SCIENTIFIC ARTICLE

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Multidimensional evaluation of Agricultural Knowledge and Innovation Systems

ABSTRACT

The Agricultural Knowledge and Innovation Systems (AKIS) are responsible for the flow of information, knowledge, and innovation between the actors of the agricultural and food sector, as well as between those engaged in education, research, and extension. Strengthening cooperation and interaction between actors has become a cross-cutting objective of the European Union's Common Agricultural Policy (CAP). The CAP Strategic Plans in the Member States aim to develop agriculture through two interventions (support of EIP operational groups and the provision of knowledge exchange and dissemination actions). However, the AKIS goes beyond the CAP support, as several additional actions and incentives under national competence are needed for a modern, knowledge-based agricultural economy and well-functioning AKIS. Each EU Member State has developed its own AKIS, according to its specific conditions and needs. Previous studies on the comparison of AKIS across Member States have attempted to collect and analyse the specificities of each Member State, mainly through primary data collection. These studies are less capable of providing an objective comparison of AKIS systems in the Member States based on a common methodology. Although there are several indicator systems available to measure innovation performance, these indicator systems address the national/regional innovation performance but do not provide an adequate picture of the innovation performance of the agricultural economy. The aim of this study is to develop a framework for objective benchmarking of the Agricultural Knowledge and Innovation Systems supporting the agricultural economy of each EU Member State. To this end, the authors have created the AKIS index.

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Introduction

The second pillar of the Common Agricultural Policy was initially governed by Regulation (EC) No 1257/1999, which explicitly prioritised the adaptation of new and innovative technologies. Among the six rural development priorities outlined in Regulation (EU) No 1305/2013, the first priority emphasised knowledge transfer and the promotion of innovation in forestry, agriculture, and rural economies. During the 2014–2020 programming period, the European Commission introduced a new instrument to foster innovation, namely the support for EIP-AGRI operational groups. The EIP (European Innovation Partnership for Agricultural Productivity and Sustainability) serves as a network for innovation projects within individual Member States. The EIP-AGRI brings together the operational groups from Member States, aiming to connect various actors (farmers, advisors, researchers, agribusinesses, NGOs) across different innovation and agriculture sectors, thereby facilitating the development, utilisation and dissemination of new knowledge. The 2014–2020 programming period marked a significant advancement in the development of Agricultural Knowledge and Innovation Systems (AKIS). In addition to measures directly promoting innovation, it also fostered an environment conducive to innovation and networking (Fieldsend, 2020).

The CAP Strategic Plan Regulation for 2020-2027 consolidates the interventions financed under the European Agricultural Guarantee Fund (EAGF) and the European Agricultural Fund for Rural Development (EAFRD). Council Regulation (EU) 2021/2115 outlines nine specific objectives, along with an additional objective that horizontally integrates goals aimed at modernising agriculture and rural areas. Member States are required to outline the intervention logic they plan to implement in their National Strategic Plans, thereby enhancing coherence among the various subsystems of Agricultural Knowledge and Innovation Systems (AKIS) (Regulation (EU) 2021/2115, p. 9).

AKIS has become an integral part of the Common Agricultural Policy (CAP), facilitating the flow of information, knowledge, and innovation among stakeholders in the agricultural and food economy, as well as participants in education, research, and advisory services (Röling and Engel, 1991; EU SCAR, 2012). Over the past years, AKIS has undergone significant conceptual and substantive evolution, paralleling its integration into policymaking. Originally, the term AKIS referred to "Agricultural Knowledge and Information Systems" (Fieldsend, 2020). Gradually, the terminology shifted from "information systems" to "innovation systems", reflecting a broader scope. Today, AKIS is understood as "Agricultural Knowledge and Innovation Systems" (EU SCAR, 2012). Extending beyond the framework of CAP, the AKIS approach encompasses the development of relationships among relevant organisations, institutional infrastructures, various incentives, and budgetary mechanisms (EU SCAR, 2012). In the agricultural sector, the notion of a sectoral innovation system can be conceptualised within the AKIS framework: an innovation-generating ecosystem that integrates, within a given sector, the domain of products and technologies together with the relevant actors and institutions – research and higher-education organisations, advisory service providers, companies, producer groups, and public authorities (Malerba, 2002; Wintjes, 2016). Each sectoral system has its own specific knowledge base, technological requirements, network of relations, input structure, and demand side; these elements jointly influence the development of innovation processes. At the same time, the operation of the system is strongly shaped by innovation policy, as well as by various national and international incentives, the main purpose of which is to ensure the diffusion of knowledge and results. In European agriculture, this logic is institutionally framed by the Common Agricultural Policy (CAP).

There are notable differences among Member States concerning the fragmentation of AKIS, the number and diversity of actors, the types of institutions involved, the levels and subsystems of governance, funding schemes, and the characteristics and performance of their agricultural economies (OECD, 2023). Although Birke *et al.* (2022) highlight that no universal blueprint exists for designing an ideal AKIS, this study aims to develop a framework for objectively comparing Agricultural Knowledge and Innovation Systems of EU Member States.

The authors of this paper aim to answer the following research questions:

- How can the available baseline data for the assessment of AKIS be organised systematically?
- What quantifiable indicators can be developed to examine the subsystems of AKIS?
- What relationships exist among these indicators, and how do they influence one another?
- In what ways are the AKIS subsystems of different Member States similar or distinct?
- Can a ranking of Member State AKIS be established, and can the Member States be grouped based on certain characteristics?

Factors determining the performance of agricultural knowledge and innovation systems

Several measurement systems exist for evaluating innovation performance (e.g., BISI, EIS, GII); however, these are less suited for capturing the innovation dynamics of agriculture and the complex structure of Agricultural Knowledge and Innovation Systems (AKIS). Previous comparative studies of AKIS across Member States have primarily focused on identifying and analysing national specificities, relying mainly on primary data collection. In parallel, the literature on innovation systems has developed and employed a variety of analytical approaches for their dynamic examination and assessment (Spielman *et al.,* 2009), among which indicator-based benchmark analysis is most closely aligned with the methodological framework of this study.

Complementing this, guidelines developed for AKIS assessment typically adopt a multi-step diagnostic approach, which relies extensively on the collection and processing of qualitative information (FAO, 2022). However, these studies or guides are less suitable for objective comparison based on a uniform methodology (Birke *et al.,* 2022; Spielman and Birner, 2008; Hall, 2007; Peterson and Perrault, 1998). There is broad consensus in the academic literature and policy analyses that the functioning of the AKIS is fundamentally based on knowledge creation, diffusion, and utilisation (Rivera, 2005; Kountios *et al.,* 2024a). From a functional perspective, these pillars align with the traditional components of education, research, and advisory services.

In recent years, however, digital tools and infrastructures have emerged as a distinct and increasingly essential component of AKIS, now recognised as a key pillar of contemporary frameworks. The European Union's policies place particular emphasis on advancing agricultural digitalisation, aiming to enhance knowledge flows and accelerate the diffusion of innovations across the sector (EC, 2019). Agricultural economic performance is a crucial factor shaping the overall significance of the sector. It directly influences the operational intensity and strategic importance of individual AKIS components. Research evidence from both Europe and beyond demonstrates a strong positive correlation between agricultural performance and the strength of AKIS elements, particularly research and (R&D) investment and advisory services. Farm advisory and extension services also have a clear and measurable impact on farm-level performance (Parikoglou *et al.,* 2023). In constructing the AKIS index, the research dimensions were defined based on these components. Although farm advisory systems could be conceptually treated as a separate dimension within AKIS, the lack of harmonised and comparable quantitative statistical data across EU Member States made this unfeasible. Consequently, available EU-level data on advisory services were integrated under the research dimension, acknowledging the strong functional and institutional overlap between research and advisory systems in several Member States.

Agricultural education

Educational and training institutions play a pivotal role in initiating and fostering agricultural innovation processes. These institutions have the dual capacity to generate new technologies and disseminate them through the development of human resources. Increasing emphasis is being placed on practice-oriented agricultural education and training (AET), which must align labour market needs with the supply of skilled professionals (Kapronczai, 2018). Employers expect graduates to address emerging challenges effectively, making it essential for educational programmes to integrate the latest research findings into the curriculum (EU SCAR, 2012). In addition to the traditionally prioritised technological knowledge, students must develop the ability to understand business processes, interpret market dynamics, prepare and make economic decisions, and identify genuine opportunities for innovation (World Bank, 2012). Thus, the success of innovation processes hinges on the availability of well-trained professionals who combine advanced technological knowledge with up-to-date management expertise (Takácsné, 2015).

On average, only 8.5% of today's European farmers have completed formal agricultural training, while 70% rely solely on practical experience. Since initial training falls under national responsibility, agricultural education systems vary greatly across the EU (Augère-Granier, 2017). Agricultural vocational education and training (VET) is, in most EU Member States, structurally integrated into the general education system. For comparative assessment, Eurostat indicators provide useful reference points – notably the number of individuals holding agricultural qualifications, the share of farm managers with such qualifications, and EU expenditures on training and advisory services (Eurostat, 2020). These metrics, however, yield primarily a quantitative snapshot and do not capture the content, pedagogical approaches, or institutional arrangements that differentiate agricultural VET and higher education across countries. A comprehensive understanding of system performance therefore requires supplementing statistical indicators with qualitative inquiry (e.g., curriculum analyses, case studies, and institutional comparisons). One of the major shortcomings of this dimension is that it fdoes not adequately reflect the availability of advisory services across Member States, as the only available measure is an output indicator based on CAP-funded activities. It provides no information on the quality of the advisory services, the thematic areas they cover, or the farmers who make use of these services.

Agricultural research

To ensure that agriculture keeps pace with global social and environmental challenges, it is essential to generate new knowledge and technologies that create added value in agricultural production and processing (World Bank, 2012). According to Hall (2012), agricultural innovation should not be perceived as a research-driven process but rather as a process of novel application of ideas. In agriculture, the renewal of products and technological procedures is a multifaceted task influenced by socioeconomic conditions, ecological characteristics, and innovations in biology, chemistry, and technology. The complexity and interplay of these factors complicate the identification of agricultural innovations and the evaluation of their outcomes (Huszti, 2013). Agricultural research supports the enhancement of innovation capacity among individuals and organisations, encompassing basic, strategic, and adaptive agricultural sciences, as well as disciplines beyond agriculture (World Bank, 2012).

The Member States consider the ability of the agricultural economy to provide economically, socially, and environmentally sustainable responses to environmental dilemmas as a strategic priority (Leaver, 2010). The allocation of resources for research, development, and innovation (RDI) is critically important for a country's agricultural economy. In their article, Heisey and Fuglie (2018) examine the extent to which publicly funded R&D and other factors have contributed to long-term agricultural total factor productivity (TFP) growth in high-income countries. Countries maintaining high standards in RDI activities have adapted most effectively to global economic challenges (Kapronczai, 2017). In addition to national funding and CAP resources, EU Member States can also leverage the European Regional Development Fund (ERDF) to promote their RDI activities (Läpple *et al.,* 2015). Investments in R&D, whether public or private, often result in tangible outcomes after some delay, with the link between R&D spending and productivity growth typically becoming evident only after several years (Piesse and Thirtle, 2010).

Performance of the agricultural economy

Before introducing the indicators used to measure the performance of the agricultural economy, it is important to clarify the distinction between the concept of national economic and sectoral competitiveness. *National economic competitiveness* refers to a country's ability to produce goods and services that meet the requirements of international trade while increasing the returns on its production factors. In contrast, *sectoral competitiveness* measures the efficiency of a specific sector (Porter, 1985).

A strong correlation can be observed between competitiveness, economic growth, and innovation. Innovation can lead to increased productivity, reduced dependence of agriculture on natural factors, lower production costs in agriculture, and improved environmental performance of firms by promoting resource-saving practices (Coca *et al.,* 2017). Alarcón and Sánchez (2013) stablish a strong connection between the availability of external research, development, and innovation (RDI) resources and economic performance.

Several indicators are available for analysing agricultural performance. One such indicator is the gross value added (GVA) of the agricultural sector relative to total GDP, which highlights the agricultural economy's importance. A low significance of the sector indicates a high level of economic development (Coca *et al.,* 2017). Another commonly used indicator is annual labour productivity, expressed as the agricultural gross value added per annual work unit (AWU). This metric represents the value newly created by a full-time worker (employed or self-employed) in the agricultural sector (OECD, 2022). The competitiveness of countries can be compared based on the productivity of their economies (Porter, 1985), for which *Total Factor Productivity* (TFP) is commonly used. TFP measures the ratio of total output to total input, providing an aggregate metric of economic performance. An increase in TFP indicates that output growth exceeds the growth of inputs, indicating enhanced economic performance. TFP growth serves as a key indicator of overall agricultural efficiency, resource-use effectiveness, and, consequently, sustainability. These indicators are also employed by Spielman and Mekonnen (2009) in their benchmark analysis, although the use of total factor productivity (TFP) is subject to certain limitations. On the one hand, technological progress and technical efficiency cannot be clearly disentangled (Nowak and Kubik, 2019), while on the other hand, the reliability of data at the EU level remains questionable (Wimmer and Dakpo, 2023).

Potential of the younger generation

Numerous studies have demonstrated that young farmers tend to be more open-minded and possess a higher entrepreneurial inclination, making them more likely to embrace innovation (Yoon *et al.,* 2021; Balezentis *et al.,* 2020). Support mechanisms for strengthening young farmers were already available during the 2014–2020 programming period through targeted schemes for young agricultural producers. On one hand, farmers under the age of 40 could apply for area-based additional support. On the other hand, young farmers also had the opportunity to apply for business plan-based grants under the Rural Development Programme, aimed at encouraging the process of generational renewal in agriculture (Balezentis *et al.,* 2020).

The opportunities available to the younger generation are increasingly shaped by access to digital technologies and the advancement of digital competencies. Consequently, this dimension incorporates indicators related to digitalisation. Information and Communication Technology (ICT) play a key role in fostering innovation by facilitating the transmission of agricultural research results and developments among various stakeholders (Spielman and Birner, 2008; Kiraly *et al.,* 2023). Moreover, it offers opportunities to enhance knowledge flows between knowledge producers, disseminators, and users (Coca *et al.,* 2017). Digital maturity encompasses indicators that not only assess the usage of ICT but also measure the sophistication of digital technologies employed. According to Eurostat, the *Digital Skills Indicators* are composite metrics based on activities performed by individuals in relation to internet or software use in four specific areas: information, communication, problem-solving, and software skills. Collectively, these indicators provide a comprehensive perspective on the integration and application of digital competencies.

Methodology

Determining data and indicators

The conceptual framework for the development of the AKIS index is based on both domestic and international literature (Mutua and Goda, 2021; Mazziotta and Pareto, 2013; Goda, 2012; OECD, 2008). Primary data were obtained from publicly available sources, including EUROSTAT and the AGRI-FOOD PORTAL. When selecting the basic data, an important consideration was that the indicators should be available for all member states, covering several years retrospectively, and that there should be no strong correlation among them. After collecting the raw data, they were cleaned, organised, and standardised. The composite indicator was constructed based on Goda's (2012) doctoral dissertation and the multidimensional evaluation approach of Mutua and Goda (2021). Due to the limited availability of indicators of consistent quality across EU Member States, it was not feasible to apply a principal component analysis

Table 1: Baseline data and indicators used in constructing the AKIS index.

Agricultural Education					
Indicator	**Unit of Measure**	**Reference Basis**	**Interpretation**	**Data Source**	**Period of Study**
Number of Individuals with Agricultural Qualifications	number	Number of Farmers	The ratio of students who completed agricultural training to the total number of agricultural enterprises	EUROSTAT	2014–2020
Farm Managers with Agricultural Qualifications	percentage	–	Expresses the percentage ratio of all managers to agricultural managers	EUROSTAT	2010; 2013; 2016
EU Expenditures on Training and Consulting	million euros	Rural Development Fund (EAFRD)	The amount allocated to Measures 1 and 2 relatives to the total Rural Development Fund of the MS	AGRI-FOOD PORTAL	2014–2020
Agricultural Research					
Indicator	**Unit of Measure**	**Reference Basis**	**Interpretation**	**Data Source**	**Period of Study**
Government Expenditures on Agricultural R&D	percentage	–	Percentage of GDP allocated by the government to agricultural R&D.	EUROSTAT	2014–2020
Agricultural Enterprises 'Expenditures on R&D	million euros	Enterprises' Expenditures on R&D	Expenditures on R&D by agricultural, forestry, and fisheries enterprises in million euros based on NACE Rev. 2 activities	EUROSTAT	2014–2020
Expenditures on EIP	million euros	Rural Development Fund (EAFRD)	The amount allocated to EIP within Measure 16 relative to the total Rural Development Fund of the MS	AGRI-FOOD PORTAL	2014–2021

Performance of the Agricultural Economy					
Indicator	**Unit of Measure**	**Reference Basis**	**Interpretation**	**Data Source**	**Period of Study**
Labour Productivity in Agriculture	euros/AWU	–	Represents total labour productivity in agriculture	EUROSTAT	2014–2020
Total Factor Productivity (TFP)	percentage	–	Provides the total factor productivity of agriculture expressed as a percentage (2005=100%)	EUROSTAT	2014–2020
Potential of the Younger Generation					
Indicator	**Unit of Measure**	**Reference Basis**	**Interpretation**	**Data Source**	**Period of Study**
Young Farm Managers (the proportion of farm managers under 35 years of age relative to all managers)	percentage	–	Indicates the proportion of managers under 35 years of age relative to all managers	EUROSTAT	2010; 2013; 2016
Digital Skills (individuals with above-basic digital skills)	percentage	–	Individuals with basic or above-basic digital skills	EUROSTAT	2014–2020

Source: own composition

in this study. Consequently, all indicators were included with equal weight within each dimension. Similarly, the dimensions themselves were assigned equal weights in the construction of the AKIS index, in line with the approach adopted by Spielman and Mekonnen, (2009) in the measurement of agricultural innovation systems.

The data were compiled based on four key dimensions: agricultural education, agricultural research, agricultural performance, and the potential of younger generations. To prevent outliers from distorting the AKIS index results, multi-year averages of the baseline data were calculated, as outlined in Table 1. Some baseline data do not stem from annual data collection efforts; for these, available data from the study period were utilised. In other cases, the authors used the most recent data available (e.g., data from the General Agricultural Census [ÁMÖ] and Farm Structure Survey [GSZÖ], such as the proportion of farm managers with agricultural qualifications and the proportion of young farm managers).

Standardisation of indicators, sub-indices and creation of the AKIS index

Numerous methodologies are available for constructing sub-indices, among which standardisation is the most employed approach. Using the fundamental formula applied in the calculation of the Human Development Index (HDI), our pre-processed indicators can be rescaled to fall within the range of 0 to 1, rendering the data dimensionless (Goda, 2012). Normalisation of baseline data during the development of composite indices facilitates the transformation of indicators to a unified scale, enhancing comparability (OECD, 2008). In constructing the composite index, the *min-max normalisation method* (rescaling method) proposed by Mazziotta and Pareto (2013) was employed to mitigate the impact of outliers on the index (Mutua and Goda, 2021). This transformation technique scales the values of individual indicators (x_i) within the range of 0 to 1 based on their minimum (x_{min}) and maximum (x_{max}) values. The range and relative range of variation are derived from the basic formulas, as exemplified in the HDI calculation. The formula used is as follows (Goda, 2012; McSweeney *et al.,* 2010):

$$I_i = \frac{X_i - X_{min}}{R} \qquad (1)$$

where:
I_i: The i-th sub-index
x_i: The criterion value of the i-th exam
x_{min}: The lower value of the examined indicator
x_{max}: The upper value of the examined indicator
R: The range, calculated as $x_{max} - x_{min}$, representing the difference between the two extreme values of the examined indicator

For certain sub-indices, due to their inherent nature, a lower value is considered preferable (e.g., the age structure of farm managers). Consequently, the results of these sub-indices must be subtracted from one to ensure their comparability with the other sub-index results. This adjustment is performed using the following formula:

$$1 - I_i = \frac{X_i - X_{min}}{R} \qquad (2)$$

where:
I_i: The i-th sub-index
x_i: The criterion value of the i-th exam
x_{min}: The lower value of the examined indicator
x_{max}: The upper value of the examined indicator
R: The range, calculated as $x_{max} - x_{min}$, representing the difference between the two extreme values of the examined indicator

The index values of the four determining factors (D_i) were calculated by aggregating the arithmetic mean of the sub-indices:

$$D_i = \frac{Y_jSI_a + Y_jSI_b ... + Y_jS_{in}}{n} \qquad (3)$$

where:
D_i: The determining factor of the Member State
$Y_jS_{ia.......,n}$: The sub-indices of the specific determining factor

The AKIS index is a composite indicator calculated from the aggregated values of the defined indicators. It was derived as the arithmetic mean of the index values of the key factors, using the following formula:

$$AKIS\ index = \frac{DI_a + DI_b \ldots + DI_n}{n} \quad (4)$$

where:

AKIS index: Agricultural Knowledge and Innovation System index

$DI_{a\ldots\ldots,n}$: The determining factors of the Member States

Classification of AKIS index

The classification of Member States is based on the arithmetic mean of the AKIS index, as well as its upper and lower quartiles, defined as follows. These quartiles serve as the upper and lower boundaries of the index classification.

$$\underline{X}AKIS = \frac{AKIS_a + AKIS_b + \ldots + AKIS_n}{n} \quad (5)$$

where:

$\underline{X}AKIS$: The average AKIS value of the Member States

$AKIS_{i\ldots\ldots,\,n}$: The AKIS value of the Member States

$$Med_{upper}AKIS = \frac{AKIS_{max} - \underline{X}AKIS}{2} + \underline{X}AKIS \quad (5)$$

$$Med_{Lower}AKIS = \frac{\underline{X}AKIS - AKIS_{I\,min}}{2} + AKIS_{min} \quad (6)$$

where:

$Med_{upper}AKIS$: The median of *AKIS* is higher than the median of $\underline{X}AKIS$

$Med_{lower}AKIS$: The median of *AKIS* is lower than the median of $\underline{X}AKIS$

The Member States were grouped into three clusters based on their *AKIS* index values:

AKIS Leaders: Those Member States that demonstrate outstanding performance across all dimensions of the AKIS. In these countries, research and development expenditures and digital skills play a leading role, complemented by notable achievements in agricultural education. Member States classified as AKIS Leaders have an index value exceeding the upper median ($AKIS > Med_{upper}AKIS$).

AKIS Advancers: Those Member States that make substantial efforts in education as well as in research and development but do not reach the level of AKIS Leaders. In these countries, certain elements of the index demonstrate strong performance, while other dimensions show less remarkable results. ($Med_{upper}AKIS > AKIS > Med_{lower}AKIS$).

AKIS Laggards: This category includes Member States whose AKIS index demonstrates underperformance across nearly all dimensions ($AKIS < Med_{lower}AKIS$).

Results and Discussion

Agricultural Education

The analysis of agricultural education was conducted based on the ISCED classification (from secondary education to doctoral or equivalent levels). This framework provides a standardised and comparable method for categorising the various levels and types of education.

During the analysed period, France (269,608 individuals) and Germany (152,404 individuals) had the highest number of agricultural graduates within the EU in absolute terms. However, when considering the proportion of agricultural graduates relative to the total number of farm managers, the Czech Republic leads the ranking, closely followed by the Netherlands and Belgium. In contrast, Cyprus, Romania, Greece, Malta, Latvia, and Lithuania showed the lowest proportion of agricultural graduates, a trend mainly due to their fragmented farm structures. The Czech Republic's exceptional value is partly linked to the relatively low number of agricultural holdings. According to Eurostat data, the average size of Czech farms in 2016 was 133.0 hectares, significantly larger than the EU average of 16.6 hectares. Furthermore, data from the Czech land identification system in 2017 indicate an even higher average size of 216.6 hectares for arable farms. Additionally, farm managers and employees in the Czech Republic, particularly those in large-scale enterprises, often possess high levels of education and technical competence. In these large farms, agronomists typically conduct experiments with new technologies, underscoring the emphasis on innovation and professional expertise (Mrnuštík and Sutherland, 2022).

The *indicator for farm managers with agricultural qualifications* represents the proportion of managers who completed comprehensive agricultural training relative to the total number of agricultural holdings between 2010 and 2016. According to the indicator, comprehensive training is defined as any programme undertaken after compulsory education that is equivalent to at least two years of full-time study and completed at an agricultural college, university, or other higher education institution in an agriculture-related field. Luxembourg, the Czech Republic, France, Latvia, Poland, Austria, and Estonia reported relative index values exceeding 0.5. In contrast, Romania, Cyprus, and Greece ranked at the bottom of the list. The low positions of Greece and Cyprus can be attributed to the lack of mechanisms for coordinating AKIS in these countries (Birke *et al.,* 2022).

Output indicators have limitations, as they fail to capture the quality of agricultural education or participation in short-term, non-formal training programmes. Although such programmes do not grant formal qualifications, they provide valuable knowledge and foster new perspectives among agricultural workers, thereby promoting lifelong learning. To address this gap, training and advisory activities funded through the EAFRD were included in the analysis. Comparison of expenditure shares reveals that the Netherlands and Denmark allocated the highest proportion to training and advisory services, followed by Slovenia, the Czech Republic, and Finland. In contrast, Croatia, Greece, Cyprus, Hungary, and Romania ranked among the lowest-performing countries.

In the field of agricultural education, the Czech Republic, Luxembourg, the Netherlands, and Belgium showed outstanding performance, while Cyprus, Romania, Greece, and Hungary consistently lagged behind. In countries that joined the European Union in 2004 or later, it is particularly common that practical experience is the sole foundation for farm management (Augère-Granier, 2017). However, business competitiveness can only be ensured by employees with a high level of knowledge, appropriate skills, and access to practice-oriented training (Magda *et al.,* 2008). A moderate correlation has been observed between the proportion of individuals with agricultural qualifications, expenditures on training and advisory services, and labour productivity. This suggests that in countries with higher investment in agricultural education, agricultural labour productivity tends to be more efficient. The authors align with the 2017 policy statement by the SCAR-AKIS Strategic Working Group, which emphasises the need for a new approach to agricultural education. Beyond providing fundamental agricultural knowledge and skills, the focus of education should shift toward making learning techniques more interactive and effective. Vocational training must equip farmers with a broader range of skills while also reinforcing practical knowledge. Additionally, it is essential to create a supportive environment for students that fosters trust-based relationships and ensures broad access to digital skills (Nátz *et al.,* 2022).

Agricultural research

During the 2014–2020 period, German companies allocated the highest absolute amount to agricultural research, spending an annual average of €168.4 million. However, when measured as a share of total corporate research and development (R&D) expenditures, Hungary ranked first with 1.4% during the same period. Latvia, Spain, and Romania also performed strongly, while in contrast, Estonia, Ireland, and Cyprus reported the lowest values, with companies investing only marginally in agricultural research. Notably, despite significant incentives to support educational and R&D activities in Ireland, private investments in agricultural research remain substantially below the EU average (Heisey and Fuglie, 2018). The growth rate of agricultural research in Mediterranean countries, as well as in Central European countries, continues to lag well behind the average of high-income countries (Heisey and Fuglie, 2018).

In the EU, government expenditures on agricultural research and development (R&D) accounted for an average of 2.12% of GDP between 2014 and 2020. The highest proportions of government spending were observed in Bulgaria, Spain, Finland, and Estonia. In Hungary, the share of government expenditures moderately exceeded the EU average. The leading countries during this period emphasised the presence of developments related to the agri-food value chain and agricultural innovation as priority areas in their *Smart Specialisation Strategies (S3)* for 2014–2020. This focus likely explains the prominence of the sector in public expenditures. An examination of the nominal values of R&D expenditures disbursed through the *European Regional Development Fund (ERDF)* during the same period further reveals that Spain allocated substantial resources to this purpose, highlighting its commitment to advancing agricultural research and innovation. There are several reasons why public agricultural R&D has high research intensity. First, it makes up for the relatively low level of private R&D in this sector, even though private research in farming has grown in recent years. Second, agriculture relies heavily on technology, so productivity growth depends more on innovation than on simply using more inputs. Technology-based sectors usually require more research than others. Third, governments invest in agricultural R&D not only to support food production and food security, but also to address broader public concerns, such as the environment, food safety, nutrition, and other social issues (Heisey and Fuglie, 2018).

In nominal terms, Denmark recorded the highest government expenditure on agricultural research and development (R&D), with an annual average of €872 million. This is particularly noteworthy, given that Denmark allocated negligible amounts to AKIS in its CAP Strategic Plan and was among the countries where EIP operational groups were not launched. Furthermore, Denmark spent only a minimal portion of its European Regional Development Fund (ERDF) resources on R&D, relying instead on national funding to support agricultural research. In Denmark, R&D funding is allocated to organisations closely connected to practical applications, primarily universities and the Danish agricultural knowledge centre, SEGES. Universities address the needs for basic and strategic research in agriculture and the food industry, while SEGES contributes through practice-oriented experimental development, advisory services, and implementation efforts (Birke *et al.,* 2022).

According to the aggregated value of the agricultural research index during the analysed period, three countries emerged as leaders: Hungary, Spain, and Latvia. In Hungary, corporate expenditures and their proportion to total corporate spending secured the country's top position. In contrast, in Spain and Latvia, the share of government expenditures on agricultural research and development (R&D) relative to GDP was the dominant factor contributing to their high index scores. In Hungary, corporate R&D expenditures are deductible from the corporate tax base and local business tax base, providing incentives that foster the growth of business-oriented R&D activities.

At the EU level, while the agricultural sector is considered knowledge-intensive, the scale of R&D expenditures remains significantly lower than in other sectors. From a research and development perspective, agriculture is underfunded (Heisey and Fuglie, 2018).

Performance of the agricultural economy

During the 2014–2020 period within the EU, the average Total Factor Productivity (TFP) increased by 108.7% compared to 2005 levels. The most significant productivity growth was observed in Belgium, where TFP rose by 42.7% since 2005. This remarkable increase can be attributed to the intensity of agricultural production in Belgium, which experienced a decline in TFP between 2004 and 2015, followed by substantial improvements in agricultural efficiency (Baráth and Fertő, 2017). In addition to Belgium, notable progress was achieved in Lithuania, Latvia, and Hungary. This study aligns with the findings of Kijek *et al.* (2019), who noted that in countries such as the Netherlands, France, Luxembourg, and Germany, TFP has remained relatively stable over the past 15 years. These nations are among the most advanced in terms of agricultural development, characterised by high TFP levels. As a result, agricultural productivity growth during the analysed period (2004–2016) was relatively modest in these countries. Nowak and Kubik (2019) highlight in their study that the development of the TFP index in the "new" and "old" Member States follows divergent trends. While agricultural productivity increased in the new Member States, a decline of 1.5% was recorded in the old Member States. The rise in productivity observed in the new member states was primarily attributable to technological changes as well as improvements in technical efficiency.

Another widely used indicator for measuring the economic performance of countries is *labour productivity*, calculated based on agricultural gross value added (GVA) at constant prices. This metric reflects the value of goods or services produced annually by a full-time employee. According to Martin (2001), this indicator highlights differences in economic outcomes across regions, shaped directly by factors that influence regional competitiveness. Productivity growth leads to reduced costs, increased societal welfare, and enhanced purchasing power. During the 2014–2020 period, the labour productivity indicator shows that the Netherlands stood out among EU Member States, achieving nearly €70,000/AWU (Annual Work Unit). Denmark and Belgium also performed strongly in this regard. In contrast, Poland, Latvia, Romania, and Bulgaria ranked among the least productive countries. In Hungary, the average labour productivity was €7,938/AWU, significantly below the EU28 average of €18,120/AWU.

Research by Polozova *et al.* (2021) indicates a correlation between a country's digitalisation index and productivity levels, with higher digitalisation scores corresponding to higher productivity. Correlation analyses confirm this relationship, with Poland, Romania, and Bulgaria consistently appearing among the weakest performers in both digitalisation and productivity metrics. According to Csáki and Jámbor (2019), substantial disparities in labour productivity persist between the "new" and "old" Member States of the EU in the agricultural sector. These differences can partly be attributed to divergent specialisation patterns. Central and Eastern European countries predominantly focus on cereal and raw material production, whereas EU15 countries prioritise the production of animal products and processed goods. Consequently, the added value per worker in agricultural production is higher in Western Europe.

Potential of the younger generation

Eurostat's Digital Skills Indicators are composite metrics based on activities performed using the internet or software, assessing skills in the 16–74 age group across four specific domains: information, communication, problem-solving, and software usage. These indicators provide insights into individuals' digital competencies and how extensively they leverage internet and software opportunities in their daily life. Luxembourg and Denmark have the highest proportion of individuals with above-basic digital skills, at 50% and 48.7%, respectively. Luxembourg leads in overall digital skills scores, followed by Denmark, the Netherlands, Finland, and Sweden. In contrast, Romania, Bulgaria, Poland, Italy, and Cyprus rank lowest in digital skills.

These findings align with Polozova *et al.* (2021), who noted that Romania and Bulgaria consistently score lower on all digitalisation indicators compared to other European countries. However, these countries also hold the greatest potential for improvement. The EU28 average is 30.67%, with Hungary ranking eighth lowest at 24.7%. Achieving high levels of digital skills cannot be attributed solely to economic performance. On the contrary, attaining advanced digital skills requires exceptional economic policies that prioritise human capital development and foster the growth of high-tech enterprises through the creation of an optimal institutional environment (Leogrande, 2022). Cross-country analyses by van Kessel *et al.* (2022) highlight a positive correlation between high capital stocks and income levels and the advancement of digital skills. However, they also emphasise that the cost of internet access has a marginal effect on digital skill levels. These trends extend to agriculture, where high agricultural performance and a well-structured, adequately funded educational system show a strong correlation with the digital skills of sector participants.

In terms of the age structure of farm managers, Austria, Poland, and Slovakia performed best during the 2013–2020 period, while Cyprus and Portugal ranked lowest. This is further supported by the article of Zagata and Sutherland (2015), which highlights Eurostat figures showing considerable national differences in the number of young farmers. The data suggest that there is no shortage of young farmers at the national level in countries such as Germany, France, Switzerland, Finland, Austria, the Czech Republic, and Poland. By contrast, the apparent shortage of young farmers is found mainly in countries with a higher prevalence of small-scale holdings, particularly Portugal, Italy, Romania, and Greece. The statistical analysis also reveals marked differences in farm structures between older and newer Member States, and supports the view that young sole holders are more likely to manage modernised, profitable farms.

Examining the role of the younger generation is essential for understanding how the age of agricultural business managers influences the decision-making processes of farms, particularly from an innovation perspective. Young farmers tend to be more open to comprehensive planning aimed at long-term development and invest more resources in business growth (McKillop *et al.,* 2018). Valliant *et al.* (2019) emphasise that new entrants into agriculture face specific challenges, particularly regarding access to land and land succession. Similarly, Milone and Ventura (2019) highlight that the younger generation possesses the determination necessary to sustain farming operations and introduce innovations essential for launching and managing their businesses. Access to agricultural land is the most widespread challenge faced by young farmers. How-

Table 2: Values of sub-indices of the AKIS index

Country	Agricultural Education			Agricultural Research			Performance of the agricultural economy		Potential of the younger generation	
	Number of Individuals with Agricultural Qualifications	Farm Managers with Agricultural Qualifications	EU Expenditures on Training and Consulting	Government Expenditures on Agricultural R&D	Agricultural Enterprises' Expenditures on R&D	Expendi-tures on EIP	Labour Productivity in Agriculture	Total Factor Productivity (TFP)	Digital Skills	Age Structure of Farm Managers
Belgium	0.62	0.46	0.45	0.26	0.06	1.00	0.58	1.00	0.55	0.33
Bulgaria	0.04	0.08	0.09	1.00	0.03	0.00	0.03	0.21	0.04	0.53
Czech Republic	1.00	0.74	0.53	0.63	0.23	0.01	0.16	0.26	0.35	0.43
Denmark	0.37	0.11	0.94	0.78	0.17	0.63	0.68	0.35	0.97	0.17
Germany	0.39	0.30	0.26	0.74	0.17	0.15	0.53	0.00	0.67	0.53
Estonia	0.14	0.51	0.40	0.89	0.00	0.39	0.12	0.29	0.65	0.70
Ireland	0.13	0.43	0.26	0.85	0.01	0.56	0.16	0.41	0.47	0.43
Greece	0.01	0.00	0.01	0.56	0.36	0.30	0.12	0.25	0.28	0.23
Spain	0.03	0.03	0.32	1.00	0.75	0.16	0.40	0.26	0.56	0.20
France	0.41	0.57	0.18	0.48	0.45	0.22	0.53	0.11	0.48	0.70
Croatia	0.10	0.04	0.00	0.44	0.10	0.05	0.01	0.09	0.48	0.37
Italy	0.07	0.10	0.28	0.48	0.05	0.14	0.36	0.15	0.26	0.27
Cyprus	0.00	0.00	0.01	0.78	0.02	0.26	0.20	0.10	0.27	0.00
Latvia	0.03	0.57	0.40	0.85	0.76	0.30	0.00	0.52	0.40	0.30
Lithuania	0.03	0.29	0.23	0.52	0.12	0.17	0.04	0.58	0.54	0.47
Luxembourg	0.26	1.00	n/a	0.00	n/a	n/a	0.43	0.21	1.00	0.73
Hungary	0.04	0.07	0.03	0.70	1.00	0.34	0.05	0.51	0.37	0.37
Malta	0.03	0.02	0.43	0.19	0.26	0.01	0.10	0.01	0.67	0.23
Netherlands	0.68	0.15	1.00	0.44	n/a	0.40	1.00	0.09	0.92	0.20
Austria	0.28	0.51	0.25	0.26	0.05	0.32	0.30	0.22	0.66	1.00
Poland	0.04	0.53	0.08	0.37	0.31	0.01	0.00	0.38	0.25	0.90
Portugal	0.04	0.04	0.15	0.26	0.55	0.06	0.10	0.25	0.51	0.03
Romania	0.01	0.00	0.04	0.26	0.61	0.04	0.00	0.19	0.00	0.27
Slovenia	0.08	0.23	0.59	0.59	0.04	0.11	0.02	0.10	0.48	0.30
Slovakia	0.40	0.18	0.30	0.33	0.13	0.02	0.11	0.27	0.49	0.80
Finland	0.45	0.20	0.53	0.89	0.04	0.37	0.20	0.12	0.89	0.53
Sweden	0.25	0.40	0.50	0.26	n/a	0.65	0.37	0.16	0.83	0.37

Source: own calculations

ever, other significant obstacles include the lack of experience, start-up capital, and collateral for loans (Eistrup *et al.,* 2019). These barriers underline the need for targeted policies and support mechanisms to enable young farmers to overcome structural challenges and contribute to the innovation and sustainability of the agricultural sector.

AKIS index

Addressing the methodological aspects of the research questions, indicators are available for characterising the subsystems of AKIS that meet the criteria of availability and accessibility. Consequently, the AKIS index can be constructed and, furthermore, can be recalculated using the available indicators, ensuring its adaptability and reusability for future analyses.

Based on the AKIS index, the countries classified as *AKIS Leaders* include Belgium (0.55), the Netherlands (0.54), Denmark (0.52), and Luxembourg (0.45). These countries have well-functioning and well-supported AKIS systems, as corroborated by the findings of the ProAKIS project. Even in countries where AKIS is less centralised, such as the Netherlands and Belgium, the system remains robust. In these nations, AKIS systems are well-designed and developed with consistently applied incentives, contributing to their effectiveness and sustainability.

The countries classified as *AKIS Advancers* include Sweden (0.43), Finland (0.42), France (0.42), Estonia (0.41), Austria (0.41), the Czech Republic (0.41), Latvia (0.40), Germany (0.38), Ireland (0.37), Spain (0.37), Hungary (0.34), Slovakia (0.32), Lithuania (0.32), Poland (0.30), and Slovenia (0.25). In these countries, certain subsystems of AKIS are well-supported and function effectively. These nations generally coordinate their AKIS systems in an organised manner through established mechanisms. However, the further development of AKIS systems remains necessary to enhance their overall performance and alignment with best practices.

Countries with weaker AKIS development are classified as *AKIS Followers*, including Italy (0.22), Greece (0.21), Bulgaria (0.21), Malta (0.20), Portugal (0.20), Croatia (0.18), Cyprus (0.16), and Romania (0.14). These countries allocate limited resources to AKIS. Although numerous actors participate in their systems, their activities are uncoordinated and exert minimal influence on the system's evolution. Greece, Portugal, and Romania exhibit some of the weakest AKIS structures, primarily due to their high level of fragmentation and the limited strength of linkages among the various actors involved. The Greek AKIS is particularly ineffective, as the absence of effective coordination by national institutions has resulted in weak interconnections between actors. Similarly, the Portuguese AKIS faces significant

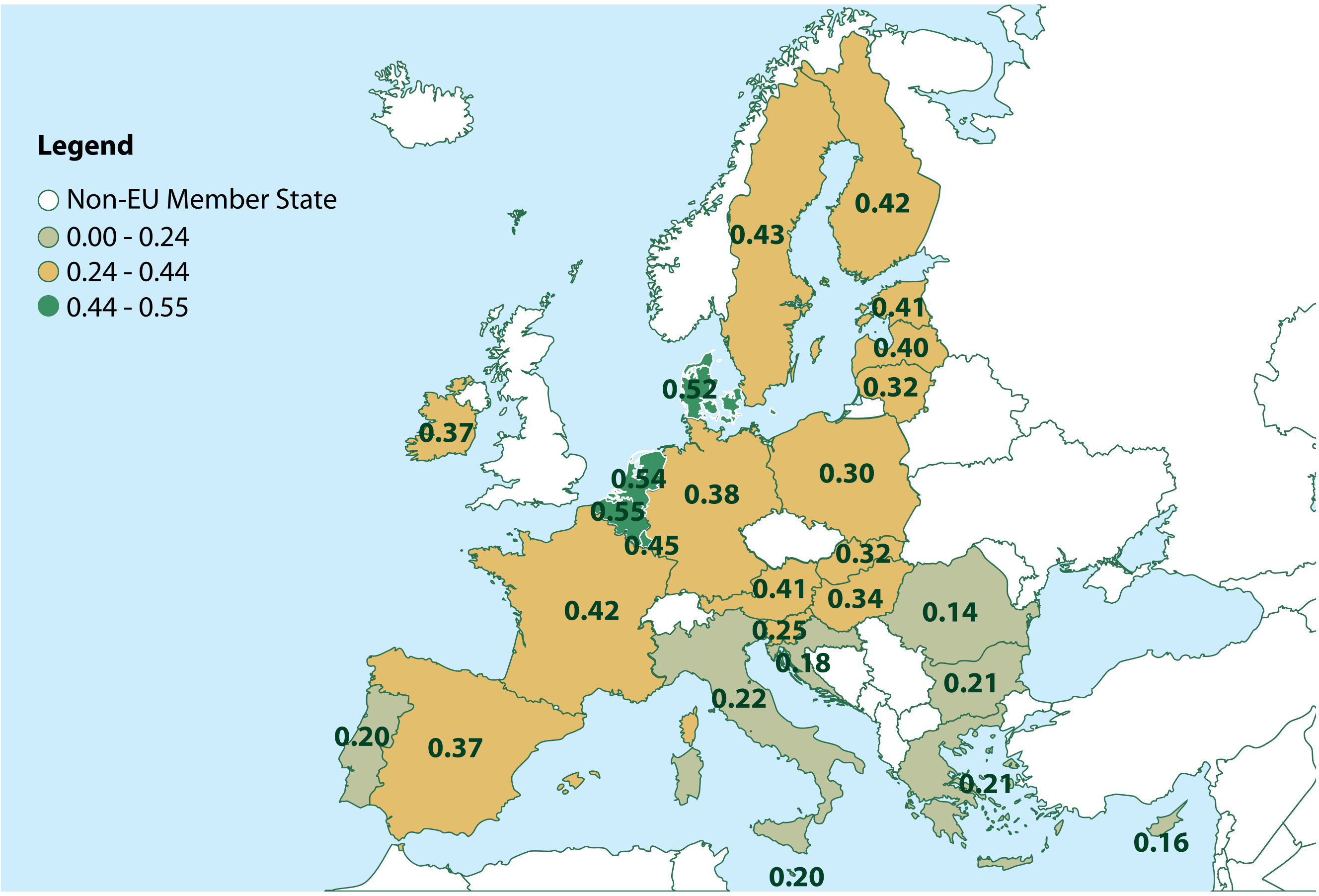

Figure 1: AKIS index according to EU Member States.
Source: Own calculations and editing based on the AKIS index

challenges: despite the presence of a large number of stakeholders, the lack of systematic coordination by public authorities undermines its overall functionality (Kountios *et al.,* 2024b).

Conclusions

Since 2008, the EU has systematically worked on developing the Agricultural Knowledge and Innovation System (AKIS) through various CAP incentives, referred to in the literature as AKIS-related measures. The composite index highlights that factors beyond the CAP also have a significant impact on the development of AKIS in Member States and, ultimately, on the innovation capacity of the agricultural sector. One such factor is the level of government expenditures on research and development, where the European Regional Development Fund (ERDF) plays a pivotal role. In the agricultural education category, formal education determines the qualifications of actors within the sector. Decisions in this area are influenced not only by agricultural administration but also by policymakers in the education domain. Furthermore, private sector investments in agricultural research, training, and other educational measures can be substantial, though official data on these expenditures remain limited. Differences in research intensities may be related to general budgetary constraints, the political-economic characteristics of publicly funded scientific research, or the extent to which certain countries and the private sector rely on adopting research results from elsewhere (Heisey and Fuglie, 2018). The collective performance of AKIS actors influences innovation capacity, while the open sharing of knowledge is essential for fostering innovation.

In summary, the most advanced AKIS systems are found in Western and Northern European countries, which are also considered the most innovative Member States in terms of agriculture. In these countries, active partnerships exist between farming organisations, research institutions, and universities. Additionally, the role of private capital in financing innovation systems is significant and cannot be overlooked.

The index results highlight areas with development potential in certain countries. The McKinsey report underscores significant opportunities for digitalisation in Central and Eastern European countries, supported by high levels of human development and education, advanced infrastructure, and substantial industrial capacities (Novak *et al.,* 2018). However, in Central and Eastern Europe, the diversity of partners involved in innovation systems is low, the intensity of interactions among them is weak, and knowledge flow to farmers is predominantly conducted by public organisations. This is partly because potential AKIS actors in these countries are not incentivised to engage in knowledge transfer, often misunderstand innovation processes, and fail to perceive the benefits arising from collaborative interactions (Georgieva, 2022).

A critique of the composite index is that, beyond input and output indicators, it has limited capacity to incorporate efficiency metrics, with such measures only applicable in the case of agricultural performance (e.g., FTE and labour productivity). Another limitation of the index is its inability to integrate the advisory services of Member States. In 2003 the European Commission legislated for advisory services within the CAP. The objective was to ensure that all Member States provide farmers with the necessary support to better align production goals with environmental, health, and animal welfare regulations. However, the organisation of these systems remains under the jurisdiction of individual Member States (Labarthe and Laurent, 2013). The assessment of advisory services typically relies on the number of advisors operating in the sector and the number of organisations providing advisory services. These indicators are available through CAP performance and output metrics on the DG AGRI-managed Agri-Food Portal. However, due to incomplete data across Member States, comparative analysis is not feasible. In this study, advisory services and information flows among agricultural actors were analysed using the amount of CAP expenditures allocated to advisory and training services. While this approach provides insights into the role of advisory systems, the lack of comprehensive and comparable data remains a significant limitation.

In recent years, there has been significant progress in the understanding, funding, and support of AKIS, with Member States adopting a more structured approach than before. However, the AKIS approach is primarily interpreted at the level of CAP Strategic Plans. The authors of this study emphasise that substantial resources and numerous policy incentives influencing AKIS extend beyond the scope of the CAP and agricultural administration.

Thus, aligning AKIS strategies with various support policy instruments is essential for achieving tangible innovation and knowledge transfer outcomes in agriculture. The composite index is a valuable tool for measuring the extent of changes driven by coordinated incentives, providing policymakers with critical feedback on the effectiveness of efforts to advance AKIS development.

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