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Assessing interaction intensity and relational diversity within the Agricultural Knowledge and Innovation Systems: the AKIS-Interact Index

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Abstract

Interactions among actors are recognised as fundamental to the well-functioning of Agricultural Knowledge and Innovation Systems (AKIS), yet operational metrics for measuring these interactions remain limited. This study addresses this methodological gap by developing the AKIS-Interact Index, a composite indicator that integrates interaction intensity and relational diversity into a single framework to assess actor embeddedness and systemic connectivity within the AKIS.

The AKIS-Interact Index was developed through an iterative process of empirical application and methodological refinement conducted from 2020 to 2025. Interaction intensity was measured using the arithmetic mean of interaction scores, while relational diversity was quantified using the Shannon entropy index. The framework was validated through its application to the Italian AKIS using data through interviews, stakeholder consultations and focus groups.

The empirical application revealed a moderate level of systemic embeddedness within the Italian AKIS, characterised by moderate interaction intensity and a very high level of relational diversity. The results indicate that interactions are broadly distributed across actor categories, despite important differences in relationship strength. The analysis identified four distinct relational profiles: systemic connectors, specialised hubs, diffuse connectors and peripheral actors. These findings demonstrate that relying on assessing interaction intensity alone may mask important differences in actor embeddedness that become visible when relational diversity is incorporated into the assessment.

1. Introduction

Agricultural Knowledge and Innovation Systems (AKIS) originated as a conceptual framework describing the coordinated “set of actors, and the links and interactions between them, engaged in the generation, transformation, transmission, storage, retrieval, integration, diffusion and use of knowledge and information” aimed at supporting decision-making and innovation in agriculture (Röling 1992; Röling and Engel, 1990). Early AKIS formulations focused mainly on the relationships among research, education, and advisory services and their role in innovation uptake (Nagel 1980, Bachmann 2000). Over time, however, the AKIS concept evolved from a linear knowledge-transfer model towards a systemic innovation framework that encompasses a broader range of actors, including private enterprises, policymakers, non-governmental organisations (NGOs), farmer organizations, and other actors, reflecting the complexity of agricultural innovation processes (Klerkx and Leeuwis 2009, Klerkx et al. 2012)

This evolution reflects a progressive attention from the individual actors composing the system to the interactions connecting them. Within contemporary AKIS approaches, interactions are increasingly recognised as the mechanisms through which knowledge is exchanged, combined and co-created. Consequently, AKIS well-functioning depends not only on the presence of actors and infrastructures, but also on the quality, intensity and configuration of the relationships that enable knowledge and innovation flows throughout the system.

The European Union (EU) has embedded the AKIS as a cornerstone of the Common Agricultural Policy (CAP), recognising its role in supporting innovation, sustainability and knowledge exchange across agricultural systems. Within the CAP Strategic Plans (Annex I of Commission Implementing Regulation (EU) 2022/1475), Member States are required to describe the structure and functioning of their national AKIS, as well as to develop an overall strategy for strengthening knowledge flows and collaboration, particularly, between advisory services, research institutions and CAP networks. Therefore, interactions among AKIS actors have become a direct object of policy design, monitoring and evaluation.

The EU evaluation framework identifies “strengthened collaboration among AKIS actors” as a key success factor (10.1.2) for assessing the effectiveness of AKIS strategies, creating a growing demand for tools capable of assessing

the quality and extent of these interactions (European Commission, 2023).

Despite this increasing policy relevance, operational metrics for measuring AKIS interactions remain limited. While, existing AKIS assessments predominantly focus on actor mapping, governance arrangements and network visualization (Knierim et al. 2015, Birke et al. 2022), much less attention has been devoted to the measurement of interaction intensity (Kassem et al., 2022), and almost none to the assessment of how interactions are distributed across actor categories (Aparicio-Montero et al. 2019). This gap represents a significant challenge for the monitoring and evaluation of AKIS strategies, particularly in view of the mandatory interim and ex-post evaluations required under the CAP Strategic Plans 2023–2027.

To address this challenge, this paper develops and refines a methodological framework for assessing interactions within the AKIS. Building on the relational matrix originally developed by Aparicio-Montero et al. (2019), subsequently applied in Malta, Italy (Cristiano et al. 2020) and Spain (Cruz et al. 2021), this study further develops the approach through an iterative process of empirical application and methodological refinement.

The resulting AKIS-Interact Index (AKIS-Interact) is a composite indicator combining measures of interaction intensity and relational diversity to provide a more comprehensive assessment of actor embeddedness and systemic connectivity within the AKIS.

2. Conceptual and theoretical background

The conceptual framework underpinning the AKIS-Interact builds on five key elements: (i) the role of interactions within the AKIS, (ii) the diversity of interaction forms and functions, (iii) the variety of actor categories involved, (iv) the distinction between interaction intensity and relational diversity, and (v) the measurement of relational diversity. These elements provide the conceptual basis for the methodology adopted in this study.

2.1 Interactions within the AKIS

AKIS are commonly conceptualized as systems composed of actors, institutions, infrastructures and the relationships connecting them. While actors and infrastructures constitute the structural components of the system, interactions represent their dynamic and functional dimension. Through interactions, knowledge is generated, exchanged, interpreted and applied, enabling key innovation system functions, such as knowledge diffusion, collective learning, coordination, resource mobilisation and the legitimisation of innovation processes (Hekkert and Negro, 2009, Klerkx et al. 2012, Bergek et al. 2015).

Accordingly, the well-functioning of the AKIS depends not only on actor diversity and infrastructural availability, but also on the quality, intensity and configuration of interactions among them. Strong interconnections allow activating system resources, facilitating collective learning and enabling the diffusion and scaling of innovation. Conversely, fragmented networks, weak research–practice linkages and insufficient institutional coordination may constrain knowledge flows and reduce innovation capacity (Lamprinopoulou et al. 2014, Minh 2019, Zahran et al. 2020). From this perspective, interactivity constitutes a distinct dimension of AKIS functioning and should therefore be assessed alongside actors, institutions and knowledge infrastructures (de Boon et al. 2022, Gutiérrez Cano et al. 2023, Amerani et al. 2024, Kountios et al. 2024, Birke et al. 2022).

In this study, interactions are understood as the relational mechanisms through which knowledge, resources, meanings and innovation opportunities circulate within AKIS. They are not limited to the transmission of information from one actor to another; rather, they include the processes through which knowledge is exchanged, interpreted, adapted,

combined and used in specific institutional, social and territorial contexts (Knierim and Birke, 2023, Sutherland et al. 2023, Fielke et al. 2020, Klerkx and Begemann 2020, Daum et al. 2025).

Interactions within AKIS take multiple and overlapping forms (Annex 1). First, they include knowledge-related interactions, such as information flows, advisory exchanges, training, peer learning and the translation of scientific, technical, experiential and local knowledge into actionable practices (Kassem et al. 2022, Alaie 2020, O'Sullivan et al. 2022, Kabirigi et al. 2022). Second, interactions include collaborative and co-innovation relations, such as multi-actor partnerships, innovation platforms, Operational Groups and participatory experimentation, through which actors jointly frame problems, combine different knowledge domains and develop context-specific solutions (Fieldsend et al. 2021, Mikwamba et al. 2021, Odera et al. 2025, Paschen et al. 2021). Third, they include coordination, brokerage and governance interactions, which connect otherwise fragmented actors, mediate between knowledge domains, mobilise resources and align innovation processes with institutional and policy priorities (Klerkx et al. 2012, Zahran et al. 2020, Bachev 2022; Bachev 2023; Sutherland and Prager 2025). These forms may be formal or informal, horizontal or vertical, unidirectional or reciprocal, and often coexist within the same AKIS.

Building on the relational matrix developed by Aparicio-Montero et al. (2019), which operationalised the broad actor classification developed within the PROAKIS FP7 project, this study adopts a refined set of 17 actor categories as the structural basis for assessing interactions within the AKIS. The categories and their descriptions are reported in Annex 2.

2.2 Interaction intensity and relational diversity

The literature on innovation and knowledge networks suggests that interactions differ not only in their form and function, but also in their strength and distribution across actors. In particular, the intensity of relationships has long been recognised as a relevant factor influencing knowledge exchange, trust building and collective learning processes. Strong ties are often associated with repeated interactions, mutual trust and effective knowledge sharing, particularly for complex and tacit knowledge (Hansen 1999, Rowley et al. 2000), whereas weak ties can facilitate access to novel information and bridge otherwise disconnected groups (Granovetter 1983, Uzzi 1997). Recent studies confirm that both tie types play complementary roles in innovation diffusion (Villarroel-Molina et al. 2023).

At the same time, AKIS and microAKIS studies show that different actors play distinct roles at different stages of the innovation process and that farmers often assemble diverse knowledge networks depending on their innovation needs and contexts (Sutherland & Labarthe, 2022). From this perspective, interactions should not be interpreted solely in terms of their intensity, but also in relation to how they are distributed across actor categories.

Recent studies argue that effective AKIS performance depends not only on the presence of diverse actors and infrastructures, but also on the quality and configuration of interactions among them (Birke et al. 2022, Kountios et al. 2024). Similarly, studies on actor networks and agroecological innovation systems show that innovation outcomes are strongly influenced by the structure of relationships through which actors' access, exchange and mobilise knowledge, resources and influence (Klerkx et al. 2012; Pigford et al. 2018; Hermans et al. 2015). Castella et al. (2022) further emphasise that the networking process itself constitutes a critical component of innovation dynamics, as changes in network configurations influence how knowledge is generated, shared and utilised.

Consequently, actors may display similar levels of interaction intensity while maintaining substantially different relational configurations. For example, an actor may interact intensively with a limited number of actor categories, whereas another may maintain interactions of comparable intensity distributed across a broader range of actors. These alternative configurations may create different opportunities for knowledge circulation, brokerage, collective learning and innovation.

This distinction provides the conceptual basis for combining interaction intensity and relational diversity within the AKIS-Interact framework. Assessing only interaction intensity alone may overlook important differences in actor embeddedness and systemic connectivity. Therefore, a more comprehensive understanding of interactions within the AKIS requires considering both the strength and the distribution of interactions across the system.

In this context, Shannon entropy has been widely used to assess diversity, uncertainty and distribution patterns in complex systems (Gotelli and Chao 2013, Zachary and Dobson 2021, Suurkuukka et al. 2014). Originally developed in information theory (Shannon 1948), it has subsequently been applied across multiple disciplines (ecology, organisational studies, network analysis and systems research) because it captures not only the presence of elements but also the balance of their distribution (Frizelle 2011, Sellitto et al. 2025, Cao et al. 2023). Frizelle (2011) argues that Shannon entropy provides a generic systems measure capable of capturing the degree of variety and distribution within interacting system elements, making it particularly suitable for analysing complex socio-technical configurations characterised by heterogeneous actors and multiple interaction pathways.

Several studies have employed Shannon entropy to characterise relational and structural diversity. More recently, Sellitto et al. (2025) applied Shannon entropy to assess supply-chain complexity, showing that the distribution of relationships among actors provides strategic information that cannot be derived from the strength or volume of interactions alone. Their findings support the idea that diversified relational structures contribute to adaptive capacity and system performance. Similarly, studies of innovation and collective intelligence suggest that diversified relational structures facilitate access to heterogeneous knowledge sources and support the generation of novel combinations of knowledge (Cao et al. 2023).

These contributions highlight the relevance of Shannon entropy as a means of representing relational diversity in systems characterised by multiple actors and heterogeneous interaction patterns. Particularly, within the AKIS conceptualization, the index provides information on whether actors rely on a few strategic relationships or maintain more diversified interaction portfolios across different actor categories. Integrating the Shannon entropy into the AKIS-Interact Index therefore allows a more systemic assessment of actor embeddedness and knowledge circulation than interaction intensity alone.

2.3 Conceptual framework of AKIS-Interact

Building upon the above conceptual considerations, this study argues that the assessment of interactions within AKIS should simultaneously consider two complementary dimensions: interaction intensity and relational diversity.

Interaction intensity captures the average strength of relationships among actor categories and provides information on how strongly actors interact within the system. Relational diversity captures whether interactions are highly concentrated around a limited number of actor categories or evenly distributed across a broader and more diversified relational portfolio. Consequently, while interaction intensity measures the magnitude of relationships, relational diversity captures their configuration across the system. Together, these dimensions reflect not only how strongly actors are connected, but also how widely their interactions are distributed across the AKIS. Therefore, considering these dimensions jointly allows a more comprehensive assessment of actor embeddedness and systemic connectivity than either dimension alone.

This conceptualisation forms the basis of AKIS-Interact, which integrates interaction intensity and relational diversity within a single analytical framework for assessing systemic connectivity within AKIS. By combining these two dimensions, AKIS-Interact enables the identification of different patterns of actor embeddedness within the system, distinguishing, for example, systemic connectors, specialised hubs, diffuse connectors, and peripheral actors.

3. Methodology for the index development

The AKIS-Interact index engages an entity–relationship model (ERM) that support the definition of the inter-relational system in place between predefined actor categories within a given innovation system (Elmasri & Navathe, 2015).

The empirical application to the Italian AKIS is used as a proof of concept to demonstrate the type of information that the index can support the identification of interaction intensity, relational diversity and actor profiles within an innovation system, through generating for research, policy and evaluation purposes.

3.1 Iterative refinement and validation process

The development and refinement of AKIS-Interact emerged from repeated cycles of application, observation, feedback and refinement carried out between 2020 and 2025. This process involved interviews, stakeholder consultations, Communities of Practice and focus groups conducted within AKIS-related research and capacity-development activities (Reason & Bradbury, 2008). The resulting insights contributed to refining the conceptual structure of the index, improving the usability of the relational matrix and adapting the assessment approach to the practical realities of AKIS evaluation.

The following insights emerged from this process, and they were integrated within the AKIS-Interact development.

3.1.1 Refinement of the assessment tool

Repeated applications of the relational matrix highlighted several challenges related to both usability and actor categorisation.

Respondents, particularly practitioners such as advisors and farmers, reported difficulties in understanding and using the relational matrix owing to its limited readability in A4 format and the requirement to enter information in actor–actor intersection cells. Consequently, the assessment instrument was redesigned into a more user-friendly survey format. Moreover, the tool was further refined by adding specific examples illustrating the different forms of interaction associated with each Likert-scale level. This improvement supported respondents in interpreting the response options more consistently and in assigning interaction scores more reliably across actors' interactions.

At the same time, the iterative applications revealed the need to refine the actor classification. Over the research period, respondents became more familiar with AKIS concepts and developed greater awareness of AKIS actor types and their respective roles. This learning occurred alongside changes within the Italian AKIS, including the emergence of new actors and functions, and the consolidation of EIP-Agri Operational Groups, Local Action Groups, organic and territorial districts and other intermediary organisations in brokerage, networking, advocacy and access-to-resources functions. This ultimately contributed to the refinement of the original classification from 14 to 17 actor categories and to the introduction of clearer definitions and explanatory notes within the survey tool.

The initial unfamiliarity with actors such as applied research institutions, impartial advisors, NGOs and financial bodies reflected both the broad PROAKIS FP7 project classification and limited visibility and embeddedness of some of these actors at local level.

The iterative refinement process also led to modifications in the response scale used to assess interactions among actor categories. The study initially adopted a five-point Likert scale following Aparicio-Montero et al. (2019), but this was subsequently reduced to a three-point scale to address respondents' difficulty in assessing interaction levels across different actor categories. These changes directly responded to recurring difficulties in providing nuanced assessments, prioritizing data quality over theoretical granularity to more effectively capture perceptions in complex

agricultural innovation systems research. Although five-point scales are often recommended for reliability, the iterative applications of AKIS-Interact suggested that simpler scales are preferable when respondents have limited knowledge of the broader AKIS. Three-point Likert scales reduce cognitive fatigue and central tendency bias, facilitating more consistent judgements of complex actor relationships (Bishop and Herron 2015, Jebb et al. 2021).

3.1.2 Insights from stakeholders' validation

The iterative applications of the relational matrix revealed an important methodological challenge related to respondents' systemic perspective. While the original question formulated by Aparicio-Montero et al. (2019) asked respondents to assess the extent to which different AKIS actors interact with one another, many stakeholders, particularly farmers, higher education institutions, and some agricultural advisors, generally found it challenging to accurately assess the degree of interaction among actor categories outside their own categories.

Therefore, for the specific purpose of collecting data for index development, the question was temporarily reformulated as: "To what extent do you interact with each of the following actor typologies within the AKIS?".

This limitation appeared to be associated with a restricted systemic understanding of the AKIS and the relatively low visibility and engagement of some actor categories, such as NGOs and financial institutions, within innovation processes. Similar challenges have been reported in previous AKIS studies, which highlight the need to strengthen actors' awareness of the broader innovation system and its interdependencies (Aparicio-Montero et al. 2019; Cristiano et al. 2023).

The same issue emerged when respondents were asked to assess bidirectional relationships among actor categories. Since its first application in Aparicio-Montero et al. (2019), the relational matrix used for data collection has consistently highlighted respondents' difficulty in assigning bidirectional values to relationships involving actor outside their own category. This challenge is particularly relevant because bidirectionality does not imply symmetry: the perceived strength of a relationship from actor A to actor B may differ from that perceived from actor B to actor A. As a consequence, the assessment framework was adapted towards a unidirectional approach. This modification improved the consistency of responses and reduced biases associated with limited systemic knowledge of the AKIS.

3.2 Operationalisation of AKIS-Interact

The conceptual theoretical framing is operationalised in the AKIS-Interact approach through an actor–actor relational matrix. Each row and column of the matrix represents one category of AKIS actor, while each cell captures the perceived intensity of the relation between two actor categories. Responses were supported by a Likert scale: 1 for weak relations, 2 for project based or casual relation, 3 for strong relation or/and formalized.

In this way, the matrix translates the relational mechanisms summarised in Table 1A, such as knowledge exchange, brokerage, co-innovation, vertical and horizontal linkages, and institutional coordination, into comparable empirical observations. The matrix allows the recognition of different actor categories contributions to AKIS functioning through distinct but interdependent roles: some actors generate codified knowledge, others translate and disseminate it, others mobilise experiential knowledge, provide resources, connect markets, create enabling policies, or facilitate collective learning.

To test the model through empirical evidence on degree of interaction between AKIS actors in Italy within the CAP strategic plan 2023–2027 programming period, a survey from July 2020 to April 2025 was launched to collect data from AKIS key actors in the Italian Agriculture and Forestry sector. The survey involved interviewing respondents using a structured questionnaire.

All in all, a total number of 37 observations were involved in the index development over the following steps of the overall iterative research approach followed to design the index:

- Interviews conducted for the purpose of the preparation of the report of the AKIS 2020 (i2connect H2020 project) (July – September 2020): 11 respondents;
- Interviews conducted for the purpose of the preparation of the report of the AKIS 2020 (i2connect H2020 project) (July – September 2024): 20 respondents;
- Interviews conducted during one meeting of the Community of Practice held for modernAKIS HEU project (October 2024): 2 respondents;
- 2 Focus groups held under modernAKIS HEU project for the purpose of the capacity development workshops (March 2025 and April 2025): 4 respondents.

Snowball sampling was used to select interviewees. While a probability sampling approach would theoretically be ideal, the heterogeneous and decentralized nature of the Italian AKIS made it impractical to construct a complete sampling frame. Therefore, relying on key actors and experts was a strategic necessity. This approach was deliberately chosen to ensure a comprehensive representation of all actor typologies within the index.

4. Construction of the AKIS-Interact Index

AKIS-Interact combines two complementary dimensions of AKIS functioning:

1. interaction intensity, measured through the arithmetic mean of interaction scores; and
2. relational diversity, measured through a normalised Shannon diversity index.

The AKIS-Interact approach aims to assess four complementary aspects of interactions within an AKIS: (i) the strength of interactions among actors; (ii) the diversity of actor relationships across the system; (iii) the overall configuration of relational patterns that support knowledge exchange, coordination and innovation processes and (iv) relational profiles of the different categories of AKIS actors (Fig. 1).

Source: Authors' elaboration

4.1. Measurement of Interaction intensity

The interaction intensity component was computed as the arithmetic mean of respondents' scores for each actor–actor relation. This formulation follows the standard use of the arithmetic mean for summarising numerical observations and deriving average scores across comparable units, as described by Jain & Gupta (2004).

The interaction intensity index is defined as:

$$I_i = \frac{1}{n} \sum_{j=1}^{n} x_{ij}$$

where:

- I_i = interaction intensity of actor i;
- x_{ij} = interaction score between actor $i$and actor j;
- n = number of actor categories considered.

To facilitate integration with the diversity component, the intensity score is normalised using the Max Abs Scaling method as:

$$I_i^* = \frac{I_i}{3}$$

where:

$$0 \leq I_i^* \leq 1$$

4.2. Measurement of Relational diversity

To capture the diversity of actor relationships within the AKIS, relational diversity is measured using the Shannon diversity index, widely employed in ecology, information theory and network studies to assess diversity and distribution patterns (Frizelle 2011, Sellitto et al. 2025, Cao et al., 2023).

The Shannon diversity index is defined as:

$$H_i = -\sum_{j=1}^{n} p_{ij} \ln\left(p_{ij}\right)$$

where:

$$p_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}}$$

and p_{ij}represents the proportion of actor i's total interaction intensity associated with actor j.

To allow comparison across actor categories, the diversity measure is normalised as:

$$H_i^* = \frac{H_i}{\ln\left(n\right)}$$

where:

$$0 \leq H_i^* \leq 1$$

Values close to 0 indicate highly concentrated interaction patterns, whereas values close to 1 indicate more evenly distributed interactions across actor categories.

4.3 Relational profiles of AKIS actors

The combined interpretation of these dimensions makes it possible to identify different relational profiles within the AKIS (Fig. 2). Actors characterised by both strong and diversified interactions is interpreted as systemic connectors, facilitating knowledge circulation across multiple actor categories. Actors displaying strong but more concentrated interaction patterns is interpreted as specialised hubs, whose influence derives from a limited number of strategically important relations. Actor categories exhibiting diversified but weaker interactions function as diffuse connectors, while those characterised by both low interaction intensity and low diversity are peripheral actors within the relational structure of the system.

Figure 2: Relational profiles of AKIS actors

Source: Authors elaboration

5. Results

5.1 Overall AKIS-Interact Index

The AKIS-Interact Index combines interaction intensity and relational diversity into a single composite measure. To ensure that actors score highly only when both dimensions are simultaneously strong, the composite index is calculated using a geometric mean:

$$AKIS - Interact\ index_i = \sqrt{I_i^* \times H_i^*}$$

where:

- AII_i = AKIS-Interact Index for actor i;
- I_i^* = normalised interaction intensity;
- H_i^* = normalised relational diversity.

The index ranges from 0 to 1.

Higher values indicate actors characterised by both strong and diversified interaction patterns, reflecting a high degree of systemic embeddedness within the AKIS. Lower values indicate weak interaction intensity, limited relational diversity, or both.

The following sections show the results about the AKIS-Interact and the relational profiles of AKIS actors in Italy.

5.2 Descriptive statistics

Table 1 presents the sample characteristics of AKIS key actors who participated in the survey. The sample comprised 10 (27.0%) observations from public administrations in knowledge and innovation, and 9 (24.3%) from research institutes, 7 (18.9%) from private agricultural advisory services, 5 (13.5%) represented farmers and farmer-based organizations, and 4 (10.8%) from universities. Agricultural education/high schools and public impartial agricultural advisory services were each represented by 1 (2.7%) actor.

Table 1
Sample characteristics of interviewees

Category	Frequency (n = 37)	Percent (%)
Universities	4	10.8
Research Institutes	9	24.3
Agricultural education/High Schools	1	2.7
Public Agricultural Advisory Services	1	2.7
Private Agricultural Advisory Services	7	18.9
Farmers and Farmers' based organisations (FBOs)	5	13.5
Public administrations in knowledge and innovation	10	27.0
Source: Authors' elaboration based on survey		

Table 2 presents the interaction intensity of AKIS actors.

Table 2
AKIS actor intensity index

Cat. of Actors	Actors from Universities	Actors from Research Institutes	Actors from Agricultural education/High Schools	Actors from Public Impartial Agricultural Advisory Services	Actors from Private Impartial Agricultural Advisory Services	Actors from Farmers and FBOs	Actors from Public administrations in knowledge and innovation
	Overall Average	Overall Average	Overall Average	Overall Average	Overall Average	Overall Average	Overall Average
A	1.4	1.0	1.5	1.5	1.1	1.6	1.2
B	1.3	0.9	1.5	1.5	1.1	1.6	1.2
C	1.5	0.9	1.7	1.7	0.9	1.7	1.2
D	0.9	0.8	1.4	1.5	0.6	1.5	1.0
E	0.8	0.7	0.4	1.9	0.8	1.7	1.3
F	1.6	0.9	1.5	1.9	1.1	1.8	0.9
G	2.0	0.9	1.2	2.1	1.3	1.7	1.1
H	1.8	1.1	1.2	1.7	1.1	1.8	1.3
I	2.1	1.0	0.8	1.6	1.2	1.8	1.3
J	1.3	1.2	0.7	1.9	0.9	1.7	1.5
K	1.2	0.6	0.8	2.1	1.0	1.4	1.0
L	1.0	0.8	0.6	1.9	1.0	1.5	0.9
M	0.6	0.6	0.2	2.1	0.9	1.4	1.0
N	1.4	0.9	1.2	2.2	1.1	2.0	1.0
O	1.4	0.8	1.0	2.2	1.2	1.4	0.8
P	1.1	0.6	0.3	1.7	0.8	1.0	0.2
Q	0.3	0.0	0.5	0.0	0.3	0.0	0.0

Source: Authors' elaboration based on survey.

[Insert Table 2 *here]*

5.3 Interaction patterns revealed by AKIS-Interact

Table 3 presents the interaction intensity, normalised interaction intensity, relational diversity (normalised Shannon index), AKIS-Interact Index, and relational profile for the 17 AKIS actor categories. Overall, the results reveal considerable variation in interaction intensity than relational diversity across actor categories. The normalised Shannon index ranges from 0.986 to 0.998, indicating a high level of relational diversity across all actor categories. This means that interactions are evenly distributed across actor categories. Although the AKIS-Interact index combines both interaction intensity and relational diversity, the observed differences in the AKIS-Interact values are driven primarily by variation in interaction intensity rather than by the breadth of actors' relational diversity within the AKIS.

Table 3
Interaction intensity, relational diversity and AKIS-Interact values by actor category

Code	AKIS actor category	Interaction intensity index	Normalized interaction intensity index	Relational diversity (Normalised Shannon Index)	AKIS-Interact Index	Relational profile
A	Universities	1.505	0.502	0.988	0.704	Specialised hub
B	Research institutes	1.449	0.483	0.986	0.690	Specialised hub
C	Applied research institutes / technology centres	1.465	0.488	0.990	0.695	Specialised hub
D	Agricultural education / high schools	1.208	0.403	0.991	0.632	Peripheral actor
E	Lifelong training providers	1.267	0.422	0.990	0.646	Peripheral actor
F	Public agricultural advisory services	1.355	0.452	0.990	0.668	Specialised hub
G	Private agricultural advisory services	1.392	0.464	0.991	0.678	Specialised hub
H	Farmers and farmer-based organisations	1.546	0.515	0.994	0.716	Systemic connector
I	Cooperatives and their federations	1.617	0.539	0.996	0.733	Systemic connector
J	Public administrations involved in knowledge and innovation	1.517	0.506	0.992	0.708	Systemic connector
K	Input and knowledge service providers	1.367	0.456	0.993	0.673	Systemic connector
L	Financial entities and banks	1.169	0.390	0.995	0.623	Diffuse connector
M	Other funding organisations	1.123	0.374	0.998	0.611	Diffuse connector
N	Demonstration farms	1.432	0.477	0.988	0.687	Specialised hub
O	Agri-food processors / industry	1.390	0.463	0.992	0.678	Systemic connector
P	Distributors and retailers	1.122	0.374	0.990	0.608	Peripheral actor
Q	Other AKIS actors (LAGs, Producers' Organisations, Regulatory Councils,	0.887	0.296	0.995	0.542	Diffuse connector

Source: Authors’ elaboration based on survey

Annex 1. Forms of interactions within AKIS

Code	AKIS actor category	Interaction intensity index	Normalized interaction intensity index	Relational diversity (Normalised Shannon Index)	AKIS-Interact Index	Relational profile
	Livestock Integrators, etc)					
Source: Authors' elaboration based on survey						
Annex 1. Forms of interactions within AKIS						

[Insert Table 3 *here]*

Cooperatives and their federations (I) recorded the highest AKIS-Interact index (0.733), followed by farmers and farmer-based organisations (H) (0.716) and public administrations involved in knowledge and innovation (J) (0.708). These actors also recorded the highest normalised interaction intensity values, while maintaining high levels of relational diversity. Their combination of strong connectivity and broad relational embeddedness characterises them as systemic connectors, reflecting their central role in linking multiple actor groups and facilitating knowledge exchange throughout the AKIS. Input and knowledge service providers (K), and agri-food processors (O) also emerged as systemic connectors (Fig. 3).

Universities (A), research institutes (B), applied research institutes and technology centres (C), public and private agricultural advisory services (F and G), and demonstration farms (N) recorded relatively high AKIS-Interact indices (0.668–0.704). These actor categories combine comparatively high interaction intensity with similarly high levels of relational diversity and characterised as specialised hubs (Fig. 3). This suggests that their role may depend on a more concentrated set of relevant institutional, knowledge, or advisory relations.

A different pattern emerges for financial entities and banks (L), other funding organisations (M), and other AKIS actors (Q). Despite exhibiting higher levels of relational diversity (0.995–0.998), these actor categories show relatively low interaction intensity, resulting in lower AKIS-Interact values (0.542–0.623). These actor categories are classified as diffuse connectors (Fig. 3); they are weakly connected on average, but their limited interactions are relatively spread across the system.

Agricultural education and high schools (D), lifelong training providers (E), and distributors and retailers (P) appear as peripheral actors, with an AKIS-Interact index ranging from 0.608 to 0.646. These actor categories combine comparatively low interaction intensity with lower or below-average relational diversity, suggesting a more limited role in knowledge exchange and innovation processes within the AKIS.

At system level, the AKIS-Interact Index indicates an overall interaction intensity of 1.342, corresponding to a normalised intensity score of 0.447. This suggests a moderate-low average strength of relations within the Italian AKIS. By contrast, the system-level Shannon relational diversity score is very high (0.992), indicating that interactions are broadly distributed across the actor–actor matrix rather than concentrated in a small number of relational pairs. The resulting composite AKIS-Interact Index is 0.666, suggesting a system with relatively broad relational coverage but still limited average interaction strength.

5.4 Relational diversity and actor profiles in Italy

Figure 3 presents the relational profile of Italian AKIS categories. The figure plots each actor category according to its average interaction intensity and normalised Shannon relational diversity. The vertical and horizontal reference lines represent the system averages for interaction intensity and relational diversity, respectively. The four quadrants identify

systemic connectors, specialised hubs, diffuse connectors, and peripheral actors. The figure illustrates how the AKIS-Interact Index distinguishes actors with similar interaction intensity but different relational configurations.

The results suggest that some actor categories (H, I, J) combine relatively high interaction intensity with high relational diversity, indicating a broad embeddedness within the AKIS and a potential role in connecting multiple knowledge domains. Other actor categories (A,B,C,F,N) display moderate or high interaction intensity but lower diversity values suggesting that their interaction patterns are concentrated around a smaller set of strategic relationships. Conversely, some actors (Q, M, L) show relatively diversified relational portfolios despite lower average interaction intensity, while others (D,E,P) occupy more peripheral positions characterised by both low interaction intensity and low relational diversity.

Note

Bubble size represents the AKIS-Interact Index. Dashed lines indicate system averages: Interaction intensity = 1.34; Relational diversity (Shannon index) = 0.99

Source: Authors' elaboration based on survey

6. Discussion

The empirical results provide an important validation of the AKIS-Interact Index as a meaningful composite measure of systemic embeddedness. The actor categories identified by the index as more interactive and systemically connected, particularly farmers and farmer-based organisations, cooperatives and their federations, agricultural advisory services, and public administrations involved in knowledge and innovation, correspond closely to the actor roles and interaction patterns already highlighted in previous analyses of the Italian AKIS. In particular, Cristiano et al. (2020) and Arzeni et al. (2023) confirm the centrality of researchers, farmers and their organisations, public administrations, cooperatives and Operational Groups in structuring interactive innovation processes in Italy. This convergence between the index-based relational profiles and previous qualitative and empirical studies suggests that the combination of interaction intensity and relational diversity provides a robust proxy for actors' systemic embeddedness within AKIS.

The results support the argument that actor embeddedness cannot be adequately understood through interaction intensity alone. Consistent with the literature (Birke et al. 2022, Kountios et al. 2024; Klerkx et al. 2012; Pigford et al. 2018; Hermans et al. 2015; Castella et al. 2022), actors may occupy different positions within innovation systems not only because of the strength of their interactions but also because of how these interactions are distributed across actor categories. Relational diversity therefore provides additional information on the breadth and configuration of actors' knowledge networks, complementing traditional measures of interaction intensity.

A key scientific contribution of AKIS-Interact lies in its capacity to move beyond project-level and case-study-based analyses of interaction innovation, that is more in line with the assumption that a well-functioning AKIS depends on overall system connectivity. Much of the existing literature on interactive innovation and AKIS relational dynamics focuses on specific projects, Operational Groups, innovation platforms, advisory initiatives or localised case studies (Adamsone-Fiskovica and Grivins 2022, Amerani et al. 2023, Arzeni et al. 2023). These studies provide valuable insights into how interaction, co-learning and knowledge exchange unfold in concrete innovation settings, but they rarely offer a metric capable of assessing the relational configuration of an entire AKIS. AKIS-Interact moves beyond project-level or case-study-based analysis by providing a system-level measure of interaction intensity and relational diversity across all relevant actor categories. In this sense, the index contributes to bridging micro-level evidence on interactive innovation with macro-level needs for AKIS assessment, comparison and policy evaluation.

The index also advances AKIS assessment by operationalising interactivity as a measurable and comparable property of innovation systems. Rather than considering interaction and interconnections only as a qualitative or normative principle, AKIS-Interact translates it into an empirical metric that can be used for scientific, policy and practical purposes. Scientifically, it provides a reproducible index for comparing actor embeddedness across AKIS contexts and for testing hypotheses on the relationship between interaction patterns, knowledge circulation and innovation system performance. It also highlights that interaction intensity alone is insufficient to understand actor embeddedness, since actors with similar levels of interaction may differ substantially in the diversity of their relational portfolios. The identification of systemic connectors, specialised hubs, diffuse connectors and peripheral actors further illustrates this point. Rather than ranking actors according to a single dimension, the framework highlights differentiated relational functions within the innovation system. This observation is consistent with innovation systems literature emphasising that actors contribute to knowledge exchange, brokerage, coordination and collective learning through different but complementary roles.

An interesting finding of this study concerns the consistently high levels of relational diversity observed across actor categories. While interaction intensity varies considerably among actors, relational diversity remains high throughout the system. This suggests that the Italian AKIS is characterised by a relatively broad relational coverage, in which most actor categories maintain connections with a wide range of actors. From this perspective, the principal challenge may not be the existence of connections, but rather their intensity and continuity. Future applications of AKIS-Interact in other national contexts will be useful for determining whether this pattern reflects a specific feature of the Italian AKIS or a broader characteristic of agricultural innovation systems.

From a policy perspective, AKIS-Interact responds to the growing need for operational tools to monitor collaboration and knowledge flows within CAP Strategic Plans. Current evaluation frameworks recognise strengthened collaboration among AKIS actors as a key success factor, but they provide limited guidance on how this dimension can be measured. The index can therefore support ex-ante diagnosis, ongoing and ex-post evaluation of AKIS strategies by identifying under-connected actor categories, structural weaknesses and changes in relational configurations over time. In this sense, it can help transform interactivity from a general policy objective into a monitorable dimension of AKIS functioning.

The practical relevance of the index is further strengthened by its online implementation. The tool can be applied autonomously by AKIS Coordination Bodies, evaluators, researchers and other stakeholders, who can collect data, download results and use the evidence to support institutional dialogue, self-assessment and strategic planning. Repeated application of the same metric enables standardised serial data collection, making it possible to compare the evolution of interaction intensity and relational diversity over time. This longitudinal use is particularly relevant for assessing whether AKIS strategies and other policy interventions contribute to strengthen interactivity, broader knowledge flows and more balanced relational integration among AKIS actors, along with focusing on possible less interconnected actors or identifying peripheral ones in view to formulate more targeted policy interventions.

During the three focus groups held in Italy between October 2024 and April 2025 where some AKIS coordination bodies expressed the expectation to use the index for the purpose of systematic assessment of the degree of interaction of their AKIS. These discussions confirmed the value of the index as a diagnostic tool for AKIS analysis within the CAP framework and as a means to support structured and evidence-based institutional dialogue among stakeholders. As a result, an online tool was developed to enable interested stakeholders, particularly AKIS coordination bodies, to assess the state of inter-actor relationships within AKIS in each Member State.

7. Conclusions

This study developed and applied the AKIS-Interact Index, a composite indicator designed to assess AKIS actor connectivity and systemic embeddedness within AKIS through the combined analysis of interaction intensity and relational diversity. By integrating these two dimensions, the framework addresses an important methodological gap in AKIS assessment: the need to move beyond actor mapping and to capture how strongly and how widely actors are connected within the system.

The application to the Italian AKIS showed that actors may differ not only in the average strength of their relationships, but also in the distribution of these relationships across actor categories. This allows the identification of differentiated relational profiles, including systemic connectors, specialised hubs, diffuse connectors and peripheral actors.

The findings suggest that the Italian AKIS is characterised by broad relational coverage but moderate interaction intensity, indicating that the main challenge may be less the absence of connections than their strength, continuity and strategic activation. AKIS-Interact therefore offers a useful framework for research, policy and evaluation purposes, particularly in the context of CAP Strategic Plans and AKIS strategies. Its repeated application could support monitoring over time, comparative analysis across contexts and evidence-based institutional dialogue. Future research should test the index in other national and regional AKIS and further explore dimensions such as interaction quality, power relations and temporal dynamics.

Use of AI

The authors used an AI-based language to perform English language proofreading of the manuscript. No AI tools were used for content generation or data analysis.

Declarations

Author Contribution

S.C. took the lead in conceptualizing the study, conducting the analysis, writing the manuscript and visualizing. V.C. contributed to data collection, interpretation of the results and contributed writing the manuscript. P.P. contributed writing and critically revising the manuscript. E.K.T. contributed to data analysis, interpretation of the results, and manuscript writing. All authors contributed to the article and approved the submitted version.

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Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

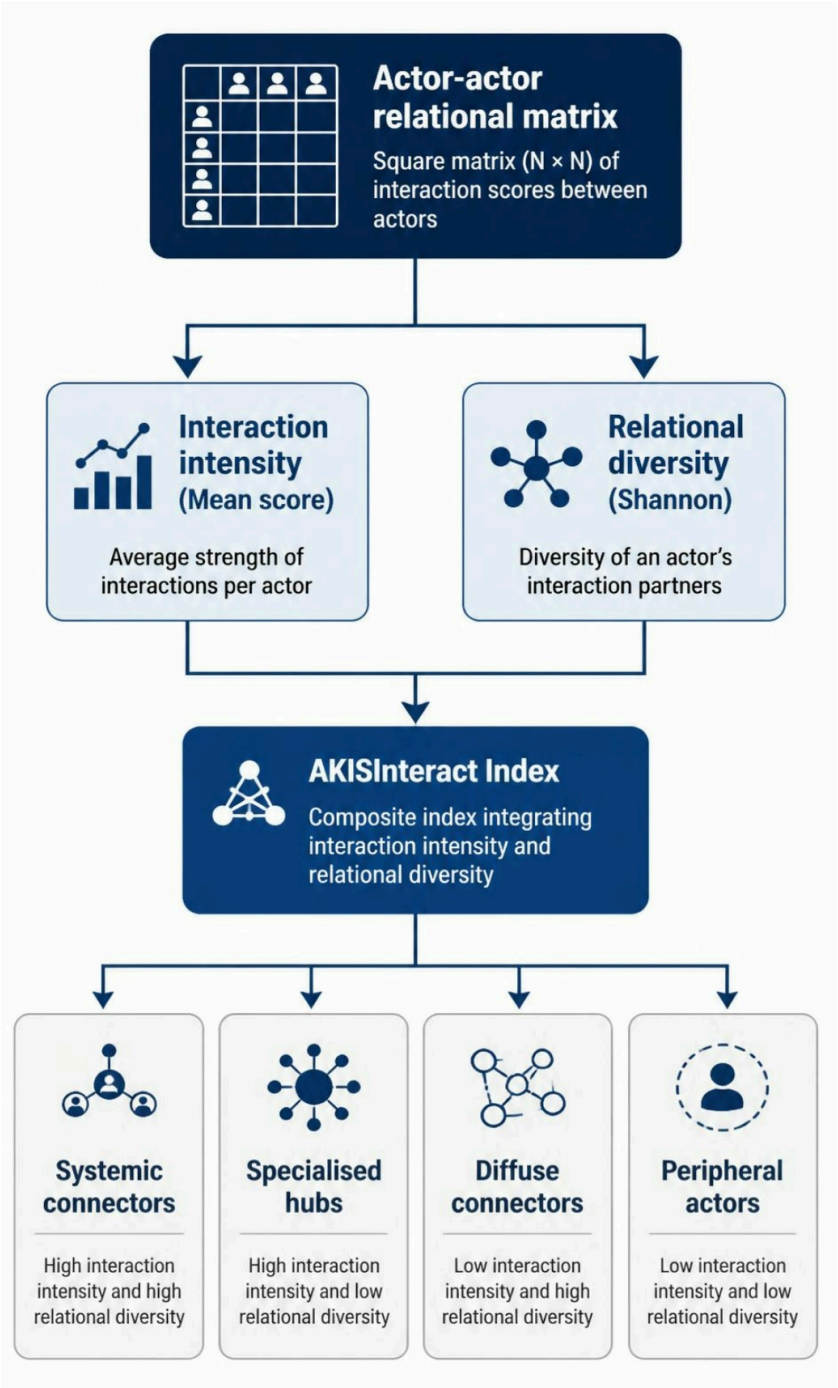


Figure 1

Conceptual architecture of the AKIS-Interact Index

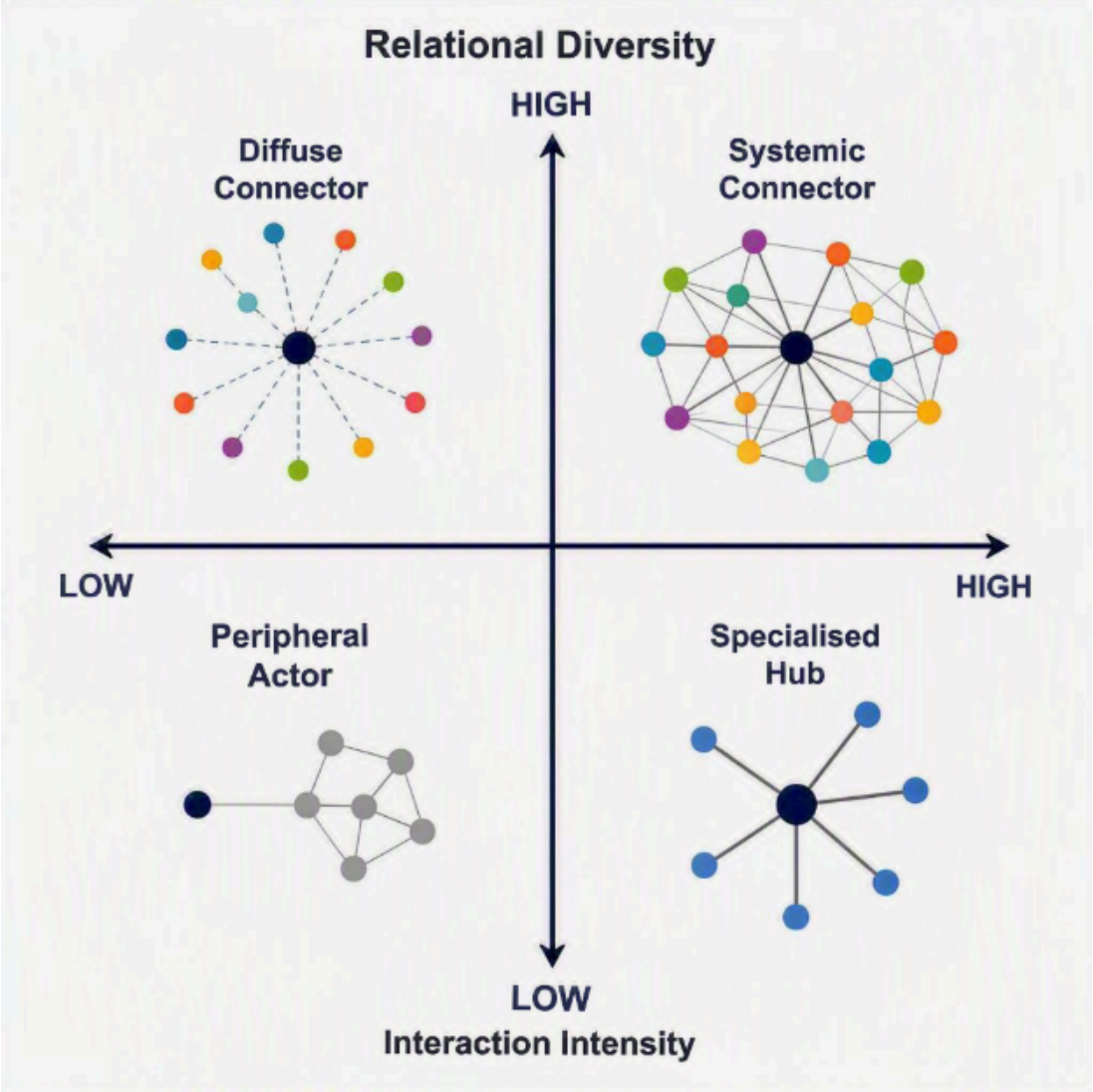


Figure 2

Relational profiles of AKIS actors

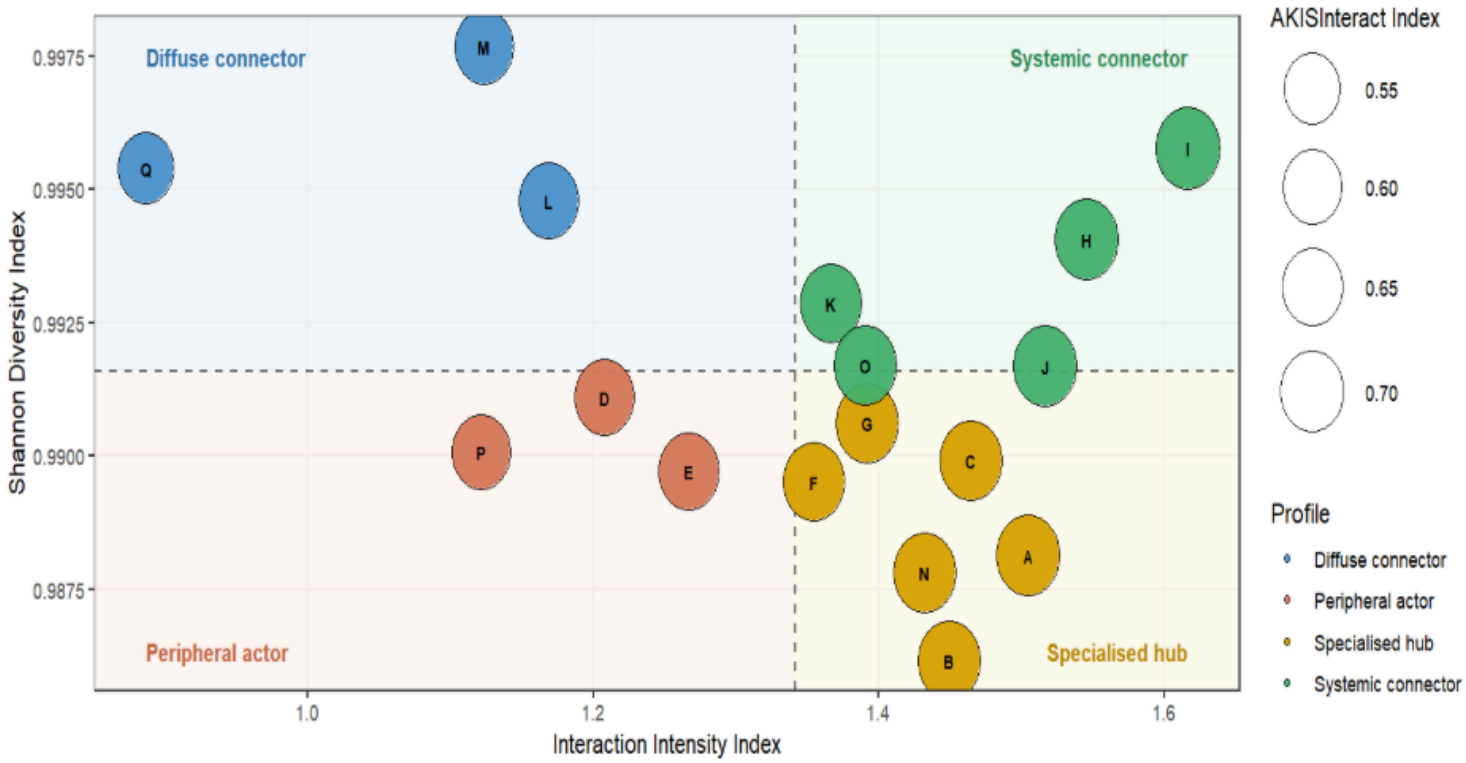


Figure 3

Relational profiles of AKIS actors