and is valid for all farmers (Dittrich et al., 2020). This assumption can be relaxed with a higher order NAM (see below).

The matrix of predictor variables may include both variables of interest to test a particular hypothesis as well as covariates to control for homophily among farmers. Homophily means that farmers preferentially establish ties to other farmers with similar characteristics. If such characteristics are at the same time correlated with the behaviour of interest (here level of AES participation), we might find putative network effects (endogenous or exogenous) that are not the result of social influence but the result of homophily. In this case, a farmer's behaviour is not influenced by the behaviour or the characteristics of their peers, but is just the result of sharing the same characteristics with peers and being therefore connected with these peers. This reversed causal direction cannot completely be ruled out with our data. However, we tried to control for homophily by including farmer attributes as covariates that might lead to preferential tie formation (Keil et al., 2017; Murendo et al., 2018; Varshney et al., 2022). Three of these were used before to find farmer clusters, that is, farm size, land-use system, and farmer's experience in agriculture (Section 2.3). In addition, we included the farmers' interest in topics related to biodiversity conservation as this attribute is likely to affect tie formation. We estimated this interest as a farmer's degree in a knowledge exchange network concerning topics related to nature conservation. This network was similar to the one described in Section 2.4.1, but with undirected ties. The four covariates were not strongly correlated with each other ($|R|<0.5$; Table S2).

To test H2a, we did not include any further predictor variables. A significantly positive autocorrelation parameter ρ would indicate that a general endogenous network effect is operative. To test more specifically whether the conservation behaviour of large-scale farmers would influence the conservation behaviour of small-scale farmers (H2b), we had to fit a fourth-order NAM, that is, a model with four different autocorrelation parameters and four corresponding weight matrices (Kreft et al., 2023). For this purpose, we distinguished between small-scale farmers managing less than 500 ha ($n=49$) and large-scale farmers managing more than 500 ha ($n=21$). The general formula was as follows:

$$y=\begin{bmatrix} y_S \\ y_L \end{bmatrix}=\begin{bmatrix} \rho_{SS}W_{SS} & \rho_{SL}W_{SL} \\ \rho_{LS}W_{LS} & \rho_{LL}W_{LL} \end{bmatrix}\begin{bmatrix} y_S \\ y_L \end{bmatrix}+X\beta+\varepsilon$$

$$=\left(\rho_{SS}\begin{bmatrix} W_{SS} & 0 \\ 0 & 0 \end{bmatrix}+\rho_{LL}\begin{bmatrix} 0 & 0 \\ 0 & W_{LL} \end{bmatrix}+\rho_{SL}\begin{bmatrix} 0 & W_{SL} \\ 0 & 0 \end{bmatrix}+\rho_{LS}\begin{bmatrix} 0 & 0 \\ W_{LS} & 0 \end{bmatrix}\right)\begin{bmatrix} y_S \\ y_L \end{bmatrix}+X\beta+\varepsilon \quad (2)$$

where y_S and y_L contain values for the dependent variable for small- and large-scale farmers, respectively. W_{SS} and W_{LL} are weight matrices reflecting the subnetworks of either small-scale or large-scale farmers only, and W_{SL} and W_{LS} reflect the subnetworks representing relations between small- and large-scale farmers. Correspondingly, the network autocorrelation parameters measure the influence of small-scale peers' behaviour on small-scale farmers' behaviour (ρ_{SS}), the influence of large-scale peers' behaviour on small-scale farmers' behaviour (ρ_{SL}), the influence of small-scale peers' behaviour on large-scale farmers' behaviour (ρ_{LS}) and the influence of large-scale peers' behaviour on large-scale farmers' behaviour (ρ_{LL}). A significantly positive ρ_{SL} would verify H2b.

So far, we used Formulas (1) and (2) to test for endogenous network effects. However, the same models can also be used to test for exogenous network effects (H2c and H2d) and correlated effects (H2e and H2f). To this end, we added one specific predictor variable for each hypothesis within the design matrix X. For exogenous network effects, this predictor variable measured an aggregated characteristic of each farmer's peers. For correlated effects, this predictor variable measured a characteristic of each farmer themselves. Due to the limited sample size and the inclusion of covariates to control for homophily, we tested each hypothesis separately. To test H2c, that is, whether social learning affects farmers' behaviour, the added predictor variable measured the aggregated propensity of a farmer's peers to share knowledge on topics related to biodiversity conservation. This measure was used because information on the actual knowledgeability of each farmer was lacking. As an estimate for each farmer's propensity to share biodiversity-related knowledge, we used the number of peers they provide with knowledge, that is, their out-degree in the knowledge-exchange network for topics related to biodiversity conservation (Section 2.4.1). The aggregated propensity of a farmer's peers to share knowledge was then calculated as the sum of their propensity scores (Kreft et al., 2023). Similarly, to test H2d, that is, whether peer support affects farmers' behaviour, we added a predictor variable that measured the amount of support a farmer receives from their peers. We quantified this amount by the in-degree in the support network for achieving conservation goals (Section 2.4.1), considering only ties from farmers. To test H2e, that is, whether farmers' level of AES participation is associated with receiving professional information, we added a predictor variable that measured a farmer's connection to advisory non-profit organizations. For this purpose, we created a general, that is, topic-independent, knowledge exchange network and calculated each farmer's in-degree considering incoming ties from non-profit organizations only. The same network was also used to quantify farmers' connection to private companies when testing H2f, that is, whether farmers' level of AES participation is associated with ties to private companies.

We used both the simple and the fourth-order NAM to test H2c to H2f. However, due to sample size limitations, the number of covariates in X had to be restricted to one or two in the fourth-order NAMs given that the model already included four Wy-terms. Therefore, we tried all possible combinations of one or two covariates and selected the one yielding the lowest AICc.

All NAMs were fitted with the function glm of the R-package stats. Prior to modelling, we Box-Cox transformed all quantitative variables to increase the symmetry of their distribution and then centred and scaled them to yield comparable regression coefficients. Since the glm function cannot handle missing values, missing values had to be imputed. The data matrix of 70 farmers × 5 variables included three missing values (0.86%) with three farmers having one missing value. We used the R package mice (van Buuren & Groothuis-Oudshoorn, 2011) to create 100 imputed datasets, for each of which the above modelling procedure was conducted. The model results were then pooled across datasets using Rubin's (1987) rule.

3 | RESULTS

3.1 | Farmer clusters

The HCA suggested that the 70 interviewed farmers can be grouped into four homogeneous clusters (Figures S2 and S3). Cluster 1 ($N=24$) represents experienced arable-crop farmers with moderate farm sizes (mostly <600 ha) and an intermediate number of crop types grown (median 3.5). We will refer to this cluster as 'arable-crop farmers'. Cluster 2 ($N=11$) consists of smallholder grassland farmers (farm sizes mostly <30 ha) who are often less experienced ('grassland

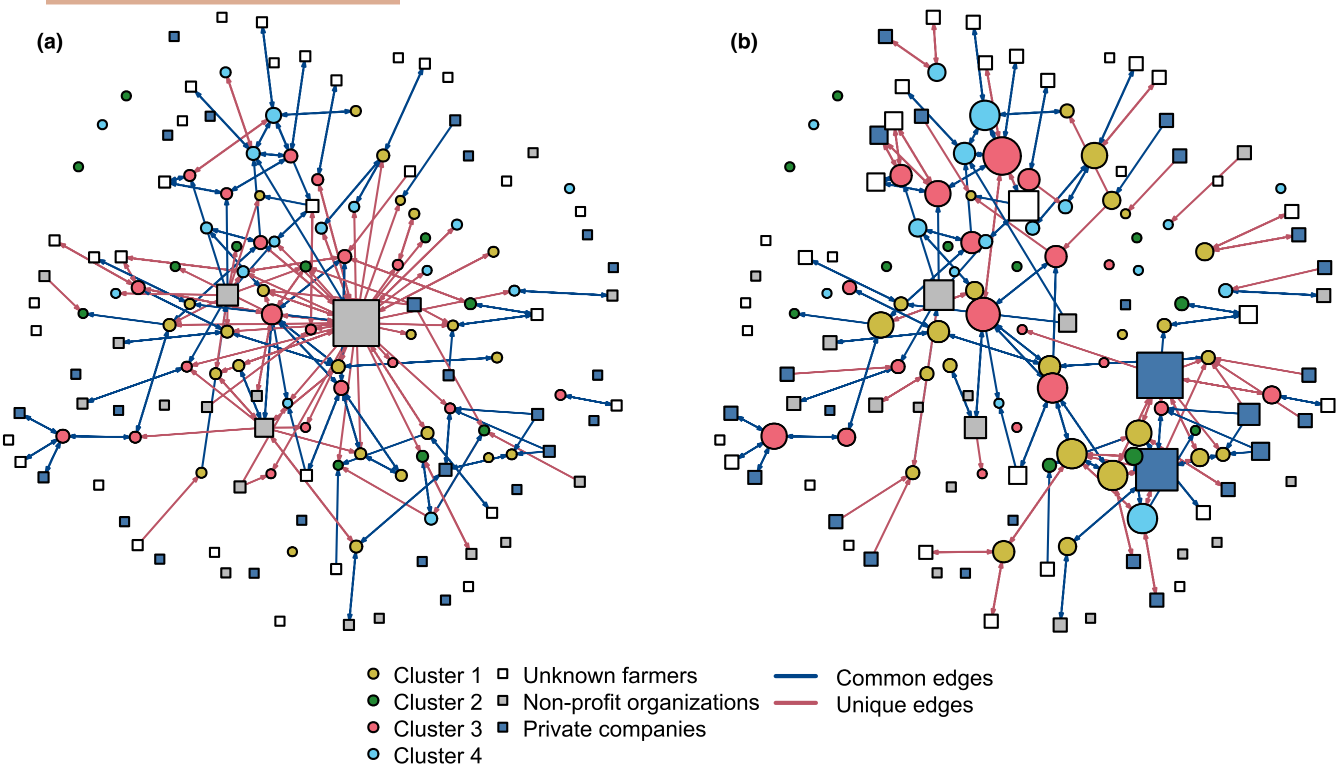

FIGURE 1 Knowledge exchange networks among farmers and other organizations concerning topics related to biodiversity conservation (a) and agricultural production (b). Node size is scaled according to out-degree centrality.

farmers'). Cluster 3 ($N=19$) represents experienced large-scale farmers (median farm size 770 ha, maximum 2300 ha) with both arable land and grassland ('large-scale farmers'). They grow a high number of different crop types (median = 5; incl. cereals, maize, oilseed rape and beets). Cluster 4 ($N=16$) comprises small-scale farmers (farm size mostly <85 ha) with both arable land and grassland ('small-scale farmers'). They are often less experienced and grow only a few different crop types (median = 2; no maize, less often oilseed rape or beets; mostly cereals and green fodder).

The four farmer clusters differed in their level of AES participation. While a clear majority of farmers in Clusters 2–4 participated in at least one AES (64%, 67% and 87%, respectively), about half of the arable-crop farmers did not participate in any AES (48%). Large-scale farmers were most engaged and participated often in two or more different AES (Figure S3n).

TABLE 1 Structural characteristics of the knowledge exchange (KEN) and support (SPN) networks concerning biodiversity conservation (BioCon) and agricultural production (AgrPro).

Network	Network size[a]	#farmers[b]	Centralization[c]
KEN BioCon	224	64	0.25
KEN AgrPro	204	55	0.05
SPN BioCon	147	61	0.24
SPN AgrPro	190	60	0.19

[a]Network size = the number of edges in the graph (integer).
[b]#Farmers = the number of interviewed farmers connected to at least one other node (in-degree OR out-degree >0).
[c]Centralization = a graph-level measure of centrality based on node-level out-degree centrality; normalized by its theoretical maximum value to make it comparable among graphs (between 0 and 1).

3.2 | Farmers' knowledge exchange networks

Most farmers ($N=64$) exchanged knowledge on topics related to biodiversity conservation and basically created one large network together with other (not interviewed) farmers, non-profit organizations and private companies (Figure 1a, Table 1). This network had a centralized structure with one non-profit organization in the centre as the key provider of knowledge. Accordingly, non-profit organizations were the actor group with the highest mean out-degree centrality (Figure 2c). However, many farmers perceived themselves not only as knowledge receivers but also as knowledge providers. In particular, large-scale farmers (Cluster 3) exhibited a relatively high mean out-degree centrality (Figure 2c). However, this group of farmers was also relatively large in our dataset and therefore knowledge flow from large-scale farmers to the other farmer clusters was not significantly higher than expected (Figure 3a). Smallholder grassland farmers (Cluster 2), in contrast, were least involved in knowledge exchange related to biodiversity conservation both in terms of knowledge reception (Figure 2a) and knowledge provision (Figure 2c). All farmer clusters received most of their knowledge from non-profit organizations, which passed information on to farmers significantly more often than expected by chance (Figure 3a).

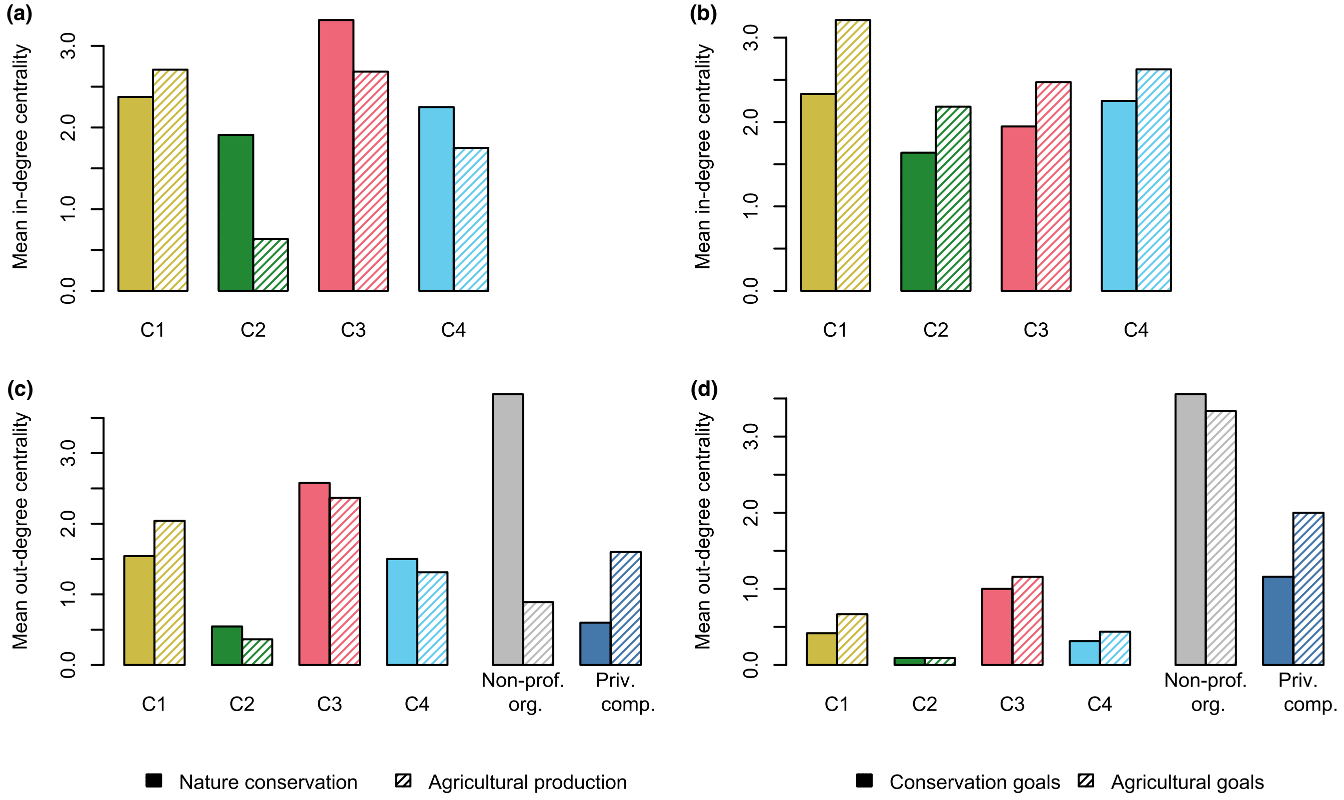

FIGURE 2 In-degree and out-degree centrality of different actor groups in knowledge exchange and support networks: a) mean in-degree centrality in knowledge exchange networks, b) mean in-degree centrality in support networks, c) mean out-degree in knowledge exchange networks, and d) mean out-degree centrality in support networks. Bars represent farmer clusters (C1 to C4), non-profit organizations and private companies.

The knowledge-exchange network related to agricultural production was slightly smaller than that related to biodiversity conservation, involved fewer farmers ($N=55$) and appeared less coherent (Figure 1b; Table 1). Besides one large network connecting 49 farmers, there were several small subnets. The structure was much less centralized and lacked a single main knowledge provider. Accordingly, central knowledge providers could be found in different actor groups here. Among farmer clusters, large-scale farmers (Cluster 3) were again those with the highest out-degree centrality, followed by arable-crop farmers (Cluster 1; Figure 2c). Large-scale farmers chose other large-scale farmers for advice on agricultural production more often than expected (Figure 3b). Thus, large-scale farmers act as key providers of knowledge related to agricultural production, but mostly within their own cluster. As in the knowledge exchange network concerning biodiversity conservation, grassland farmers were least involved in knowledge exchange on agricultural production (Figure 2a,c). Unlike in the knowledge exchange network concerning biodiversity conservation, non-profit organizations played only a subordinate role. Instead, some private companies yielded a relatively high out-degree centrality indicating their role as central knowledge providers (Figures 1b and 2c). In particular, arable-crop farmers (Cluster 1) asked mostly private companies for advice on agricultural production, more often than expected (Figure 3b). Arable-crop farmers were the only farmer cluster more active in exchanging knowledge on agricultural production, while the other clusters were more active in exchanging knowledge on biodiversity conservation (Figure 2a,c).

The two knowledge exchange networks had not only a different structure (Figure 1), but also showed a moderate QAP correlation ($R=0.56$, $p<0.001$). Most of the ties were unique to either of the networks, with 39% of ties occurring in both networks.

3.3 | Farmers' support networks

The farmers' support networks for achieving conservation goals and agricultural goals both involved most of the farmers ($N=61$ and 60, respectively), appeared relatively coherent with only one large subnetwork and had a relatively centralized structure with the same non-profit organization in the centre as in the knowledge exchange network concerning biodiversity conservation (Figure 4, Table 1). Two thirds of all ties (67%) were common to both networks yielding a QAP correlation of $R=0.81$ ($p<0.001$). However, the size of the support network for achieving agricultural goals was larger (Table 1) with more unique ties (55) than in the support network for achieving conservation goals (12; Figure 4). Accordingly, all farmer clusters yielded higher centrality values in the support network for achieving agricultural goals than in the support network

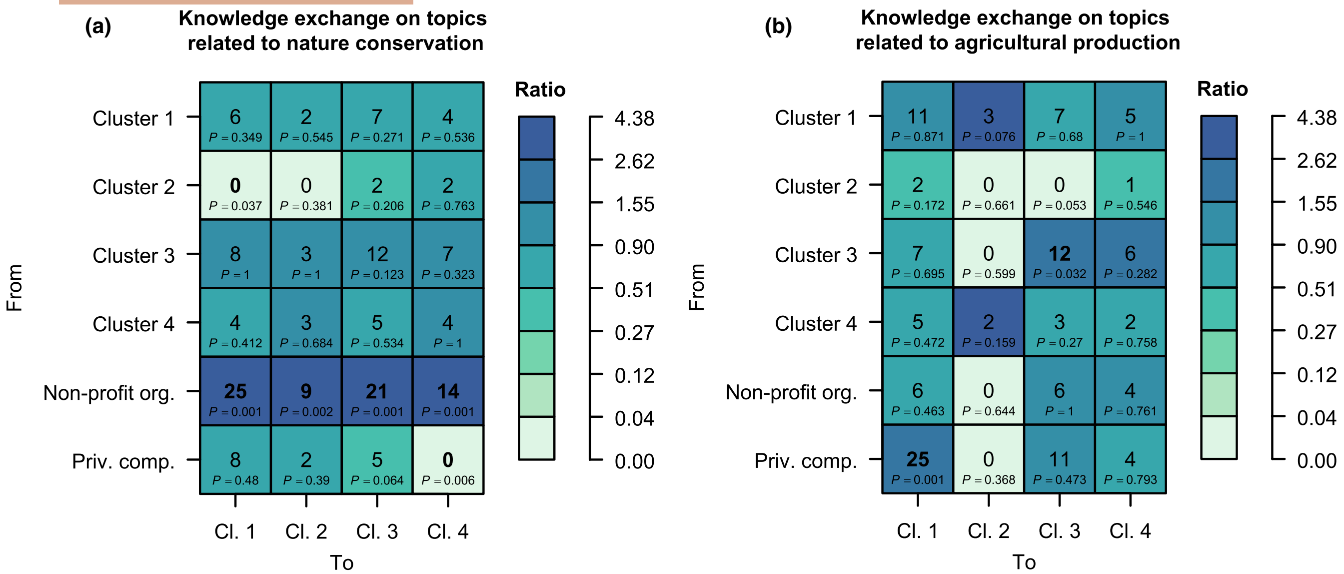

FIGURE 3 Knowledge exchange among actor groups as derived from the directed knowledge exchange networks related to a) nature conservation and b) agricultural production (Figure 1). Farmers are grouped into four clusters according to a hierarchical cluster analysis (Figures S2 and S3). Cell entries represent edge counts, that is, the number of ties pointing from one actor group to another. Cell colour represents the ratio of observed over expected edge counts under the null hypothesis that farmers choose at random which actors they ask for information (see main text). Edge counts significantly ($p < 0.05$) larger (ratio > 1) or smaller (ratio < 1) than expected are printed in bold face.

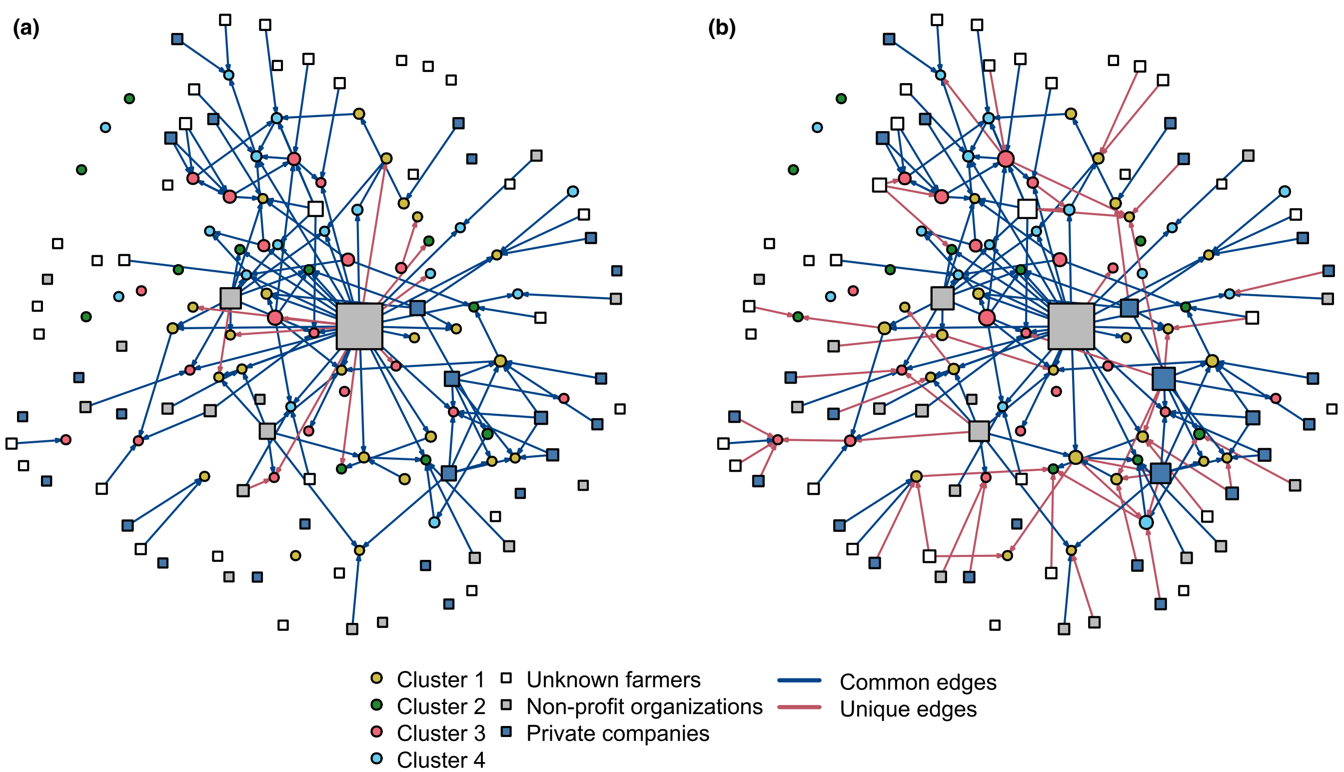

FIGURE 4 Support networks of farmers concerning support to achieve conservation goals (a) and agricultural goals (b). Node size is scaled according to out-degree centrality.

for achieving conservation goals (Figure 2b,d). In both support networks, non-profit organizations were the most central providers of support, while farmers seemed to receive support much less often from other farmers (Figure 2d). In the support network for achieving agricultural goals, private companies are also key providers of support (Figure 2d).

3.4 | Network effects on farmers' level of AES participation

The number of agri-environmental schemes a farmer participated in (#AES) was not generally related to the #AES their peers participated in (H2a; Figure 5a). When allowing for different network influence among small- and large-scale farmers, peer influence was evident among large-scale farmers (Figure 5b), while there was no evidence that small-scale farmers would mimic the behaviour of large-scale farmers (autocorrelation parameter ρ_{SL} not significantly different from zero, H2b). Peer support (H2d) had a strong positive effect on #AES in both first-order and fourth-order NAMs (Figure 5a,b). Neither ties to peers with a propensity to share biodiversity-related knowledge (H2c), nor ties to non-profit organizations (H2e) or private companies (H2f) showed a significant effect on #AES. In general, pure arable-crop farmers participated in fewer AES than farmers with mixed land-use systems. A similar tendency, but less statistically clear, could be observed for pure grassland farmers (Figure 5a,b).

4 | DISCUSSION

Our social network analysis revealed marked differences in the networking behaviour of farmers both between farmer clusters and between knowledge exchange networks related to biodiversity conservation and agricultural production. At the same time, our results show that, across clusters, farmers with incoming support ties feel mostly supported for achieving both their conservation as well as their agricultural goals. Moreover, NAMs showed that, more than any knowledge exchange, support by peers determines the farmers' level of AES participation. In the following, we discuss our findings and their implications for a broader dissemination of sustainable land use.

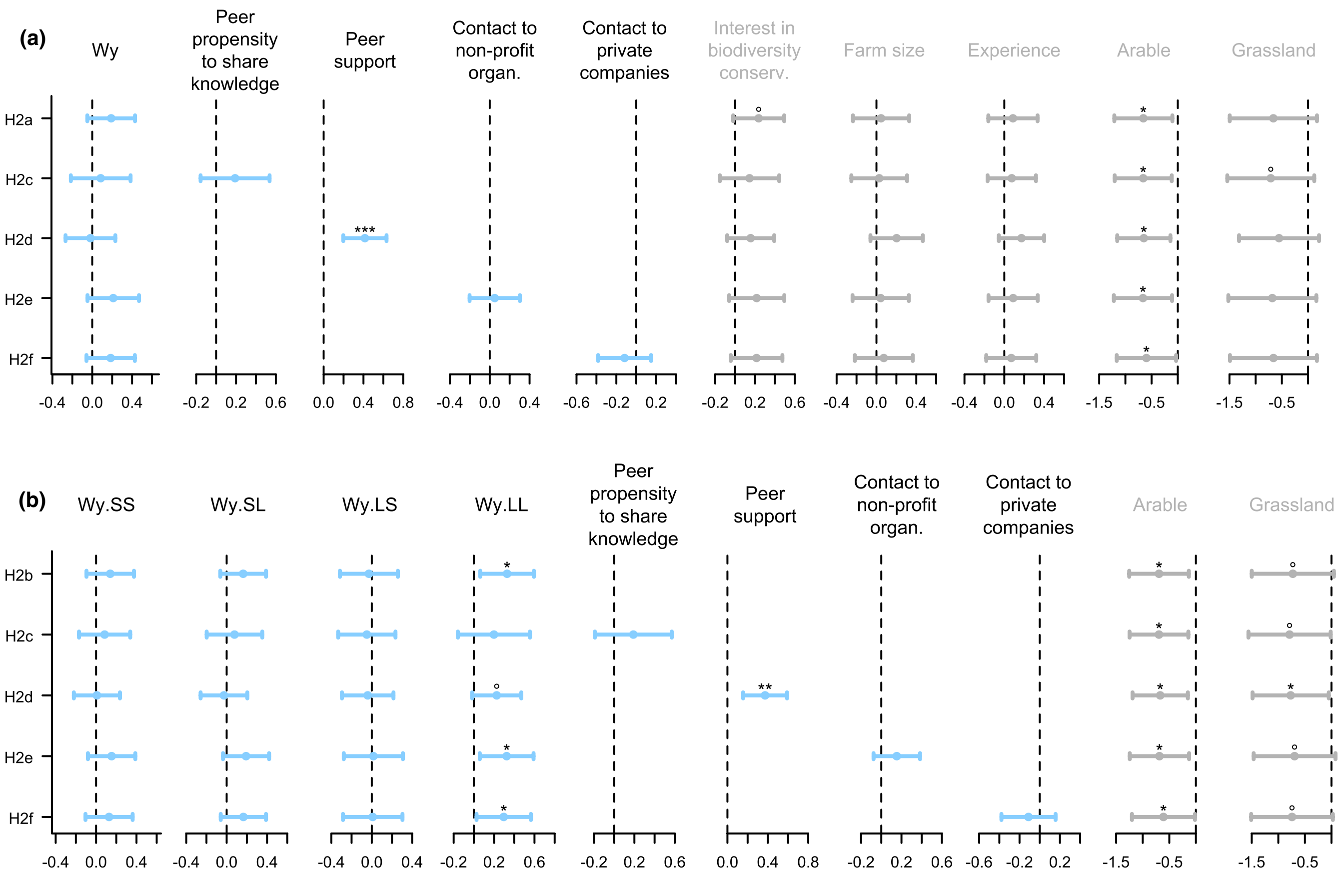

FIGURE 5 Parameter estimates resulting from network autocorrelation models (NAM) with the aim to test the different components of Hypothesis 2. Panel (a) shows the parameter estimates of first-order NAMs for testing hypotheses H2a and H2c to H2f. The first column (Wy) depicts the network autocorrelation parameter ρ, that is, the influence of a farmer's peers' behaviour on that farmers' own behaviour. Panel (b) shows parameter estimates of the fourth-order NAMs for testing hypotheses H2b to H2f. The first four columns (Wy.XX) depict the network autocorrelation parameters ρ_{SS}, ρ_{SL}, ρ_{LS} and ρ_{LL}, which measure the influence of the small-scale peers' behaviour on small-scale farmers' behaviour (SS), the influence of the large-scale peers' behaviour on small-scale farmers' behaviour (SL), the influence of the small-scale peers' behaviour on large-scale farmers' behaviour (LS), and the influence of the large-scale peers' behaviour on large-scale farmers' behaviour (LL). Depicted is the estimate (point), its 95% confidence interval, and its level of significance (**$p \leq 0.01$, *$p \leq 0.05$, °$p \leq 0.1$). Effects of control variables that are not relevant for testing hypotheses H2a to H2f are printed in grey. Note that the estimates of the categorical variable FarmType (here, coded with two binary indicator variables Arable and Grassland) appear larger and are not comparable to the estimates of the continuous predictor variables, as their standard deviation is <1.

4.1 | Distinct knowledge exchange networks related to biodiversity conservation and agricultural production

The two knowledge-exchange networks showed marked differences in terms of their structure, established ties and the most central knowledge providers, which is in line with our first hypothesis (H1a). Non-profit organizations were the most central providers of knowledge related to biodiversity conservation and central for all four farmer clusters (Figures 1a, 2c and 3a), while they played a secondary role in disseminating knowledge related to agricultural production (Figures 1b, 2c and 3b). Non-profit organizations are important for disseminating knowledge regarding conservation, as was shown to be the case in the Swiss lowlands (Gabel, Home, Stolze, Birrer, et al., 2018). Among the non-profit organizations, the most central one was the LPV, which conducted the interviews with the farmers. The central role of the LPV was expected given our sampling approach. Nevertheless, since the role of the LPV was not central in the knowledge exchange network related to agricultural production, we believe that farmers indeed perceive the LPV as a competent advisor for the implementation of conservation measures, and that its centrality was not solely an artefact of the research process. Landcare associations are often acknowledged as acting as coordinators for farmers engaged in biodiversity conservation (e.g. Leventon et al., 2017). Other non-profit organizations in our study consulted by many farmers for conservation-related topics included the regional farmer association (Sächsischer Landesbauernverband) and a regional training centre operated by the Saxonian authority for the environment, agriculture and geology (LfULG), which advises on incorporating policy and legal regulations into farming practices. The central role of such non-profit organizations in disseminating conservation-related knowledge reflects that biodiversity conservation is of high societal interest and is the responsibility of the whole of society.

Biodiversity conservation is, however, not a means for making profit by private companies, who played a minor role in the exchange on conservation-related topics (Figures 1a and 2c). In contrast, agricultural production is not only of societal interest, but also allows for profit to be made both by the farmers and by private companies who sell their input products with the promise to enhance agricultural production in the short term. Large-scale farmers and large private companies are therefore largely involved in the knowledge exchange for production-related topics (Figures 1b, 2c and 3b). This suggests that if biodiversity conservation is profitable for farmers, they might have a higher intrinsic motivation to implement conservation measures and to share their knowledge with other farmers. Such thinking aligns with the assumption, but also experience from practice, that farmers participate in AES for economic reasons (Gabel, Home, Stolze, Pfiffner, et al., 2018; Wittstock et al., 2022), as they presumably attribute an instrumental value to biodiversity. Other work also shows that farmers value biodiversity intrinsically and are thus motivated to use AES or even non-awarded measures (Klebl et al., 2024; Siebert et al., 2006). Given the diversity of values related to biodiversity and its conservation, but also the importance of production, public and not-for-profit advice should be available to farmers (Knuth et al., 2018). Then, their land-use decisions would be decoupled from private companies or large-scale farmers who might pursue profit-oriented goals rather than the goal of long-term sustainability.

Most farmers (Clusters 2–4) were more active in exchanging knowledge on conservation-related topics, probably as a result of contacting farmers through the LPV. However, arable-crop farmers (Cluster 1) were more active in exchanging knowledge related to agricultural production (Figure 2a,c). These farmers were the only group who actively (i.e. more than expected by chance) sought advice on production-related topics from private companies (Figure 3b), which are large, internationally operating providers of fodder, seed, fertilizers, pesticides and agricultural technology. As agricultural advice is not provided by the government, farmers engage differently with public and private services to receive the information for their farms (Sutherland et al., 2013). We assume that private companies provide information and advice for farmers on topics related to their products and how they may be used in their production system. Previous work showed that Swiss fruit farmers advised by pesticide companies were more likely to implement pesticides for dealing with fruit fly (*Drosophila suzukii*) infestations, compared to farmers who were advised by public advisory services and were more likely to use nets to prevent infestations (Wuepper et al., 2021). Although private advice does not need to exclude advice on or participation in AES, we found that arable-crop farmers participated in significantly fewer AES than farmers with mixed land-use systems (Figure 5a,b), while half of them did not participate in any AES (Figure S3n). This seems to imply that these farmers are influenced by these companies, who want to sell their products, but that this goal is not congruent with any potential conservation activities of their customers. While private, commercialized advice might be more personalized, it has generally not integrated knowledge related to biodiversity, likely due to its disconnection with the public research and education sector (Labarthe & Laurent, 2013; Prager et al., 2016).

4.2 | Largely overlapping support networks related to conservation and agricultural goals

In contrast to our first hypothesis (H1b), the support networks related to conservation and agricultural goals were not distinct, but rather overlapping and had a similar structure (Figure 4). Although non-profit organizations played a subordinate role in disseminating production-related knowledge, they were perceived almost as central as a supporter for achieving agricultural goals as for achieving conservation goals (Figure 2d). The LPV was regarded as the central supporter for both goals (Figure 4). To understand this apparent contradiction between the knowledge-exchange and support networks, there are several points to consider. Meeting agricultural goals for farmers is not necessarily synonymous with 'high agricultural production'. Farmers strive to manage their farms in a profitable way that allows them to meet their agricultural goals by receiving subsidies and payments through the implementation of AES, in which the LPV and other non-profit organizations provide support. In this sense, the support provided by non-profit organizations probably does not consist in the provision of knowledge on agricultural production, but in the assistance in identifying the appropriate programmes (including AES) and applying for them. The LPV is a central supporter that is well aware of the fact that farmers must be able to make a profit, and therefore helps farmers to combine agricultural production and biodiversity conservation accordingly. As such, our study confirms the key role that landcare associations take in the management of cultural landscapes (Park & Bieling, 2021). Given that the LPV is a non-profit organization, it seems that the dichotomy between these agricultural production and biodiversity conservation goals is potentially only present when profit is solely based on production, as is the case with arable-crop farmers. While this dichotomy is reinforced in top-down approaches (e.g. governmental ministries), on farms, biodiversity conservation and production are not necessarily segregated.

4.3 | Peer support rather than knowledge exchange determines AES participation

Peer support (H2d) turned out to be the most important network mechanism to explain farmers' participation in AES (Figure 5a,b). In the face of the observed support network for achieving conservation goals, this result was unexpected given that actors outside of the farmer community, in particular non-profit organizations, appeared to be the most central providers of support for achieving conservation goals (Figures 2d and 4a). However, a strong positive effect of peer support on the adoption of sustainable farming practices has also been observed in other farmer communities, where farmers rated the support by peers as more important than any coaching or training from external professionals (Ataei et al., 2022; Bjørnåvold et al., 2022). Our results support this notion for participation in AES and suggest that promoting mutual support among farmers might be an effective measure to disseminate biodiversity-friendly farming practices.

In contrast, there was no evidence that the level of AES participation would be associated with knowledge flow from peers (H2c) or external actors (H2e, H2f). Concerning the knowledge flow from private companies to farmers, a likely reason is that much of the variation in farmers' level of AES participation was already explained by the farmers' land-use system (which served as a covariate). As discussed above (Section 4.1), pure arable-crop farmers participated in fewer AES (Figure 5a,b and Figure S3n) and at the same time were often in contact with private companies for advice on agricultural production (Figure 3b). Concerning the knowledge flow from non-profit organizations, we have to consider that this actor group is rather diverse. While the most central knowledge providers on conservation-related topics (the LPV and LfULG) certainly have an interest in facilitating AES participation among farmers, other non-profit organizations, such as the regional farmer association or any farmer cooperatives, might pursue different goals. The German farmer association is known for striving to maintain a conventional agrifood system that does not necessarily support small-scale (i.e. agrarian, peasant) farming and practices that contribute to conservation efforts (Friedrich et al., 2022; Nowack & Hoffmann, 2020). Moreover, participation in farmer cooperatives can either encourage or discourage farmers from participating in AES (Peerlings & Polman, 2009; van Dijk et al., 2015), and is therefore rather ambiguous for biodiversity conservation on farms. The result that the propensity of a farmer's peers to share conservation-related knowledge had no effect on AES participation was unexpected. There are many examples where social learning has led to the diffusion of new practices (e.g. Kreft et al., 2023; Magnan et al., 2015; Nyantakyi-Frimpong et al., 2019). It is, however, in line with our knowledge-flow analysis, which indicated that farmers do not approach their peers within the same cluster more often than expected by chance to get advice on biodiversity conservation (Figure 3a). We see, therefore, a high potential in promoting knowledge exchange among farmers, and therefore to amplify social learning. As discussed below, large-scale farmers would take a key role in this process.

4.4 | The key role of large-scale farmers

With first-order NAMs, we found no evidence for a general endogenous network effect. Only when differentiating between small- and large-scale farmers in our fourth-order NAMs, we found that holders of large farms (i.e. those with >500 ha land) participated more often in AES when they had ties to other holders of large farms who participated in AES (Figure 5b). This indicates large-scale farmers perceive themselves as a farmer community more than smallholder farmers do. Although not entirely congruent with farmer Cluster 3 (Figure S3c), we can still assume that the exchange of knowledge (Figures 2a,c and 3) as well as the exchange of resources (Figures S4 and S5) is more intense among holders of large farms. A similar pattern has been observed in other farmer communities. For instance, large farms in Germany had a central role in adopting and disseminating knowledge about precision farming (Kutter et al., 2011). Also, intensive farmers in Spain with large farms dominated knowledge exchange among farmers, while small-scale farmers held more peripheral positions in the network (Albizua et al., 2020). However, in contrast to these farmer communities, where large-scale farmers disseminated modern farming practices across the entire farmer community, we found no indication that the large-scale farmers in our study region would influence the small-scale farmers' decisions related to AES participation. In our study, large-scale farmers participated in the highest number of AES compared to other clusters (Figure S3n), which confirms previous findings (Wittstock et al., 2022). Moreover, during the interviews, large-scale farmers more often than other farmers reported implementing further, non-awarded conservation measures, such as planting and maintaining hedgerows, installing nesting aids for birds or bats or setting up perches for birds of prey (Figure S3o). Still, we found no evidence that this apparently greater engagement in biodiversity conservation is mimicked by farmers with smaller farms (H2b; Figure 5b).

One proposed explanation for why large farms are more engaged in biodiversity conservation is that the scale of change and therefore risk involved for implementation is lower than it is for smaller farms (Brown et al., 2021). They can dedicate more and smaller areas to biodiversity conservation in such a way that complements their work processes. Moreover, the effort of implementing AES is proportionally higher for smaller farms also because they often do not have the resources or staff to deal with extra work associated with applying for and implementing AES (Paulus et al., 2022). While social learning through farm field days and demonstrations might encourage small-scale farmers to learn from large-scale farmers, the social norms and needs among small-scale farmers may simply be too different from those of large-scale farmers. The social norms regarding 'good farming' of each of these farmer groups may reinforce the practices they use, limiting the transferability of experiences between them. Each farmer group may follow their own cultural or social identities of what it means to be a 'good farmer', which is largely constrained by economic challenges, as has been previously found in the United Kingdom (Sutherland & Burton, 2011) particularly among organic farmers (Sutherland, 2013). As such, institutional efforts to support small-scale farmers may open opportunities for them to become more active in AES implementation. This will largely depend on local support for facilitating social interactions (Junquera et al., 2022). In such cases, large-scale farmers might at least provide experiential knowledge regarding the implementation of diverse AES.

5 | CONCLUSION

Our analysis of farmers' social networks in a typical Central European cultural landscape indicates that the proclaimed dichotomy in using land either for agricultural production or for biodiversity conservation does indeed partly exist, but at the same time appears to be overcome in the perception of many farmers. This may be due to the farmers included in our survey, who all have some kind of relationship with the local LPV to address local management needs and possibilities. In this context, the farmers we surveyed largely do not consider agricultural goals to be incompatible with conservation goals, and biodiversity conservation is an important issue for most farmers. Nevertheless, we found arable-crop farmers, the largest cluster in our sample, to participate in fewer AES and to focus often solely on production, while being in intensive exchange with large, internationally operating, private companies. These farmers' motivation to implement conservation measures might be enhanced if alternative information on agricultural production is freely accessible and offered by well-funded public advisory services. In such a case, site-specific ecological knowledge could be incorporated into knowledge on alternative production methods and sustainable farming practices.

Moreover, our study revealed that, although peer support involves mostly support for achieving both conservation and agricultural goals, the overall level of peer support is limited in relation to the support provided by external actors. In combination with our finding that peer support has a strong positive effect on AES participation, we conclude that mutual support among farmers should be promoted to effectively facilitate biodiversity-friendly farming practices.

Finally, our study shows that there is a high potential for the promotion of social learning among farmers about conservation-related topics, particularly if the context of different farming systems (e.g. small-scale vs. large-scale or farmer clusters as those found here) and the associated ideas regarding 'good farming' are reflected upon. The well-connected large-scale farmers with their comprehensive experience in both agricultural production and participation in AES play a central role. They should be more involved in strategies to foster the communication among farmers to support a wider dissemination of biodiversity-friendly farming.

AUTHOR CONTRIBUTIONS

Tobias Naaf, Maria Kernecker, Andreas Vierling, Stefanie Bülow and Heike Weidt conceived the ideas and designed methodology; Andreas Vierling, Stefanie Bülow and Heike Weidt oversaw the interviews; Tobias Naaf analysed the data; Tobias Naaf and Maria Kernecker led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

Three co-authors are affiliated with the landcare association that contacted and interviewed the farmers. Many farmers named this landcare association as important for providing advice on agri-environmental schemes. Data analysis was performed by the co-authors affiliated with ZALF. Therefore, results were produced independently of the landcare association.

DATA AVAILABILITY STATEMENT

The data of this study are publicly available on GESIS (https://doi.org/10.7802/2928). Note that some farmer attributes (age, experience in agriculture, farm size) had to be categorized in order to conform to data protection legislation and to preclude the restoration of a reference to any farmer person.

RESEARCH ETHICS

As there was no established human ethics process for the Leibniz Association nor for landcare associations at the time of designing and conducting this study, there is also no formal ethics approval for this study. The farmers included are not considered vulnerable, nor did we cause any psychological or emotional risks with our research, since we followed appropriate ethical standards. Specifically, we respected personal data, time needs and minimized any effort for farmers. Farmers were informed regarding the research goals, the voluntary nature of their participation in the interviews, the anonymization of their responses and data storage and protection. All farmers gave oral, informed consent to be interviewed. The names of all interviewed farmers and any contact persons were encoded by the co-authors affiliated with the LPV, and the researchers only used the codes for their analyses. Only for the interpretation of the findings did the LPV disclose the identity of some of the most influential actors. As such, farmers' information and data related to their networks remain protected with the co-authors from the LPV and are not used for any other purposes.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1. Questionnaire for structured interview with farmers.
Table S1. Agri-environmental schemes (AES) in which the interviewed farmers participated.
Table S2. Correlation among covariates used in network-autocorrelation modelling.
Figure S1. Location of the study region "Altkreis Delitzsch" in northwest Saxony, Germany.
Figure S2. Clustering of farmers with the Ward method.
Figure S3. Differences in farmer attributes among the four farmer clusters.
Figure S4. Resource-exchange networks among farmers and other organizations.
Figure S5. Mean in- and out-degree centrality for the resource-exchange networks.

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