1828

AKADÉMIAI KIADÓ

UNIVERSITY of DEBRECEN

International Review of Applied Sciences and Engineering

DOI:
10.1556/1848.2025.00988

ORIGINAL RESEARCH PAPER

Forecasting innovation status and trends with ARIMA analysis and Linear Trend Model in the European Union

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Received: January 18, 2025 • Accepted: March 2, 2025

ABSTRACT

The European Union's (EU) future will be fundamentally determined by innovation-based competitiveness. The study examines what characterized the EU's innovation status as a whole and its member states between 2017 and 2024. For the situation analysis, the study examines the development of the Summary Innovation Index (SII) values describing the innovation status of the member states using the ARIMA model and K-means clustering. The study estimates the expected innovation status of the EU and its member states in the medium term using the Linear Trend Model. The results show that innovation is the least coordinated area of the EU cohesion policy, as there is a significant gap in the innovation status of the member states. In the case of the two extreme innovation values, the difference is four times greater. By this ratio, the average innovation development of the Scandinavian states is higher than the development level of some Eastern European member states. The extrapolation results show that the innovation gap will likely persist in the medium term despite continuous modernization.

KEYWORDS

innovation, SII index, European Union, extrapolation, innovation gap

1. INTRODUCTION

The so-called Draghi report on the competitiveness of the European Union (EU) was completed in 2024. One of the report's key findings was that competitiveness now depends less on labor costs and is more determined by the knowledge and skills level of the workforce. In addition, security is one of the key areas of sustainable growth. Another significant finding of the report is that the competitiveness of the EU is rapidly deteriorating. If the EU does not take effective reforms, Europe's economic and political importance may be fatally weakened compared to its global competitors (USA, China) [1].

There have been many studies on the development of EU competitiveness and innovation status, some of which are presented in the following section of this article. One study found that significant disparities were observed in the EU countries regarding the level of development of the knowledge-based economy (KBE), including innovation, during the period under review. This disparity has implications for socioeconomic status, competitiveness, and innovation performance. The KBE level is highest in North-West and Central Europe and lowest in the Eastern and South-Eastern European regions [2]. The following study examined the relationship between competitiveness, innovation, and the company's legal form. It found statistically significant differences in the competitiveness of national economies based on legal forms. This implies that effective corporate governance is crucial to increasing competitiveness, productivity, and profitability. Although each legal form of a company has its characteristics, the skills and abilities of business leaders often play a crucial role in effectively obtaining financial resources and strengthening market competitiveness [3]. An empirical analysis examined panel data for European Union countries between 2017 and

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2022, focusing on the Digital Economy and Society Index (DESI) and the International Management Development Institute (IMD) Global Competitiveness Index. The results differ between the groups of Central and Eastern European countries and Western European countries. The analysis revealed different effects between the two regions, but the most prominent was the skilled workforce [4]. A study used factor analysis to examine competitiveness factors and their relationship with economic growth. The results showed that the most essential factors for competitiveness are macroeconomic stability, research and development and digitalization, foreign direct investment, and trade openness [5]. A study has highlighted the importance of linking R&D, innovation, and economic development and the need to develop high-tech industries and introduce innovative measures for sustainable economic growth in EU regions. The research shows that the close interrelationship of economic, social, and environmental factors is key to prosperous societies. It also highlighted the fundamental role of building on each other in improving regional competitiveness [6]. Another study examined the combined impact of several factors on the competitiveness of EU Member States. The results showed that the business environment and human resources significantly impact global macroeconomic competitiveness. As the business sector in the EU-27 is predominantly made up of small and medium-sized enterprises (SMEs), entrepreneurial activities play a fundamental role in sustainable and competitive economic development. The study also highlighted that human resources are one of the most critical drivers of the internationalization of European SMEs [7].

Several studies have demonstrated the positive impact of innovation on economic output. The literature emphasizes the prominent role of innovation in increasing productivity and improving economic performance. In his early work, a well-known economist drew attention to “innovative disruption,” which describes transforming market structures through innovations, promoting economic dynamism and growth [8]. According to research, innovation, R&D spending, and technological investments are essential conditions for competitiveness, development, and sustainable economic growth. Raising the workforce’s education level, increasing investment in innovative research, and developing new products and services promote the development of both the private and public sectors. In addition, easier access for investors to investment markets not only strengthens the economic sphere but also contributes to improving the living conditions of society [9]. Other studies [10–12] also support innovation’s crucial role in promoting nations’ competitiveness and economic progress. According to Pino et al. [13], innovation is essential for improving the international market performance of South American companies, while the authors [14] highlight the importance of the coherence between innovative macro strategies and modern financial systems. A study examined the relationship between the innovation index and economic growth in 34 OECD countries between 1961 and 2018. The results show that the United States achieved the highest innovation index, while Luxembourg showed the highest GDP growth [15]. The following studies analyze innovation’s cost-effectiveness, innovation’s direct positive impact on economic development and social welfare, innovation potential in developing economies, and discuss theoretical and practical aspects of innovation management [16–20].

In this paragraph, this article cites studies that examine the state of innovation in the EU and attempt to formulate forecasts. A study compiled a ranking of the innovation of the economies of EU countries based on the values obtained using the Synthetic Measure of Innovation (SMD). The member countries were arranged into clusters based on the SMD values calculated for the member countries. The most innovative countries were Luxembourg, Sweden, Finland, France, and Denmark [21]. The following study examined the specificities of the EU innovation policy and assessed the parameters of the national innovation ecosystems of EU member states with different innovation potential. They also identified the factors that impact the ranking of countries in the Global Innovation Index (GII) [22]. In a study, researchers assessed the structural development of EU innovation ecosystems based on a previously developed framework. The authors emphasize that innovation efforts need to be coordinated, with particular attention to the broad involvement of society. As a result, they propose developing an integrated approach that will help strengthen innovation ecosystems in the EU [23]. A study examined the elements of the EU National Innovation Systems (NSI) and revealed each country’s specific configurations to achieve innovation outcomes. The results can serve as valuable input for EU policy-making, helping to define specific innovation pillars in each Member State. In addition, the research clearly shows the strengths and weaknesses of EU countries’ NSIs, providing policymakers and international business leaders with helpful information for developing innovation strategies [24]. The results of a study covering 1,574 companies show that innovation is positively related to corporate sustainability and that this effect also works in the opposite direction [25]. A study proposes a new method for measuring the level of innovation in the EU. Based on this method, EU regions can be grouped according to their level of innovation in all areas considered [26]. A study makes recommendations for forecasting the EU’s innovation trend. It suggests that the EU needs radical, revolutionary innovations to maintain the well-being of its citizens by decarbonizing industries. The forecasts indicate that technological developments could strengthen the EU’s global competitiveness, create new jobs, and contribute to GDP growth [27].

Literature on forecasting the EU innovation status and trends is not found in the literature databases; the study deals with most of this topic (without future forecasts) [28].

The main features of the studies cited above are summarized in the table below.

Table 1 summarizes the areas of study, periods, methodologies, and main findings of relevant studies analyzing the links between innovation and economic growth in different regions.

Table 1. Summary of relevant studies on the innovation status of countries and regions

Citation	Region/country studied	Period	Methodology	Key findings
[8] J.A. Schumpeter (2011)	Global (theory-based)	Theoretical	Theoretical framework	Innovation drives economic development and entrepreneurship
[9] A. M. Pece et al. (2015)	CEE Countries	2000–2014	Empirical analysis	R&D expenditure has a significant impact on economic growth in CEE countries
[10] A. Poltarykhin et al. (2021)	Russia	2020	Case study	Innovative systems enhance national competitiveness
[11] M. Khyareh and N. Rostami (2021)	Global	Not specified	Econometric analysis	Macroeconomic conditions influence innovation and competitiveness.
[12] OECD Oslo Manual (2005)	OECD Countries	2005	Guidelines and framework	Provides comprehensive guidelines for collecting innovation data
[13] C. Pino et al. (2016)	South America	2000–2015	Empirical analysis	Non-technological innovation improves market performance in exporting firms.
[14] S. Ghazinoory et al. (2019)	Global	2015–2019	Systematic review	Problem-oriented innovation systems address macro-level societal challenges.
[15] B.K. Dhar et al. (2023)	OECD Countries	2010–2020	Causal analysis	A causal link exists between innovation and economic growth in OECD countries.
[16] V.N. Nesterov et al. (2015)	Russia	2000–2015	Accounting and cost analysis	Effective cost management supports innovation processes
[17] S. Denkowska et al. (2020)	EU Member Countries	2005–2019	Education and innovation models	Formal and non-formal education fosters EU innovation and competitiveness
[18] M. Siwek (2021)	Global	2020	Conceptual analysis	Innovation is a key driver for economic growth.
[19] L. Terzić (2017)	Developing Economies	2005–2015	Comparative study	Innovation enhances competitiveness in developing economies.
[20] M.Z. Zhu (2013)	Global	Theoretical	Literature review	Innovation management theories support systemic implementation

Source: Own table.

The study will examine the evolution of innovation in the EU Member States from 2017 to 2024.

The research aims to provide a comprehensive analysis of the innovation situation in the European Union, with a particular focus on the EU as a whole and the innovation performance of the member states for the period 2017–2024. The study aims to identify innovation gaps and assess the effectiveness of cohesion policy, considering the innovation gaps between the EU member states. In addition, the study aims to forecast innovation performance in the medium term using the Linear Trend Model and the ARIMA and K-means clustering methods.

The study's novelty lies in the fact that it analyzes in detail the innovation status of the EU and its member states based on the data of the SII index for the period 2017–2024, a topic discussed quantitatively in little literature so far. The integrated application of the ARIMA model, K-means clustering, and the Linear Trend Model offers a new approach to analyzing the long-term development of innovation performance and exploring differences between EU member states. With this methodological combination, the study contributes to global innovation research and provides guidelines for the EU to increase its competitiveness.

The study sees the problem at the economic policy level as the decline in EU competitiveness and, therefore, discusses a problem at the macroeconomic and geopolitical level, namely that the low level of innovation in the EU also plays a role in the decline in EU competitiveness. Lazy innovation plays a key role in the decrease in EU competitiveness, which is confirmed by the fact that the US and China dominate among the most valuable and innovative startup companies globally, while EU companies are not among them. In addition, Europe's productivity gap is also primarily due to weaker innovation performance, which indicates that the EU has significantly lagged behind the technological revolution following the advent of the internet. The EU's economic and political relevance may weaken without effective reform.

The need for this study lies in the fact that the analysis of the EU's innovation performance has made it clear that there are significant differences between EU Member States, which could threaten the Union's global competitiveness in the long term. In addition, the results show that the EU's innovation gap persists due to the lack of targeted innovation policies and reform measures, especially between Eastern European Member States and the Nordic countries. Therefore, the study offers new approaches and strategic recommendations that can contribute to the unification of EU innovation systems and strengthen the EU's long-term competitiveness.

This study addresses a macro-level policy issue: the fragmentation of EU innovation performance and significant differences between Member States threaten the Union's global competitiveness. The research attempts to formulate solution proposals that can narrow the innovation gap between Member States through targeted, differentiated innovation policies and structural reforms. By applying these proposals, the EU can strengthen its competitiveness and position in global economic competition, especially against the dynamic innovation environment of the USA and China.

2. MATERIAL AND METHODS

Innovation drives progress, embodied in new products, services, or processes that transform economies and societies. Research and development (R&D) and other innovative activities improve living standards, boost long-term competitiveness, and support sustainable economic development.

To carry out the analysis, the study analyses the most relevant sub-indicator of the European Innovation Scoreboard (EIS) data, the Summary Innovation Index (SII). The European Commission has been publishing its Regional Competitiveness Reports since 2010, which provide a European overview of the competitiveness of regions based on 68 indicators. The EIS consists of three sub-indices (basic conditions for competitiveness, frameworks for improving efficiency, and innovation conditions), which comprise 11 pillars describing different aspects of competitiveness. These pillars are institutions, macroeconomic stability, infrastructure, health, primary education, higher education, training and lifelong learning, labor market efficiency, market size, technological readiness, level of enterprise development, and innovation.

The SII index provides an integrated and comprehensive picture of the innovation performance of the EU, and its member states through the average of 32 indicators influencing innovation. This allows for an accurate comparison of trends over time, dynamic changes, and differences between member states, which is essential for developing EU cohesion policies and economic strategies. Since the SII index is also included in the official EU innovation reports, it provides an internationally accepted and comparable framework for the results as a methodological choice.

The EIS (European Innovation Scoreboard) is an annual report prepared by the European Union that assesses the innovation performance of the Member States, and one of its key summary indicators is the SII (Summary Innovation Index). The SII is the average of 32 indicators that measure a wide range of factors influencing innovation. The SII serves as a comprehensive measure of the innovation performance of the Member States within the EIS, taking into account several factors (e.g., research and development, corporate innovation, human resources). Thus, the SII is one of the most important indicators of the EIS, which allows for comparisons between countries in the field of innovation [29].

The study then presents the innovation situation of the EU Member States and their comparisons using the SII index. The three methodologies selected for the analysis are as follows:

2.1. Time series analysis – ARIMA methodology

The ARIMA (AutoRegressive Integrated Moving Average) model is an effective tool for analyzing the temporal changes in SII data, especially for forecasting trends and patterns in innovation performance. The ARIMA model can consider the autocorrelation, seasonal patterns, and data trends essential for understanding innovation policies' long-term effects. The time series is first brought to a stationary state (differentiation), and then the model parameters (AR, I, MA) are optimized to increase the forecast accuracy. For example, in the case of SII, it is possible to predict how the innovation index of a given country may develop in the coming years, taking into account past trends. The following studies have applied the ARIMA model to economic analyses [30, 31].

ARIMA model uses the following equation:

$$y_t = c + \Phi_1 y\_(t-1) + \Phi_2 y\_(t-2) + \ldots + \Phi_p y\_(t-p) + \Phi_1 \epsilon\_(t-1) + \Phi_2 \epsilon\_(t-2) + \ldots \Phi q \epsilon\_(t-q) + \epsilon_t \quad (1)$$

where y_t is the current value of the SII time series, c is a constant (optional), Φ_1, Φ_2,..., Φq are the parameters of the moving average (MA) component, p,d,q are the parameters of the ARIMA model, the number of autoregressive steps (q).

2.2. Cluster analysis – K-means methodology

K-means clustering groups EU Member States based on their SII indicators to identify similarities in their innovation performance. The method groups the Member States into k groups with minimum intra-group and maximum intergroup differences. The iterative algorithm assigns countries to their median values, while the medians of the groups are continuously updated based on the average values of the group members. Clustering based on SII can help, for example, to identify groups of "innovation leaders" and "emerging innovators," thus supporting targeted policy interventions. The following studies have applied the K-means model to economic analyses [32, 33].

The K-means methodology uses the following equation:

$$J = \Sigma_{k=1}^{K} \Sigma_{i \in Ck} \|x_i - \mu k\|^2 \quad (2)$$

where J is the cumulative squared deviation (the value of the objective function to be minimized), K is the number of clusters, C_k the set of data belonging to the k-th cluster, x_i the i-th data point (SII value), μ_k the center of the k-th cluster, $\|x_k - \mu_k\|^2$ the square of the Euclidean distance between the i-th data point and the cluster center.

2.3. Trend forecasting – Linear trend model methodology

The study has available the values of the SII index of the EU member states (Table 1), and it seems trivial to extrapolate the expected medium-term values from these data. One of the most effective methods for trend extrapolation is the simple linear trend model, which makes a forecast based on the existing time series. This method is particularly suitable when the data show an increase or decrease over time and the forecast is relatively short-term. The model is often used to estimate techno-economic expected values [34]. The study forecasts the values of the SII index for 2027.

Linear trend model methodology uses the following equation:

$$y_t = a + b \cdot t \tag{3}$$

where y_t the dependent variable (the SII value at a given time), t the period (the number of years), a: the intercept of the line with the y-axis, i.e., the starting value of the trend when t = 0, b: the slope of the line, which shows how much the value of y_t changes over a unit of t-period (the rate of increase or decrease of the trend).

2.4. Relationship between SII and GDP – Granger causality test

The Granger causality test shows whether there is a statistically significant causal relationship between the value of the EU aggregate SII index and Gross Domestic Product (GDP).

Granger test methodology uses the following equation:

$$\mathrm{Y_t} = \alpha + \Sigma_{i=1}^{p} \beta_\mathrm{i} \mathrm{Y_{t-i}} + \Sigma_{j=1}^{p} \mathrm{R_k X_t - _k} + \varepsilon_\mathrm{t} \tag{4}$$

where Y_t the current value of the explained variable, Y_{t-i} past values of the explained variable (i = 1, …, p), β_i parameters expressing the effect of past values, ε_t the error term, X_{t-k} past values of the explanatory variable, (k = 1, …, p), R_k the other variable is a parameter expressing the effect of our past values.

2.5. Data

In this subsection, the study first presents the SII values of the EU member states between 2017 and 2024 as secondary data, which come from the European Commission database (Table 2). The values calculated by ARIMA follow this. These are derived from secondarily computed data from the secondary data (Table 2).

Table 2 shows the EU and member states SII values for 2017–2024. The penultimate column shows the index's rate of change from 2024 to 2017, and the last column shows the estimated value of the index for 2027.

The data in Table 3 show that the EU aggregate SII index showed a moderate but continuous increase between 2017 and 2024, increasing from 0.50 to 0.55. In parallel, the value of GDP increased more significantly, from EUR 13.2 trillion to EUR 17.3 trillion, an increase of 31% over the same period.

Table 2. SII index values in the EU member states between 2017 and 2024

Country	2017	2018	2019	2020	2021	2022	2023	2024	Change between 2017 and 2024 (%)	Trend 2027
AT	0.62	0.62	0.62	0.62	0.61	0.63	0.65	0.64	103	0.65
BE	0.61	0.62	0.60	0.66	0.66	0.69	0.68	0.68	111	0.73
BG	0.24	0.23	0.24	0.25	0.25	0.25	0.24	0.25	104	0.26
CY	0.39	0.40	0.42	0.51	0.52	0.56	0.57	0.59	151	0.70
CZ	0.42	0.41	0.42	0.43	0.43	0.47	0.48	0.50	119	0.53
DE	0.60	0.60	0.60	0.63	0.63	0.63	0.63	0.62	103	0.65
DK	0.68	0.68	0.68	0.71	0.72	0.74	0.75	0.75	110	0.79
EE	0.44	0.44	0.44	0.54	0.56	0.58	0.59	0.58	132	0.69
EL	0.35	0.35	0.35	0.37	0.39	0.43	0.43	0.43	123	0.48
ES	0.45	0.45	0.46	0.46	0.45	0.48	0.49	0.50	111	0.51
FI	0.65	0.64	0.64	0.66	0.67	0.71	0.71	0.71	109	0.75
FR	0.57	0.57	0.57	0.56	0.57	0.57	0.57	0.57	100	0.57
HR	0.31	0.31	0.31	0.34	0.35	0.38	0.39	0.38	123	0.43
HU	0.35	0.35	0.34	0.36	0.36	0.37	0.38	0.39	111	0.40
IE	0.61	0.62	0.62	0.62	0.62	0.61	0.61	0.63	103	0.62
IT	0.42	0.43	0.43	0.48	0.49	0.50	0.49	0.50	119	0.55
LT	0.38	0.37	0.38	0.42	0.43	0.43	0.44	0.46	121	0.50
LU	0.65	0.64	0.65	0.64	0.63	0.62	0.63	0.62	95	0.61
LV	0.28	0.28	0.29	0.29	0.28	0.28	0.30	0.30	107	0.30
MT	0.45	0.47	0.47	0.53	0.51	0.51	0.50	0.49	109	0.53
NL	0.66	0.66	0.68	0.67	0.68	0.69	0.70	0.69	105	0.71
PL	0.30	0.30	0.31	0.31	0.32	0.34	0.35	0.36	120	0.38
PT	0.44	0.44	0.44	0.44	0.46	0.45	0.46	0.46	105	0.47
RO	0.18	0.18	0.18	0.18	0.18	0.19	0.20	0.19	106	0.20
SE	0.69	0.69	0.70	0.71	0.72	0.73	0.73	0.73	106	0.76
SI	0.48	0.47	0.46	0.46	0.49	0.50	0.50	0.50	104	0.51
SK	0.35	0.32	0.32	0.35	0.35	0.35	0.35	0.36	103	0.37
EU	0.50	0.51	0.51	0.52	0.53	0.54	0.55	0.55	110	0.58

Source: [28].

Table 3. Data on the EU aggregate SII index and GDP (thousand billion euros, at PPP prices), 2017–2024

Variables	2017	2018	2019	2020	2021	2022	2023	2024
SII	0.50	0.51	0.51	0.52	0.53	0.54	0.55	0.55
GDP	13.2	13.6	14.1	13.6	14.8	16.1	17.2	17.3

Source: [29, 35].

3. RESULTS

This chapter presents the results of the applied methodologies.

3.1. Results of the ARIMA model analysis

Table 4 shows the main parameters of the ARIMA model (AR, MA, Constant) and the AIC and BIC values indicating the fit. These results – the autoregressive component (AR), the moving average component (MA), the constant parameter of the model, and the AIC and BIC values indicating the fit – show the changes in innovation performance over time.

According to the results of the ARIMA model, high AR coefficient values – for example, in the case of Denmark (0.680), Finland (0.650), and Sweden (0.690) – suggest that the innovation performance of these countries is strongly dependent on the values of previous periods, which reflects a stable and high level of innovation. In contrast, lower AR values and smaller 'Constant' values (e.g., Romania 0.180 and Bulgaria 0.240) indicate a lower and less stable state of innovation. Negative MA coefficient values indicate that short-term, random shocks are back-corrected in the innovation indicators, while low AIC and BIC values indicate better model fit. Thus, the table allows the detection of structural differences between member states.

Table 4. Main parameters of the ARIMA model

Country	AR	MA	Constant	AIC	BIC
AT	0.000	−0.001	0.620	15.23	16.45
BE	−0.950	0.770	0.610	14.78	16.00
BG	0.420	−0.830	0.240	13.45	14.67
CY	1.000	−0.930	0.390	16.12	17.35
CZ	0.850	−0.600	0.420	15.00	16.00
DE	0.000	0.000	0.600	14.50	15.70
DK	0.680	−0.150	0.680	13.80	15.00
EE	0.440	−0.340	0.440	14.00	15.20
EL	0.350	−0.170	0.350	14.20	15.40
ES	0.450	−0.150	0.450	14.10	15.30
FI	0.650	−0.200	0.650	14.00	15.20
FR	0.570	−0.100	0.570	14.30	15.50
HR	0.310	−0.200	0.310	13.60	14.80
HU	0.350	−0.150	0.350	13.80	15.00
IE	0.610	−0.100	0.610	14.40	15.60
IT	0.420	−0.180	0.420	14.50	15.70
LT	0.380	−0.220	0.380	13.90	15.10
LU	0.650	−0.250	0.650	14.20	15.40
LV	0.280	−0.150	0.280	13.70	14.90
MT	0.450	−0.230	0.450	14.00	15.20
NL	0.660	−0.200	0.660	14.10	15.30
PL	0.300	−0.180	0.300	13.50	14.70
PT	0.440	−0.150	0.440	13.80	15.00
RO	0.180	−0.050	0.180	13.30	14.50
SE	0.690	−0.210	0.690	14.00	15.20
SI	0.480	−0.160	0.480	13.90	15.10
SK	0.350	−0.140	0.350	13.80	15.00
EU	0.500	−0.200	0.500	15.00	16.20

Source: Own calculation.

Based on the ARIMA model analysis, the EU SII values between 2017 and 2024 show a slight but continuous increase. This trend suggests that the EU's innovation performance is gradually improving, mainly driven by cohesion between Member States and the support of the everyday innovation policy. Based on the model parameters, it can be assumed that innovation performance will remain stable or slightly increase.

However, there are significant differences between individual Member States. For example, the Scandinavian countries (Sweden, Denmark, Finland) have exceptionally high values, while some Eastern European countries, such as Romania and Bulgaria, show low innovation performance.

Cyprus, the Czech Republic, Greece, Croatia, and Lithuania had dynamically increased indexes above average. The growth trend in these EU Member States results from the low starting SII value and the innovation effort.

Among the "old" EU Member States, Austria and Germany achieved ratios of around 1.04, indicating relatively lower growth. This may mean that their innovation performance is developing slower, as they started from a high level, so further development is more limited in these two Member States.

In contrast to the increase in the index of the previously mentioned Member States, only Luxembourg's indicator decreased. The decrease can be explained mainly by the initial SII value being among the highest at the beginning of the examined period. Perhaps the support for innovation or the economic priorities may have changed during the period in the member state.

The general trend of the SII index of the EU member states shows that an increase can be observed in most countries, as demonstrated by the values of the ratios above 1. This means that their innovation performance will exceed the 2017 level by 2024. The EU average also reflects a similar increase; the increase in the index value is 10 percent.

3.2. Results of K-means clustering

The results of K-means clustering are shown in the table below:

The data in Table 5 show the changes in the SII index of EU member states over time. Based on the patterns of changes, four clusters were formed using the K-means algorithm:

Table 5. SII cluster analysis results by EU member state

Count.	Trend Strength	AR Compon.	MA Compon.	Count.	Trend Strength	AR Compon.	MA Compon	Count.	Trend Strength	AR Compon	MA Compon
AT	0.02	0.00	−0.00	ES	0.05	0.39	−0.18	LV	0.02	0.00	−0.00
BE	0.07	−0.95	0.77	FI	0.06	0.20	−0.06	MT	0.04	0.33	−0.23
BG	0.01	0.42	−0.83	FR	0.00	−0.00	−0.00	NL	0.03	−0.00	0.00
CY	0.20	0.99	−0.93	HR	0.07	0.58	−0.28	PL	0.06	0.43	−0.18
CZ	0.08	0.85	−0.59	HU	0.04	0.30	−0.13	PT	0.02	−0.00	0.00
DE	0.02	0.00	−0.00	IE	0.02	0.00	−0.00	RO	0.01	−0.23	0.25
DK	0.07	0.57	−0.13	IT	0.08	0.44	−0.30	SE	0.04	0.16	−0.17
EE	0.14	0.91	−0.34	LT	0.08	0.60	−0.35	SI	0.02	0.18	−0.13
EL	0.08	0.49	−0.18	LU	−0.03	−0.33	0.27	SK	0.01	0.00	0.00

Source: Own calculation.

Cluster 1 countries: Austria (AT), Bulgaria (BG), Germany (DE), France (FR), Ireland (IE), Luxembourg (LU), Latvia (LV), Netherlands (NL), Portugal (PT), Romania (RO), Slovenia (SI), Slovakia (SK). In this cluster, the average growth (Trend Strength) is 0.018, the average AR component is −0.111, and the average MA component is 0.097.

Previous data suggest that the cluster contains countries with lower growth rates, where innovation systems are less self-sustaining, as shown by the low, harmful AR component. Based on the positive MA component values, these countries are more sensitive to short-term economic fluctuations, which indicates a more unstable innovation environment. These countries started with a high level of innovation, but their growth potential is more limited, or their support for innovation is low.

Cluster 2 countries: Belgium (BE), Czech Republic (CZ), Denmark (DK), Greece (EL), Spain (ES), Finland (FI), Croatia (HR), Hungary (HU), Italy (IT), Lithuania (LT), Malta (MT), Poland (PL), Sweden (SE). In this cluster, the average growth (Trend Strength) is 0.058, the average AR component is 0.436, and the average MA component is −0.272. This cluster contains countries with relatively stable innovation systems but has only achieved moderate growth. A positive AR component indicates that these countries show sustainable innovation development in the long term. In contrast, a harmful MA component suggests they are less sensitive to short-term fluctuations. This cluster covers a broad spectrum, from countries with already developed innovation systems (e.g., Sweden, Finland) to countries starting from a lower level but growing (e.g., Bulgaria, Hungary).

No EU member state was included in the third cluster.

Cluster 4 countries: Cyprus (CY) and Estonia (EE). In this cluster, the average growth (Trend Strength) is 0.170, the average AR component is 0.956, and the average MA component is −0.635.

This cluster contains the most dynamically developing countries, where innovation performance shows outstanding growth. The high AR component indicates that these countries have built up innovation systems that are sustainable in the long term. Based on the negative MA component values, these countries are less sensitive to short-term economic fluctuations, which indicates stable development. These EU member states show a good example of how significant growth can be achieved from an initial low level with the help of targeted policies and support.

Figure 1 illustrates that, based on the changes in the SII index over time, 12 EU member states fall into the first cluster, 13 into the second, and two into the third. The countries in the first cluster typically show moderate growth

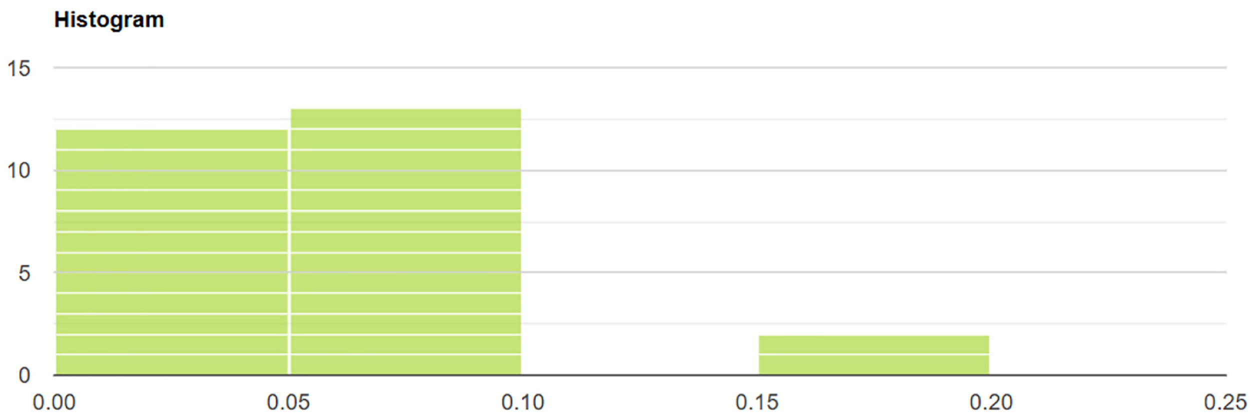

Fig. 1. Clusters of EU member states based on changes in the SII index over time
Source: Own figure.

and relative stability in their innovation performance. In contrast, the countries in the second cluster show lower growth rates and greater sensitivity to short-term economic fluctuations. In contrast, the countries in the fourth cluster – Cyprus and Estonia – have achieved outstanding innovation development, which shows the most dynamic growth pattern within the EU.

3.3. Trend extrapolation results

The expected values of the SII index for 2027 are shown in the last column of Table 2. Based on the results of the calculation, the EU member states can be classified into four groups.

The Scandinavian countries (Sweden, Denmark, Finland) have the highest extrapolated SII values. These countries have already stood out in 2017–2024 and are expected to strengthen their leading role further by 2027.

The next group is the middle-performing countries. According to extrapolation, Central European countries, such as the Czech Republic, Poland, and Hungary, will achieve moderate but continuous growth. These countries are located in the middle band of innovation development, where the basis of growth can be improved infrastructure, increasing R&D spending, and EU subsidies.

Next is the group of lagging countries. Several former Eastern Bloc countries, such as Bulgaria and Romania, are expected to remain in the group with low innovation performance. Although some growth can be observed, these countries will still lag significantly behind the EU average. The low starting level and structural economic problems also limit the pace of development.

The fourth group includes countries showing stagnation. In the case of Luxembourg, the extrapolated values suggest that the country's SII index remains stagnant at a high level or shows only minimal change. This is likely because Luxembourg already had one of the most advanced innovation systems at the beginning of the period under review, so its further development opportunities are limited.

The bar chart in Fig. 2 shows the SII values of the EU Member States in 2024, and the values extrapolated to 2027 using a linear trend model, which clearly illustrates the expected changes in the innovation performance of each country. The chart shows that the expected SII values for 2027 increase for most Member States, especially for the Scandinavian countries, such as Sweden and Denmark, which are already among the leaders. In contrast, some countries, such as Bulgaria and Romania, although showing some improvement, remain at a lower innovation level. The bar chart also highlights significant differences between the innovation performance of the EU Member States, which indicates that innovation gaps will persist in the future.

3.4. Granger test results

According to the Granger causality test results, no statistically significant causal relationship exists between SII and GDP. The results of the most important statistical tests are: F-test: $F = 0.3303$, $P = 0.5963$ (not substantial, as $P > 0.05$), Chi-square test: $\chi^2 = 0.5780$, $P = 0.4471$ (not significant). Likelihood ratio test: $\chi^2 = 0.5554$, $P = 0.4561$ (insignificant).

This indicates that the current data do not support the conclusion that changes in SII over time predict changes in GDP or vice versa.

Figure 3 visually illustrates the different pace of growth between the SII index and GDP. The SII index gradually increases, while GDP follows a more significant, fluctuating trend. This difference highlights that economic growth and innovation performance are not necessarily parallel.

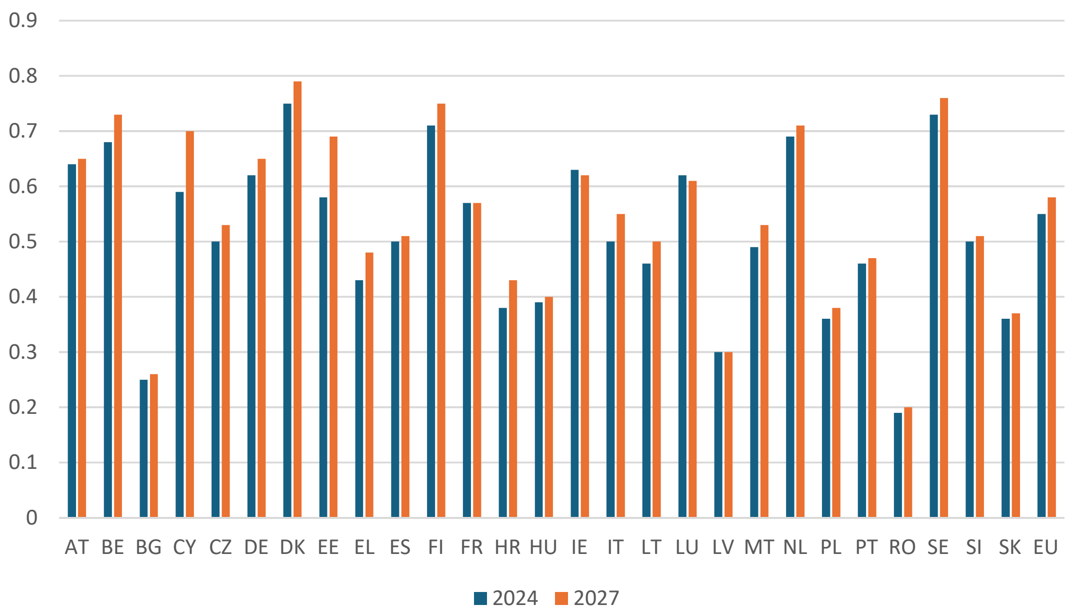

Fig. 2. SII index values for 2024 and extrapolated values for 2027 by EU member state
Source: Own figure.

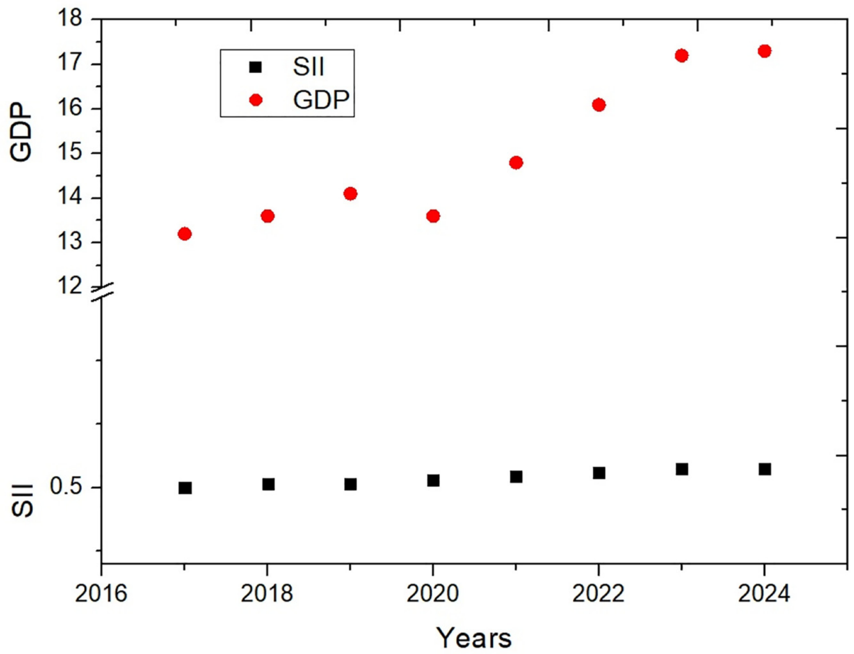

Fig. 3. EU aggregate SII index and GDP value data, 2017–2024
Source: Own figure.

4. DISCUSSION

This study examined the innovation performance of the European Union and its 27 member states over the period 2017–2024 based on SII (Summary Innovation Index) data. The results show that the EU's innovation performance generally improves despite significant differences between Member States. One of the main merits of the study is that it provides a detailed picture of innovation trends based on the most recent data, a rarely examined but critical topic for the EU's cohesion policy and economic strategy.

Using the ARIMA model, the study examined the evolution of the EU SII index over time, which showed a slight but continuous increase. This positive trend is due to the EU's cohesion policy and the cooperation between Member States, which strengthened the Member States' innovation systems. However, there are differences between the individual Member States: while the Scandinavian countries (Denmark, Sweden, Finland) achieved exceptionally high innovation performance (0.75, 0.730.71), some Eastern European Member States, such as Romania and Bulgaria, started from lower SII levels (0.18 and 0.24) and are still at low levels today (0.19 and 0.25). Interestingly, in the case of Cyprus, the Czech Republic, Greece, Croatia, and Lithuania, the innovation index showed an above-average increase, which can be attributed to the low initial level and targeted innovation policies. However, Luxembourg is the only country that showed a decreasing trend. This decrease can probably be explained by the fact that the government already had the highest innovation performance at the beginning of the period under review (0.65), and its economic priorities may have changed since then, as the SII index value in 2024 decreased to 0.62.

Three clusters were defined based on the innovation performance of the EU Member States. The countries in the first cluster show slightly varying innovation performance, where long-term stability dominates. This suggests that the innovation systems in these EU Member States are sustainable and less sensitive to short-term economic fluctuations; their SII index values grow evenly but not very dynamically. The countries in the second cluster show the lowest SII growth and are more sensitive to short-term changes. This indicates a lower self-sustaining innovation capacity and a more unstable innovation environment in these Member States. The EU Member States in the third cluster are among the most dynamically developing countries in the field of innovation, with exceptionally high growth and strong innovation stability in this area.

The research is significant because it provided new and fresh insights into the dynamics of EU innovation performance by analyzing the SII index. The results showed that although the EU's overall innovation performance is improving, the differences between Member States remain significant (the extreme values of the SII index in 2024 were 0.19 in Romania and 0.75 in Denmark).

The research showed that smaller countries such as Cyprus and Estonia can achieve dynamic development with appropriate fiscal policy support, while countries starting from a high level, such as Germany and Austria, find it more challenging to increase their innovation index value further.

Such studies can contribute to developing more targeted innovation policies and increasing the EU's economic competitiveness.

The following are articles in the literature that critically comment on using the SII index or reach conclusions that differ from this study's results.

A previous study showed similar results, highlighting the relationship between the Global Innovation Index and ESG factors (human, natural, social, and economic capital). Based on the analysis, the increase in innovation is closely related to the symmetrical improvement of the pillars of sustainability. This again supports the key importance of continuous and long-term development of innovation capacity. Promoting innovation at the EU, regional, and national levels is essential for the EU to respond effectively to the challenges of global competitiveness [36]. Another study examined the innovation performance of the European Union between 2000 and 2020, measuring innovation in terms of patents, trademarks, and designs. The results showed that the EU's overall innovation efficiency has improved over time, with each programming period proving more successful than the previous one. However, there are significant differences between Member States, with Luxembourg being a clear leader in innovation efficiency, while Greece and Portugal scored the lowest over the period under review [37]. A study examined the most and least innovative countries in the EU using a methodology similar to the SII index. In 2019, Group 1, the group of most innovative countries, was dominated by the Nordic countries, often considered the most innovative countries in Europe. Group 3, which includes the least innovative countries, included ten countries in 2019. This group mainly comprised Southern European countries and the former Eastern Bloc member states. According to the results, the least innovative countries were Croatia, Poland, Latvia, Bulgaria and Romania [38].

A study examined the relationship between R&D expenditure and the global innovation index for EU countries. The results show a positive and significant relationship between R&D expenditure and the innovation index in the long run, while in the short run, this relationship was negative [39]. The study cited does not consider the use of the SII index optimal, as it mainly focuses on providing information on countries' innovation performance and only for a given year [40]. It makes a similar statement to the previous one [41]. The author of this study does not accept the last statement, as the SII index is a good choice because it comprehensively reflects the average of more than 30 factors influencing innovation, thus providing an integrated picture of the innovation performance of the EU and its Member States. In addition, the index is also used in official EU reports, which ensures its use as an internationally accepted, comparable, and reliable measure for the analysis of innovation status. A significant proportion of the studies on the subject also accept and apply the SII index. Finally, a citation follows from a study that examined the territorial distribution of the knowledge-based economy (KBE) in the EU. The results are similar to this study's, which also presents the territorial distribution of innovation. The highest KBE levels were measured in North-Western and Central European countries, while the lowest values were in Eastern and South-Eastern European countries [42].

5. CONCLUSIONS

The study draws robust conclusions from the analyses performed using the ARIMA model, K-means clustering, and Linear Trend Model methodology using the SII index data. One conclusion is that the EU's innovation practice is one of the least coordinated areas of EU cohesion policy. This is evidenced by the extreme values of the SII index across Member States and the uneven growth of innovation indices across Member States. Several Member States achieved dynamic growth in their innovation development between 2017 and 2024, while some Member States showed almost no innovation development. One of the main reasons for the innovation gap is that the innovation component of EU cohesion policy is not sufficiently targeted or flexible enough to address the different economic and technological situations of Member States effectively. Innovation support is often general and does not always consider regional differences or country-specific needs.

The other conclusion is that, according to the stability forecasts given by ARIMA for time trends, innovation gaps between EU Member States may persist in the future in the EU unless targeted intervention is made. These projections highlight the need for differentiated and targeted policy measures to reduce innovation gaps, considering the differences between individual EU Member States. If the EU does not pay sufficient attention to developing the innovation systems of lagging Member States, this will further reduce the EU's global competitiveness in the long term.

The extrapolated projection shows that by 2027, Scandinavian countries such as Sweden, Denmark, and Finland will remain the most innovative in the EU. Meanwhile, some former Eastern Bloc countries, such as Bulgaria and Romania, will remain among the countries with low innovation performance. Middle-income countries such as the Czech Republic, Poland, and Hungary will show moderate but steady growth, while Luxembourg will remain at a high but stagnant level of innovation. Based on the extrapolated data, it is reasonable to conclude that the innovation gap between the Nordic and Eastern European countries will persist shortly.

The Granger test results show no statistically significant causal relationship between SII and GDP. This finding suggests that the relationship between innovation performance and economic growth in the EU is complex and not necessarily linear or instantaneous. This complexity means that the impact of innovation on economic growth in the EU is more indirect in the longer term, for example, through improvements in productivity, technological progress, and the labor market.

Based on the findings, the study suggests that the EU should introduce targeted innovation support programs, paying special attention to Member States with weaker innovation performance (such as Eastern European countries) to strengthen R&D investments, digital transformation, and technological knowledge transfer. Another solution proposed by the study (applied in parallel with the previous one) is to share the good practices of the most innovative Member States – such as the Scandinavian countries – as widely as possible and to develop an integrated EU innovation strategy by strengthening cooperation. This would enable the Union to reduce the innovation gap between EU Member States and increase its global competitiveness against the world's leading economies in the long term.

The findings and policy recommendations of the study primarily concern the aggregate innovation performance of the EU and are, therefore, generalizable at the macroeconomic level in the EU context. However, innovation is a complex and regionally variable phenomenon, and further local analyses are thus needed to develop specific measures for each EU Member State.

6. FUTURE RESEARCH DIRECTIONS

Future research should move towards a more refined, regional, and industry-level analysis of Member State innovation performance, integrate other innovation metrics (such as the Global Innovation Index or R&D expenditure data), and examine complex macroeconomic factors over a more extended period. In addition, it may be essential to use qualitative research methods, such as interviews and case studies, which provide deeper insights into the innovation policies and decision-making processes of the Member States.

REFERENCES

[1] European Commission, "The future of European competitiveness Part A | A competitiveness strategy for Europe". [Online] https://commission.europa.eu/document/download/97e481fd-2dc3-412dbe4cf152a8232961_en?filename=The%20future%20of%20European%20competitiveness%20_%20A%20competitiveness%20strategy%20for%20Europe.pdf. Accessed Nov 28, 2024.

[2] I. Bąk, K. Wawrzyniak, and M. Oesterreich, "Competitiveness of the regions of the European Union in a sustainable knowledge-based economy," *Sustainability*, vol. 14, p. 3788, 2022. https://doi.org/10.3390/su14073788.

[3] I. K. Vozárová and R. Kotulič, "The impact of EU subsidies on the competitiveness of Slovak farms from the perspective of legal form," *Agriculture*, vol. 14, p. 1300, 2024. https://doi.org/10.3390/agriculture14081300.

[4] G. Hurduzeu, I. Lupu, R. Lupu, and R. I. Filip, "The interplay between digitalization and competitiveness: evidence from European countries," *Societies*, vol. 12, p. 157, 2022. https://doi.org/10.3390/soc12060157.

[5] T. Boikova, S. Zeverte-Rivza, P. Rivza, and B. Rivza, "The determinants and effects of competitiveness: the role of digitalization in the European economies," *Sustainability*, vol. 13, 2021, Art no. 11689. https://doi.org/10.3390/su132111689.

[6] A. Kouskoura, E. Kalliontzi, D. Skalkos, and I. Bakouros, "Assessing the key factors measuring regional competitiveness," *Sustainability*, vol. 16, p. 2574, 2024. https://doi.org/10.3390/su16062574.

[7] D. Kiseľáková, B. Šofranková, M. Gombár, V. Čabinová, and E. Onuferová, "Competitiveness and its impact on sustainability, business environment, and human development of EU (28) countries in terms of global multi-criteria indices," *Sustainability*, vol. 11, p. 3365, 2019. https://doi.org/10.3390/su11123365.

[8] J. A. Schumpeter, "The theory of economic development,"in *The Entrepreneur: Classic Texts by Joseph, A. Schumpeter*, T. Knudsen, M. Becker, and R. Swedberg, Eds., Redwood City: Stanford University Press, 2011, pp. 43–78. https://doi.org/10.1515/9781503627369-004.

[9] A. M. Pece, O. Ecaterina, O. Simona, and F. Salisteanu, "Innovation and economic growth: an empirical analysis for CEE countries," *Proced. Econ. Finance*, vol. 26, 2015. https://doi.org/10.1016/S2212-5671(15)00874-6.

[10] A. Poltarykhin, M. Ponomarev, and S. Nikolaev, "Increasing the competitiveness of the national economy through the creation of an innovation system," *Econ. Manag. Probl. Solutions*, vol. 3, no. 10, 2021. https://doi.org/10.36871/ek.up.p.r.2021.10.03.008.

[11] M. Khyareh and N. Rostami, "Macroeconomic conditions, innovation, and competitiveness," *J. Knowledge Economy*, vol. 13, 2021. https://doi.org/10.1007/S13132-021-00752-7.

[12] OECD, Oslo Manual, "Guidelines for Collecting and Interpreting Innovation, Data, 3rd Edition. The Measurement of Scientific and Technological Activities," OECD, Publishing, Paris, 2005. https://doi.org/10.1787/9789264013100-en.

[13] C. Pino, C. Felzensztein, A. M. Zwerg-Villegas, and L. Arias-Bolzmann, "Nontechnological innovations: market performance of exporting firms in South America," *J. Business Res.*, vol. 69, no. 10, 2016. https://doi.org/10.1016/j.jbusres.2016.03.061.

[14] S. Ghazinoory, S. Nasri, F. Ameri, G. A. Montazer, and A. Shayan, A. "Why do we need a 'Problem-oriented Innovation System (PIS)' for solving macro-level societal problems?" *Technol. Forecast. Social Change*, vol. 150, 2019, Art no. 119749. https://doi.org/10.1016/j.techfore.2019.119749.

[15] B. K. Dhar, J. Shaturaev, K. Kurbonov, and R. Nazirjon, "The causal nexus between innovation and economic growth: an OECD study," *Social Sci. Q.*, vol. 104, no. 4, 2023. https://doi.org/10.1111/ssqu.13261.

[16] V. N. Nesterov, A. S. Akhtyamova, and E. S. Domracheva, "Accounting and analysis in managing the cost of innovation. Mediterranean," *J. Social Sci.*, vol. 6, no. 1 S3, p. 217, 2015. https://doi.org/10.5901/MJSS.2015.V6N1S3P217.

[17] S. Denkowska, K. Fijorek, and G. Węgrzyn, "Formal and non-formal education and training as an instrument fostering innovation and competitiveness in EU member countries," *J. Competitiveness*, vol. 12, no. 3, 2020. https://doi.org/10.7441/joc.2020.03.05.

[18] M. Siwek, "Innovativeness as a driving force and an opportunity for economic growth," *Studia Prawno-Ekonomiczne*, vol. 118, 2021. https://doi.org/10.26485/spe/2021/118/16.

[19] L. L. Terzić, "The role of innovation in fostering competitiveness and economic growth: evidence from developing economies," *Comp. Econ. Res. Cent. East. Europe*, vol. 20, no. 4, 2017. https://doi.org/10.1515/cer-2017-0028.

[20] M. Z. Zhu, "Theoretical perspective in innovation management implementation: a literature review,", in *The 19th International Conference on Industrial Engineering and Engineering Management: Management System Innovation*. Springer Berlin Heidelberg, 2013. https://doi.org/10.1007/978-3-642-38427-1_176.

[21] E. Dworak, M. M. Grzelak, and E. Roszko-Wójtowicz, "Comparison of national innovation systems in the European Union countries," *Risks*, vol. 10, p. 6, 2022. https://doi.org/10.3390/risks10010006.

[22] A. Kuzior, I. Pidorycheva, V. Liashenko, H. Shevtsova, and N. Shvets, "Assessment of national innovation ecosystems of the EU countries and Ukraine in the interests of their sustainable development," *Sustainability*, vol. 14, p. 8487, 2022. https://doi.org/10.3390/su14148487.

[23] S. González Fernández, R. Kubus, and P.-I. J. Mascareñas, "Innovation ecosystems in the EU: policy evolution and horizon Europe proposal case study (the actors' perspective)," *Sustainability*, vol. 11, p. 4735, 2019. https://doi.org/10.3390/su11174735.

[24] M. P. Duarte and F. M. P. de Oliveira Carvalho, "How digital transformation shapes European Union countries' national systems of innovation: a configurational moderation approach," *J. Innovation Knowledge*, vol. 9, no. 4. https://doi.org/10.1016/j.jik.2024.100578.

[25] F. Sempere-Ripoll, S. Estelles-Miguel, R. Rojas-Alvarado, and J.-L. Hervas-Oliver, "Does technological innovation drive corporate sustainability? Empirical evidence for the European financial industry in catching-up and Central and Eastern Europe countries," *Sustainability*, vol. 12, p. 2261, 2020. https://doi.org/10.3390/su12062261.

[26] K. Szopik-Depczyńska, K. Cheba, I. Bąk, A. Kędzierska-Szczepaniak, K. Szczepaniak, and G. Ioppolo, "Innovation level and local development of EU regions. A new assessment approach," *Land Use Policy*, vol. 99, Art no. 104837. https://doi.org/10.1016/j.landusepol.2020.104837.

[27] E. E. Chivot, "Enhancing Europe's sustainability through innovation and technology," *Eur. View*. https://doi.org/10.1177/17816858231204730.

[28] European Commission, "The future of European competitiveness". https://commission.europa.eu/document/download/97e481fd-2dc3-412d-be4c-f152a8232961_en?filename=The%20future%20of%20European%20competitiveness%20_%20A%20competitiveness%20strategy%20for%20Europe.pdf.

[29] European Commission, "European innovation scoreboard 2024,". [Online] https://op.europa.eu/en/publication-detail/-/publication/8a4a4a1f-3e68-11ef-ab8f 01aa75ed71a1/language-en. Accessed Dec 28, 2024.

[30] Z. Liu, Y. Cui, C. Ding, Y. Gan, J. Luo, X. Luo, and Y. Wang, "The characteristics of ARMA (ARIMA) model and some key points to be noted in application: a case study of Changtan reservoir, Zhejiang Province, China," *Sustainability*, vol. 16, p. 7955, 2024. https://doi.org/10.3390/su16187955.

[31] E. Chodakowska, J. Nazarko, and Ł. Nazarko, "ARIMA models in electrical load forecasting and their robustness to noise," *Energies*, vol. 14, p. 7952, 2021. https://doi.org/10.3390/en14237952.

[32] Z. Hou, R. Yan, and S. Wang, "On the K-means clustering model for performance enhancement of port state control," *J. Mar. Sci. Eng.*, vol. 10, p. 1608, 2022. https://doi.org/10.3390/jmse10111608.

[33] J. Park and M. A. Choi, "K-means clustering algorithm to determine representative operational profiles of a ship using AIS data," *J. Mar. Sci. Eng.*, vol. 10, p. 1245, 2022. https://doi.org/10.3390/jmse10091245.

[34] N. M.-A. Mutombo and B. P. Numbi, "Development of a linear regression model based on the most influential predictors for a research office cooling load," *Energies*, vol. 15, p. 5097, 2022. https://doi.org/10.3390/en15145097.

[35] Eurostat, "Purchasing power parities (PPPs), price level indices, and real expenditures for ESA 2010 aggregates,". [Online] https://ec.europa.eu/eurostat/databrowser/view/PRC_PPP_IND/default/table?lang=en. Accessed Dec 29, 2024.

[36] G. H. Ionescu, D. Firoiu, R. Pîrvu, M. Enescu, M.-I. Rădoi, and T. M. Cojocaru, "The potential for innovation and entrepreneurship in EU countries in the context of sustainable development," *Sustainability*, vol. 12, p. 7250, 2020. https://doi.org/10.3390/su12187250.

[37] M. Andrijauskiene, D. Ioannidis, D. Dumciuviene, A. Dimara, N. Bezas, A. Papaioannou, and S. Krinidis, "European Union innovation efficiency assessment based on data envelopment analysis," *Economies*, vol. 11, p. 163, 2023. https://doi.org/10.3390/economies11060163.

[38] E. Dworak, M. M. Grzelak, and E. Roszko-Wójtowicz, "Comparison of national innovation systems in the European Union countries," *Risks*, vol. 10, no. 6, 2022. https://doi.org/10.3390/risks10010006.

[39] M. Dritsaki and C. Dritsaki, "R&D expenditures on innovation: a panel cointegration study of the E.U. Countries," *Sustainability*, vol. 15, p. 6637, 2023. https://doi.org/10.3390/su15086637.

[40] E. Roszko-Wójtowicz and J. Białek, "Measurement of the average innovativeness change over time in the EU member states," *J. Business Econ. Management*, vol. 20, no. 2, pp. 268–93. https://doi.org/10.3846/jbem.2019.8337.

[41] C. Edquist, J. Mikel, J. Barbero, J. L. Zofío, and L. J, "On the meaning of innovation performance: is the synthetic indicator of the Innovation Union Scoreboard flawed?" *Res. Eval.*, vol. 27, no. 3, pp. 196–211. https://doi.org/10.1093/reseval/rvy011.

[42] I. Bąk, K. Wawrzyniak, and M. Oesterreich, "Competitiveness of the regions of the European Union in a sustainable knowledge-based economy," *Sustainability*, vol. 14, p. 3788, 2022. https://doi.org/10.3390/su14073788.