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Comparative Analysis of the Innovation Level of European Union Member States

Keywords: innovation level; determinants of innovativeness; European Union; European Innovation Scoreboard; chemometric techniques

JEL: O11; O30; O52

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Abstract

Theoretical background: The European Union (EU) considers innovation performance to be one of the major factors in determining the competitiveness of its economy in the coming years. Hence, it is reasonable to seek methods for assessing the innovation level of EU member states and their growth drivers.
Purpose of the article: The aim of this study was to make a comparative assessment of the level of innovation in European Union countries and the identification of its drivers.
Research methods: The survey was conducted based on the European Innovation Scoreboard pertaining to the years 2016–2023. We performed a hierarchical cluster analysis, which allowed us to reveal member state groups with a similar innovation level. To identify the key and uncorrelated drivers responsible for the clustering of EU-27, we performed a principal component analysis.
Main findings: We identify three groups of countries that share similar innovation levels. The innovation leaders were eight member states: Belgium, Denmark, Germany, Luxembourg, the Netherlands, Austria, Finland, and Sweden. Research has shown that elements associated with the academic community, high-skilled workforce, collaboration of businesses with scientists, and information and communications technology skills are most significant for the diversification of the innovation level of EU-27 in 2023. In addition, Digitalisation, Innovators and Firm Investments also contribute greatly to innovation levels. This study contributes to the discussion of the innovation level of EU member states and identifies the key drivers that differentiate EU countries in this respect.

Introduction

In the contemporary market, the essential growth factors for businesses, countries, and regions are innovation and innovation performance (Kowalski, 2021, p. 1966; Prystrom, 2020, pp. 109–110). Innovation performance is also a key driver of competitiveness in countries and regions (Podstawka et al., 2024, pp. 103–119). It can be defined in many ways, from a micro- and macro-economic perspective, and refers to selected areas of human activity, such as innovation performance of industry, agriculture, and tourism (Szopik-Depczyńska et al., 2020, p. 2). Many development strategies, including the Sustainable Development Agenda 2023 and the related Sustainable Development Goals (SDGs), also refer to innovation performance (Singh & Ru, 2023, pp. 28446–28448). Innovation policy has also been a key element of the economic development of the European Union (EU), and its fundamental task is to indicate the direction for the innovation performance development of the community and its member states and provide tools and measures for effective implementation of this policy in the context of the growth strategy of Europe 2020 (Puślecki, 2014, pp. 47–64). The EU's innovation policy affects the national innovation systems of individual member states and their innovation levels, which translates into the competitiveness of their economies and the EU as a whole. Not all innovations in a specific economy stem from their own research and development. They can also be transferred abroad. This is an essential characteristic of innovation in countries where developing innovation systems rely mainly on external technology, as exemplified in China (Kowalski, 2021, p. 1968). Economic literature predominantly views the innovation performance of economies as an evolutionary process in which the ability to create and implement change is a function of knowledge and previously acquired experience (Courvisanos & Mackenzie, 2014, pp. 41–61). Therefore, monitoring the innovation level of EU member states and identifying its drivers play an important role.

Numerous studies and analyses undertaken by scientists, entrepreneurs, and politicians have discussed improvements in instruments and methods to enhance the innovation performance of the European economy. Owing to the complexity of innovation performance, the measurement approach has been continually evolving. Some studies focus only on single indicators (e.g. R&D expenditures), which do not provide a full image of the innovation performance status (Blanco et al., 2020, pp. 1685–1710; Pelikánová, 2019, pp. 13–34). Methods for preparing international comparative indices to measure innovation performance point to a need for multi-faceted measurement (Kowalski, 2021, pp. 1968–1969). Hence, using synthetic indices based on a wide range of indicators appears to be a more comprehensive approach. The authors who used such methods in their studies were Kijek and Kijek (2010, pp. 193–204), Roszko-Wójtowicz and Białek (2017, pp. 167–180) and Edquist et al. (2018, pp. 196–211). However, most studies focus on designing an aggregate measure only and do not attempt to identify the key factors to explain a specific ranking of member states according to their innovation level. This study follows the trend of searching for methods to assess innovation levels. Considering the importance of assessing the innovation level of EU member states, this study presents a new approach to this problem. The main objective of our research was to assess the innovation level of EU member states in time and space using chemometric techniques: principal component analysis (PCA), hierarchical cluster analysis (HCA) and the innovation activities dimension (IAD), as well as to identify the most significant factors for achieving a high innovation level. The research sought to answer the following questions: How are the EU member states ranked in terms of their level of innovation? Can groups from similar countries be identified in terms of innovation? What are the most important determinants of EU countries' innovativeness? The remainder of this paper is organised as follows. Section two provides an overview of the scientific literature regarding the essence and methods of measuring innovation performance. Section three discusses the research methodology, including the classification process of EU member states based on the innovativeness level. Part four contains a comparative analysis of the member states and discusses the results. The final section presents the conclusions from the analyses and identifies possible directions for further research.

Literature review

Innovation is a key driver of economic development in the contemporary economy (Castellacci & Natera, 2016, p. 3; Dempere et al., 2023, p. 182), which, according to endogenous growth theory, becomes a competitive source (Lucas, 1988, pp. 3–42; Romer, 1994, pp. 3–22). The theory of endogenous growth is also associated with the concept of a knowledge-based economy (KOW), in which innovation plays an important role (Brodny et al., 2023; Lunduvall, 1992; Złoty, 2018). The increasing role of innovation performance in creating a competitive edge for businesses and economies as a whole is scientifically justified by, among other researchers, Solow (1957, pp. 312–320) and Arrow (1962, pp. 609–626). In addition, Drucker (1985, pp. 107–129) highlights that innovation performance, entrepreneurship, and competitiveness (capacity to compete) determine the power of the community and economy as a whole. It is assumed that innovation can increase economic competitiveness and improve the community's quality of life (Vîrjan et al., 2023).

According to the United Nations 2030 Agenda for Sustainable Development, private business investment and innovation are the primary drivers of productivity, holistic economic growth, and job creation (UNCTAD, 2021; UN DESA, 2015). The European Union sees innovation performance as the foundation of knowledge-based, sustainable economic growth, ensuring social welfare (Brodny et al., 2023, pp. 1–2). The EU's approach to the innovation performance of the economy evolved over the years (Leijten, 2019, pp. 1–21). However, it has always been supported by various programmes and strategies. The first measurable effect of interest in the problems of innovation and innovation performance in the European Union was the Green Paper on Innovation published in 1995 (European Commission, 1995a). Another step towards supporting innovation processes in the EU was the European Commission's announcement of successive action plans for innovation in Europe. The First Action Plan for Innovation in Europe was announced in 1995 (European Commission, 1995b). The Lisbon Strategy was an important support programme for innovation processes in EU member states, which assumed the creation of the most competitive economy in the world. Not all the assumptions of the Lisbon Strategy could be accomplished in individual member states of the EU within the adopted term; therefore, in 2010, it was superseded by Europe 2020 – a new socio-economic development of the European Union (Gajewski, 2017, pp. 109–127). It comprises multiple initiatives, such as the Innovation Union, which aims to leverage the strengths of member states and improve their weaknesses in the area of innovation, and hence, increase the competitiveness of EU member states. The result of the far-reaching EU policy of supporting innovation in member states and their regions was the development and implementation of several programmes, including Horizon 2020, followed by Horizon Europe, and initiatives financed by Structural Funds (Dziallas & Blind, 2019, pp. 3–29; European Commission, 2020, p. 6). Actions undertaken by the EU in particular refer to coordination of the innovation policy at the level of member states, delineation of a long-term R&D development and innovation strategy, and implementation of R&D programmes for the whole EU. Another level involves the actions undertaken by individual member states. Innovation systems at the national economy level are termed national innovation systems (NIS). Żukrowska (2017, p. 32) notes that NIS differ from country to country and they are correlated with the economic development stage of the particular member state.

Despite undertaking far-reaching actions for the development of innovation, its level differs among EU member states. Furthermore, an overview of the reference literature and empirical studies indicates that there is no single universal method for measuring this phenomenon (Kijek & Kijek, 2010, pp. 195–197; Kleszcz, 2021, p. 26). Many research papers have attempted to assess innovation levels by relying on single ratios. This is an approach presented, among other authors, by Kučera and Fiľa (2022, pp. 227–241). By contrast, Dritsaki and Dritsaki (2023, pp. 1–35) investigated the relationship between R&D expenditure and the global innovation index of EU member states. Moreover, some studies have focused only on selected countries or groups of countries. Ivanová and Čepel (2018) explored the relationship between innovation performance and competitiveness in four EU member states: Czechia, Hungary, Poland, and Slovakia. They demonstrated that the international competitiveness of these countries largely depends on their innovation level. Klement et al. (2016) analysed the innovation results of Slovakia and identified significant barriers to their implementation, in particular, in the small and medium-sized enterprises (SME) sector.

Another approach to measuring innovation level is to design indices based on indicator sets. An example of a national index is the composite Global Innovation Index (GII) published by Cornell University, INSEAD, and the World Intellectual Property Organization in partnership with other organisations and institutions measuring economies' innovation performance (Dutta et al., 2020). Another popular measure of national innovation performance is the annual European Innovation Scoreboard (EIS), which includes the Summary Innovation Index (SII) (European Commission, 2023a, pp. 1–116). Brodny et al. (2023, pp. 1–21) present a more comprehensive approach to EU member states. Their assessment focused on 12 selected indicators describing countries in terms of their research and development activity, human and social capital levels, and enterprise innovation. Roszko-Wójtowicz and Grzelak (2019, pp. 9–30) conducted interesting research utilising various linear ordering methods (Hellwig's method, TOPSIS, and GDM) to create an innovation ranking of EU member states. Their results show that the linear ordering method used, and the standardisation procedure selected contribute to the final ranking of the examined objects. Currently, eco-innovation, which has a special effect on the sustainable development of countries and regions, is an important trend in innovation research. Among the researchers representing this trend, are Sobczak et al. (2022), Hajdukiewicz and Pera (2023, pp. 145–164), and Costantini et al. (2023). An overview of the literature, therefore, implies a need to fill the research gap in assessing the innovation level of EU member states and, most importantly, in searching for its growth drivers. Reliable measurement of innovation can help policymakers better understand economic and social changes, assess the contribution of innovation to social and economic goals, and monitor and evaluate the effectiveness and efficiency of their policies (OECD, Eurostat, 2018).

Research methods

This study analyses the innovation scores of 27 EU member states from 2016 to 2023 based on the EIS, an annual report on the basic indicators of innovation performance of individual member states. Statistics have been collected according to the common methodology since 2001, and on this basis, the innovation level of particular countries has been analysed, along with the effectiveness of their innovation policy and its strengths and weaknesses (Prystrom, 2020). The latest methodology from 2023 distinguishes four main activities – Framework conditions, Investments, Innovation activities, and Impact from 12 innovation dimensions, capturing a total of 32 indicators. Each main group includes an equal number of indicators and has equal weight in the SII. According to the latest methodology, this paper considers 12 innovation dimensions aggregating the scores for 32 indicators (Table 1, X_j, j = 1,…, 32) of innovation performance.

Table 1. Innovation indicators

Types of activities	Innovation activities dimensions	Symbol if indicator	Indicators
Framework conditions	IAD1 – Human resources	X1	New doctorate graduates
		X2	Population completed tertiary education
		X3	Lifelong learning
	IAD2 – Attractive research systems	X4	International scientific co-publications
		X5	Top 10% most cited publications
		X6	Foreign doctorate students
	IAD3 – Digitalisation	X7	Broadband penetration
		X8	Individuals who have above basic overall digital skill
Investments	IAD4 – Finance and support	X9	R&D expenditure in the public sector
		X10	Venture capital investments
		X11	Direct government funding and government tax support for business R&D
	IAD5 – Firm investments	X12	R&D expenditure in the business sector
		X13	Non-R&D innovation expenditure
		X14	Innovation expenditures per person employed in innovation-active enterprises
	IAD6 – Use of information technologies	X15	Enterprises providing training to develop or upgrade ICT skill of their personnel
		X16	Employed ICT specialist
Innovation activities	IAD7 – Innovators	X17	SMEs with product innovations
		X18	SMEs with process innovations
	IAD8 – Linkages	X19	Innovative SMEs collaborating with others
		X20	Public-private co-publications
		X21	Job-to-job mobility of Human Resources in Science & Technology
	IAD9 – Intellectual assets	X22	PCT patent applications
		X23	Trademark applications
		X24	Design applications

Types of activities	Innovation activities dimensions	Symbol if indicator	Indicators
Impacts	IAD10 – Employment impacts	X25	Employment in knowledge-intensive activities
		X26	Employment in innovative enterprises
	IAD11 – Sales impacts	X27	Medium and high-tech product exports
		X28	Knowledge-intensive services exports
		X29	Sales of product innovations
	IAD12 – Environmental sustainability	X30	Resources productivity
		X31	Air emissions by fine particulates PM2.5 in Industry
		X32	Development of environment-related technologies

Source: (European Commission, 2023b).

As reported by Kleszcz (2021), a common method for measuring the innovation level of countries is designing a synthetic measure, e.g. the Summary Innovation Index, which combines data from multiple standardised indicators (X_j) using an arithmetic mean. As described in the EIS 2023 Methodology Report (European Commission, 2023b, pp. 1–73), every indicator is then assigned weight $\frac{1}{32}$, assuming that all the indicators have an identical effect (X_j) on the final SII level. However, the correlation analysis of component indicators forming specific innovation dimensions indicates that some variables strongly correlate with others; thus, they constitute redundant information. In addition, the raw SII does not allow the identification of the dimensions that generate the strongest innovation variations in EU member states.

We propose a PCA to remove the collinearity of variables, reduce the number of dimensions identifying the parameters carrying relevant information on the analysed phenomenon, and unveil the hidden structures in the primary dataset. An added value of PCA is also a biplot, which facilitates understanding the data structure and provides information on the correlation between the analysed features.

For p-dimensional feature vector $\mathrm{X} = [X_1, X_2, \dots, X_p]$ the first PC is obtained as a linear combination which maximises the variance of

$$Z_1 = a_{11}X_1 + a_{12}X_2 + \cdots + a_{1p}X_p \tag{1}$$

and is constrained so that $\sum_i a_{1i}^2 = 1$. Vector $a_1 = [a_{11}, a_{12}, \dots, a_{1p}]$ represents the direction of the maximum variability in the data. The subsequent PCs are selected similarly, with an additional requirement assuming that they remain uncorrelated with all the previous PCs.

Numerically, PCA is computed as an eigenvector decomposition of the covariance or correlation matrix **R** for n observations: $\mathrm{X} = [x_{ij}]$, $i = 1, \dots, n$. In standard PCA terminology, the elements of eigenvectors a_k are commonly referred to as PC loadings, whereas the elements of linear combinations $\mathrm{a}_k \cdot \mathrm{X}^T$ are called PC scores, because they are the values that each individual element would score on a given PC.

PCA only yields significant results if the variables are dependent. Bartlett's test of sphericity can check this. The null hypothesis of this test assumes that the variables are uncorrelated, meaning that the correlation matrix **R** is a unit matrix. In practice, rejecting the null hypothesis implies that the data are suitable for dimensionality reduction using PCA. Whether the matrix **R** deviates significantly from the identity matrix is measured using the test statistic:

$$\chi^2 = -\left(n - 1 - \frac{2p+5}{6}\right) \log\left(det\mathbf{R}\right) \quad (2)$$

whereas det **R** means the determinant of the **R** matrix and (2) is asymptotically χ^2 – distributed with degrees of freedom equal to $p(p-1)/2$ under the true null hypothesis.

Additionally, the adequacy of the **R** matrix is assessed using the Kaiser–Meyer–Olkin (KMO) coefficient (Gie Yong & Pearce, 2013):

$$KMO = \frac{\sum_{i\neq j}\sum_{j\neq i} r_{ij}^2}{\sum_{i\neq j}\sum_{j\neq i} r_{ij}^2 + \sum_{i\neq j}\sum_{j\neq i} \hat{r}_{ij}^2} \quad (3)$$

where r_{ij}, $\hat{r}_{ij}$ are the correlation coefficients and the partial correlation coefficients between the i-th and j-th variables, respectively. In practice, the higher the KMO value (in the range 0–1), the stronger the basis for applying PCA.

Before PCA, we performed a hierarchical cluster analysis, which allowed us to reveal member state groups with a similar innovation level (emerging innovators, moderate innovators, and innovation leaders). The necessary calculations were performed using Statistica 13.3 software (StatSoft, 2006) based on standardised data, and the results are presented as tables and charts in Excel.

Results

To illustrate the innovation level of EU member states, Figure 1 shows the ranking of EU-27 based on the SII for 2016 and 2023. The countries are presented in descending order of their SII in 2023. Member states that scored the highest synthetic innovation indicator in 2023 were Denmark, Sweden, Finland, and the Netherlands, whereas the lowest scores were recorded for Latvia, Bulgaria, and Romania. During this period, innovation results increased the most for Cyprus (+0.179856), Estonia (+0.148), Greece (+0.112), and Czechia (+0.106) and decreased in two cases: France (-0.008) and Luxembourg (-0.008).

The data in Figure 1 show significant changes in the innovation ranking from 2016 to 2023. Estonia presented the highest movement in ranking (eight ranks), followed by Slovenia, Portugal, and Cyprus (five ranks). During the study period, a significant improvement occurred for Cyprus (from 17th place in 2016 to 10th in 2023) and Estonia (from 18th place in 2016 to 12th in 2023), while Portugal noted the largest drop (from 13th place in 2016 to 18th place in 2023). Estonia's promotion of the presented ranking can be explained by modern technology forming a very important part of the Estonian economy. About 15% of the GDP of Estonia is contributed by advanced technology sectors. Following the example of Finland, Estonia has made technology the most important aspect of its economy and society (de Carlos Sola, 2018). In contrast, Portugal's lower ranking is attributed, among other factors, to stagnating productivity and an ageing population. The outflow of young people from the country and talent flights are among the country's most serious problems. In addition, Coutinho and Au-Yong-Oliveira (2023) argue that the country scored the lowest for business advancement due to its low performance in innovation partnerships and knowledge transfer.

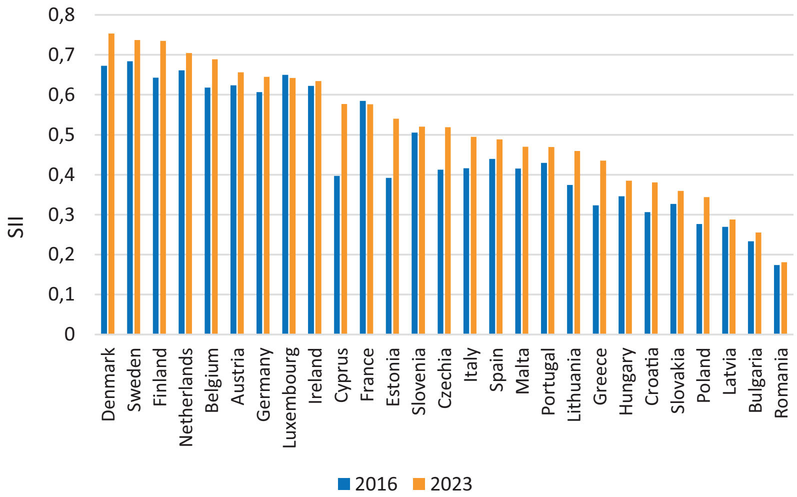


Figure 1. Innovation level of EU member states in 2016 and 2023

Source: Authors' own study.

Since the approach used in the EIS report, based on the SII, is limited only to determining the position of individual countries in terms of innovation performance, this study proposes an in-depth analysis of the innovation level by grouping EU member states according to their innovation level (Figure 2) and then identifying the factors with the most significant impact on the variation revealed.

Therefore, in the next step of the analysis, the values of the innovation dimensions were used to conduct a hierarchical cluster analysis, which identified three clusters of countries that were most similar to innovation indicators in 2023. To create a dendrogram, we used an algorithm to classify Ward's minimum variance and Euclidean distance, constituting a similarity measure between objects (EU-27). The number of clusters was determined based on the agglomeration flow chart, which shows the distances between clusters when they are combined (dashed line on the dendrogram). For comparison, according to the SII (European Commission, 2023a), countries were grouped into four groups of countries similar in terms of innovation. This was because of the different research methods used. In our approach, the starting point was hierarchical cluster analysis, and its characteristic agglomeration flowchart indicated the division of countries into three clusters. The EIS was calculated as the weighted arithmetic average of the sub-indices.

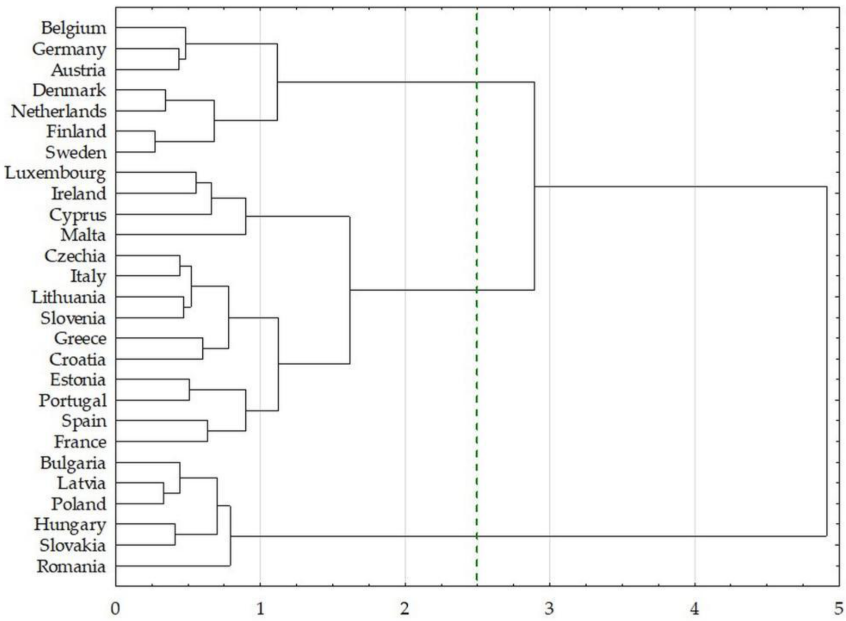
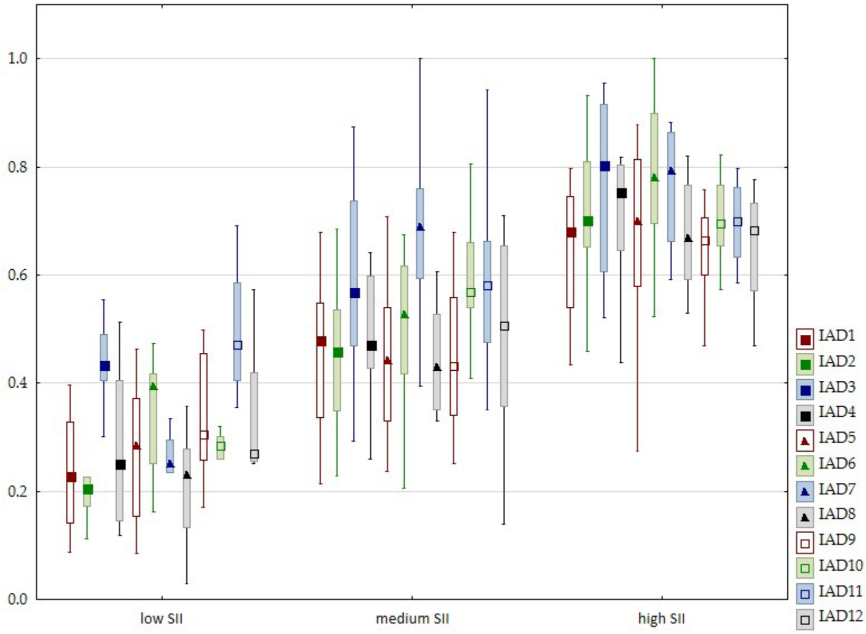


Figure 2. A dendrogram of the hierarchical cluster analysis based on the Euclidean measure and Ward's method for EU-27 countries in 2023

Source: Authors' own study.

As a result of the HCA, the first cluster comprised 14 EU member states: Luxembourg, Ireland, Cyprus, Malta, Czechia, Italy, Lithuania, Slovenia, Greece, Croatia, Estonia, Portugal, Spain, France. For this group, the average SII was 0.515 (standard deviation, *SD* = 0.074, and coefficient of variation, *V* = 14%); therefore, these countries can be considered moderate innovators. The second cluster consists of six member states of the EU: Bulgaria, Latvia, Poland, Hungary, Slovakia and Romania, since the mean SII for that group was 0.302 (*SD* = 0.076 and *V* = 25%), they could be deemed emerging innovators. The third cluster is associated with seven innovation leaders: Belgium, Germany, Austria, Denmark, the Netherlands, Finland and Sweden. The mean SII for this cluster was 0.703 (*SD* = 0.042, *V* = 6%). An interesting question is how the different dimensions of innovation (IAD) have influenced the distribution of the EU-27 member states presented on the dendrogram (Figure 2). To illustrate this point, individual innovation activity dimensions (IAD) are presented in the box plots (Figure 3) for each of the three clusters of countries identified by HCA. For moderate innovators (Cluster 1), all dimensions were average. The long whiskers for Finance and support (IAD4), Innovators (IAD7), Linkages (IAD8), Sales impacts (IAD11), and Environmental sustainability (IAD12) imply significant disparities between Cluster 1 countries in the area of these five dimensions. For emerging innovators (Cluster 2), all the dimensions except Digitalisation (IAD3), Sales impacts (IAD11), and Environmental sustainability (IAD12) featured a lower scale than those included in Cluster 1. For Cluster 3, the scale of IAD2–IAD7 was much larger (above the third quartile). The largest disparities between countries forming Cluster 3 were visible in the Firm investments (IAD5) dimension.



IAD1 – Human resources, IAD2 – Attractive research systems, IAD3 – Digitalisation, IAD4 – Finance and support, IAD5 – Firm investments, IAD6 – Use of information technologies, IAD7 – Innovators, IAD8 – Linkages, IAD9 – Intellectual assets, IAD10 – Employment impacts, IAD11 – Sales impacts, IAD12 – Environmental sustainability

Figure 3. The impact of individual dimensions of innovation on the level of Summary Innovation Index in 2023

Source: Authors' own study.

The direction of change in the innovation level of European economies is shaped by the interaction of several scientific and technological, organisational, economic, environmental, social, cultural, and political factors (Orlovska & Morozova, 2021). Therefore, identifying the key drivers of high innovation levels plays an important role in improving innovation performance. Table 2 summarises the correlation coefficients for each innovation dimension for 2023. The resulting values indicate varying correlation levels between the examined variables.

Table 2. Correlations between the Innovation activities dimensions IAD in 2023

IAD	IAD1	IAD2	IAD3	IAD4	IAD5	IAD6	IAD7	IAD8	IAD9	IAD10	IAD11	IAD12
IAD1	1.00	**0.84**	**0.74**	**0.64**	**0.55**	**0.82**	**0.49**	**0.78**	**0.64**	**0.70**	**0.54**	**0.47**
IAD2	**0.84**	1.00	**0.73**	**0.54**	**0.44**	**0.83**	**0.50**	**0.82**	**0.73**	**0.76**	**0.58**	**0.52**
IAD3	**0.74**	**0.73**	1.00	**0.46**	0.29	**0.75**	0.15	**0.51**	**0.53**	0.37	0.38	**0.41**
IAD4	**0.64**	**0.54**	**0.46**	1.00	**0.75**	**0.53**	**0.55**	**0.57**	0.36	**0.55**	0.37	0.38
IAD5	**0.55**	**0.44**	0.29	**0.75**	1.00	**0.56**	**0.64**	**0.53**	**0.50**	**0.65**	**0.64**	**0.49**
IAD6	**0.82**	**0.83**	**0.75**	**0.53**	**0.56**	1.00	**0.47**	**0.76**	**0.71**	**0.70**	**0.56**	0.38
IAD7	**0.49**	**0.50**	0.15	**0.55**	**0.64**	**0.47**	1.00	**0.71**	**0.40**	**0.86**	**0.49**	0.32
IAD8	**0.78**	**0.82**	**0.51**	**0.57**	**0.53**	**0.76**	**0.71**	1.00	**0.66**	**0.82**	**0.51**	0.39
IAD9	**0.64**	**0.73**	**0.53**	0.36	**0.50**	**0.71**	**0.40**	**0.66**	1.00	**0.66**	**0.42**	**0.44**
IAD10	**0.70**	**0.76**	0.37	**0.55**	**0.65**	**0.70**	**0.86**	**0.82**	**0.66**	1.00	**0.52**	0.38
IAD11	**0.54**	**0.58**	0.38	0.37	**0.64**	**0.56**	**0.49**	**0.51**	**0.42**	**0.52**	1.00	**0.57**
IAD12	**0.47**	**0.52**	**0.41**	0.38	**0.49**	0.38	0.32	0.39	**0.44**	0.38	**0.57**	1.00

Statistically significant correlation coefficients at the 0.05 level are marked in bold

Source: Authors' own study.

As shown by the presented data, a strong positive correlation exists between the following dimensions: Human resources (IAD1) and Attractive research systems (IAD2); Innovators (IAD7) and Employment impacts (IAD10); and Attractive research systems (IAD2) and Linkages (IAD8). The correlations between the other dimensions were mainly moderate or weak. A significant Bartlett sphericity test result (according to (2), $p < 0.0001$) for the correlation matrix (Table 2) and the Kaiser–Meyer–Olkin index of 0.77 (see (3)), provided a strong basis for principal component analysis. It is useful in reducing dimensionality, enabling the construction of new uncorrelated variables (PCs) explaining the maximum variation in the studied dataset, and revealing hidden relationship patterns between the new components (PCs) and the IAD dimensions (Stanisz, 2007). PCA was performed for standardised data depicting the 12 innovation dimensions of European economies (IAD1–IAD12) used in the EIS methodology. Significant PCA axes were selected using the Guttman–Kaiser criterion (Yeomans & Golder, 1982). The first two components (PC1 and PC2) had eigenvalues greater than 1 (Table 3), which explained almost 71% of the total variability. Table 3 is a compilation of factor loadings for all components calculated based on IADs. The load values in bold were considered the most important for interpreting the first two principal components, PC1 and PC2, which explained 60.08% and 10.81% of the total variability, respectively.

The dimensions with the greatest impact on PC1 were Attractive research systems (IAD2), Human resources (IAD1), Linkages (IAD8), Use of information technologies (IAD6), and Employment impacts (IAD10), hence PC1 can be associated with Strategic Resources. Attractive research systems includes three indicators and measures the international competitiveness of the science base by focusing on International scientific co-publications, Top 10% most cited publications, and Foreign doctorate students. Human resources comprises three indicators and measures the availability of a high-skilled workforce from the perspective of: New doctorate graduates, Population with completed tertiary education, and Lifelong learning. The Linkages dimension consists of three indicators and measures innovation capabilities, taking into account Innovative SMEs collaborating with others, Public-private co-publications, and Job-to-job mobility of Human Resources in Science & Technology. Use of information technologies is made up of two indicators: Enterprises providing training to develop or upgrade ICT skills of their personnel and Employed ICT specialists, thus, concerning the upgrading of the IT skills of employees. Employment impacts, however, comprises Employment in knowledge-intensive activities and Employment in innovative enterprises. This shows that elements associated with the academic community, high-skilled workforce, collaboration of businesses with scientists, and ICT skills were most significant as regards variations in the innovation level of EU-27 in 2023. Therefore, the PC1 interpretation is a measure of the status of these areas.

Table 3. Matrix of factor loadings calculated based on innovation dimensions

Indicator	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
IAD1	**-0.89**	-0.22	0.02	0.04	-0.18	0.04	0.14	-0.28	0.00	0.13	0.07	-0.02
IAD2	**-0.90**	-0.28	0.07	-0.14	-0.02	0.12	0.10	0.09	-0.16	-0.13	-0.02	-0.11
IAD3	-0.61	**-0.68**	-0.06	0.19	-0.19	0.03	-0.25	0.08	-0.02	0.12	-0.08	0.01
IAD4	-0.69	0.26	0.02	0.61	-0.17	0.13	0.11	0.10	-0.08	-0.04	0.06	0.06
IAD5	-0.73	**0.46**	-0.19	0.33	0.10	-0.28	-0.03	-0.07	0.05	0.00	-0.12	-0.07
IAD6	**-0.88**	-0.27	0.13	0.01	-0.06	-0.23	-0.11	-0.03	0.15	-0.20	0.10	0.02
IAD7	-0.71	**0.58**	0.20	-0.18	-0.05	0.15	-0.20	0.05	0.01	0.09	0.12	-0.05
IAD8	**-0.88**	0.04	0.26	-0.17	-0.05	0.13	0.17	0.12	0.22	0.05	-0.10	0.02
IAD9	-0.70	-0.20	0.24	0.06	0.60	-0.16	0.04	0.06	-0.06	0.10	0.05	0.02
IAD10	**-0.87**	0.26	0.21	-0.26	0.00	0.04	-0.08	-0.13	-0.14	-0.08	-0.11	0.09
IAD11	-0.68	0.10	-0.51	-0.35	-0.19	-0.30	0.09	0.12	-0.06	0.06	0.04	0.04
IAD12	-0.61	-0.03	-0.64	-0.02	0.30	0.34	-0.04	-0.05	0.07	-0.05	0.01	0.01
Eigenvalue	7.20	1.30	0.90	0.80	0.60	0.40	0.20	0.20	0.10	0.10	0.10	0.00
Variance %	60.10	10.80	7.80	6.60	5.00	3.60	1.70	1.30	1.20	1.00	0.60	0.30

Bold indicates strong (above 0.75) or moderate (0.5–0.75) correlation between PC1, PC2 and the innovation activities dimensions
Source: Authors' own study.

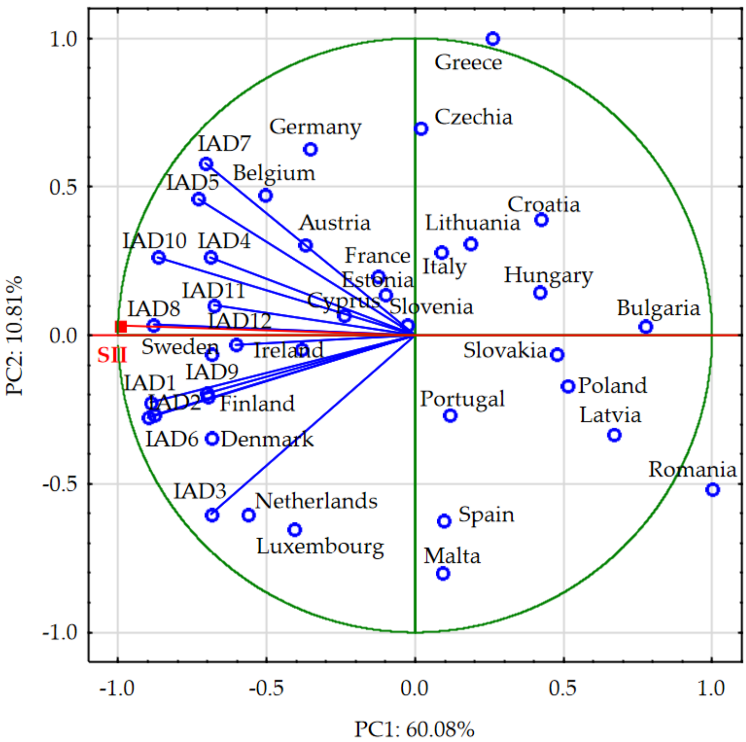
Digitalisation (IAD3), Innovators (IAD7), and Firm investments (IAD5) had the greatest impact on PC2, hence PC2 can be defined as Technological Development. The first dimension, Digitalisation, comprises two indicators: Broadband penetration and Individuals who have above basic overall digital skills. These indicators measure the number of economic entities with high-speed Internet access and the number of individuals with the aforementioned basic overall digital skills.

The Innovators dimension includes SMEs with product innovations and SMEs with business process innovations and measures the share of SMEs that have introduced innovations on the market or within their organisations, covering both product and business process innovators. Firm investments includes three indicators on R&D and Non-R&D investments that firms make to generate innovations including Business R&D expenditures, Non-R&D innovation expenditures, and Innovation expenditures per person employed. Therefore, PC2 interpretation measures the digital field status, the openness to introduce process and production changes, and companies' development expenditure, that is, investment in research and development. PC2 accounted for nearly 11% of the total variation in the innovation level of the EU-27 in 2023 (Table 3).

Considering the eigenvectors from the PCA, it is possible to specify the explicit form of new, mutually uncorrelated variables (PC1, PC2, see (1)), which can be used in further research analysis (Kleszcz, 2021):

$$
\begin{aligned}
&PC1 = 0.110 \cdot IAD1 + 0.113 \cdot IAD2 + 0.107 \cdot IAD6 + 0.108 \cdot IAD8 + 0.104 \cdot IAD10 \\
&PC2 = 0.278 \cdot IAD3 + 0.162 \cdot IAD5 + 0.260 \cdot IAD7
\end{aligned}
\tag{4}
$$

The biplot (Figure 4) is a visualization of relationships (4) and (5) and shows the influence of the selected IAD variables on the principal components PC1, PC2. The EU-27 countries were also distributed on the PC1–PC2 plane with the SII innovation index attached, revealing several important correlations. Fourteen member states scored positively on PC1, specified as Strategic Resources, indicating that they performed poorly in academic capacity, funding, and professional qualifications. Low values in the area of five dimensions – Attractive research systems, Human resources, Linkages, Use of information technologies, Employment impacts, and consequently 13 innovation indicators – made a particularly significant contribution to lower SII. Moreover, this group was predominantly made up of so-called new EU member states (except Greece and Italy). Simultaneously, it can be noted that Malta, Spain and Romania ranked among the countries with a high digitalisation index, while Greece, Czechia, and Germany demonstrated high openness to process and production innovation. The negative PC1 axis, on the other hand, correlates with high values of the IAD dimensions (above the EU-27 average) and aggregates mostly member states representing the so-called old Union (except Cyprus, Estonia, and Slovenia), which score high on SII (Figure 4).



PC1: Attractive research system, Finance and support and Employment Impacts; PC2: Digitalisation, Innovators and Firm investments

Figure 4. Biplot – results of the principal component analysis for innovation parameters in 2023

Source: Authors' own study.

Discussion

The ability to create, apply and disseminate innovation is treated as the most important factor for economic growth and development. This prompts the authors to look for measures to assess the level of innovation in EU member states. For example, Dworak et al. (2022) used a synthetic measure and divided EU countries into four groups depending on innovation. The highest-level group included Ireland, France, the Netherlands, Belgium, Sweden, Germany, Austria and Finland. Many academic papers have examined innovation in relation to countries' economic growth. For instance, Risso and Carrera (2019) explored the correlation between income inequality, innovation, and economic growth using data from 74 countries. Kiselakova et al. (2020) extended the scope of those factors by analysing patents granted, high-tech exports, gross domestic expenditures on R&D, government expenditures on education, direct investment, gross fixed capital, and tertiary educational attainment.

The literature also includes studies of the drivers of innovation in different sectors. For example, Baesu et al. (2015) analysed the innovation level drivers of the high-tech sector for European Union member states. However, it is difficult to relate the findings of our study directly to those of other studies. The only paper presenting a similar analysis is the work of Kleszcz (2021, pp. 24–45). Drawing on data and methodology from the 2019 EIS report, which also covers the UK, the author used the PCA method and attempted to identify the innovation level drivers for EU member states. Her research revealed two main drivers of the innovation level: the first combined academia, finance, and a high-skilled workforce, while the second aggregated business-related dimensions (termed "business"). These factors jointly account for 68% of the observed variance. The author obtained similar results for all detailed indicators outlined in the EIS, which validated her claim that the method used is the right alternative for innovation performance assessment (Kleszcz, 2021, pp. 24–45).

In research conducted for this study, the dimensions that significantly determined the innovation level (forming PC1) were, in order of importance: Attractive research systems, Human resources, Linkages, Use of information technologies, and Employment impact, what we defined as Strategic Resources. Digitalisation, Innovators, and Firm investments had the greatest impact on PC2, which reflects Technological Development. These two dimensions jointly explained >71% of the total variability. Compared with the findings of Kleszcz, we confirm that Attractive research systems, Human resources, and Linkages are the most important factors contributing to the improvement in the innovation level of EU member states.

Conclusions

Having realised the role of innovation in socio-economic development, member states began pursuing intensive innovation policies. A country's capacity to innovate is extremely important because it contributes to increasing the efficiency of production factors and thus stimulates economic growth. The European Union considers innovation performance to be one of the major factors in determining the competitiveness of its economy in the coming years. Hence, it is reasonable to seek methods for assessing the innovation level of EU member states and their growth drivers. Measuring the innovation performance of EU member states is a difficult task, which, on the one hand, is due to its complexity and the multifaceted nature of the phenomenon itself and, on the other hand, to the degree of diversity in European countries' economies.

In view of the above, our own approach to examining the innovation level of EU member states makes it possible to identify the most important factors determining this level. The correlations revealed can improve the effectiveness of innovation policy at the individual country and whole EU level.

For this study, we performed a hierarchical cluster analysis as the first step, which identified three clusters of countries sharing similar innovation levels: emerging innovators, moderate innovators, and innovation leaders. The first of these groups included Bulgaria, Latvia, Poland, Hungary, Slovakia, Romania, i.e. countries admitted to the EU in 2004 or later. They showed the lowest level of innovation among all member states. Luxembourg, Ireland, Cyprus, Malta, Czechia, Italy, Lithuania, Slovenia, Greece, Croatia, Estonia, Portugal, Spain, France achieved a similar innovation level, higher than in the first group. However, the so-called countries of the old Union, characterized by a relatively high level of development, such as Belgium, Germany, Austria, Denmark, the Netherlands, Finland, Sweden, achieved an above-average innovation level.

It is therefore possible to notice clear differences between the EU-14 countries and the new member states, in favor of the countries of the so-called old union with a high level of socio-economic development. Moreover, innovation leaders and most moderate innovators are found mainly in Northern and Western Europe, while emerging innovators are found in Southern and Eastern Europe which is the result of structural problems of its economies and an underdeveloped innovation support system and ineffective innovation policy conducted in these countries.

To identify the key and uncorrelated drivers responsible for the clustering of EU-27, we performed a principal component analysis. The PCA results were shown on a biplot, which made it possible to reveal several important links between IAD dimensions and the innovation level of EU member states as well as to substantiate the similarity between different countries. PCA made it possible to reduce the 12 dimensions describing the innovation performance of the EU-27 to two main innovation components (Strategic Resources and Technological Development), which explained 71% of the variation in the primary dataset. The component most influenced by dimensions such as Attractive research systems, Human resources, Linkages, Use of information technologies, and Employment impacts was PC1, while Digitalisation and Implementation of process and production changes had the greatest impact on PC2. Therefore, these dimensions contribute most to differentiating the innovation performance of the EU-27 in 2023. The proposed interpretations of the first two components, namely academia, funding, and broadly interpreted development investment, can be used to build econometric models where independent predictors are required.

The most important benefit of our research may be recommendations for possible actions at the level of individual EU member states. Our research shows that the biggest changes in terms of improving competitiveness by increasing innovation are characteristic of countries investing in the functioning of efficient and effective innovation systems, which means high financial expenditure on R&D entities and the development of a liaison between science and business. Because of budget constraints, networking between economic operators competing in the market and scientific research institutions responsible for creating new knowledge and solutions that can be transformed into innovative offerings and their commercialisation is an important issue for many EU countries.

Equally important is the expenditure on education and human resource development, which should contribute to the development of a sustainable knowledge-based economy. In addition, our study corroborated that Digitisation, Use of information technologies, and Firm investments are among the modern tools for socioeconomic growth. This implies a need for rational actions on the part of the state's economic policy to create financial and legal incentives for economic operators to invest in these areas.

The process of increasing the innovativeness of the economy is a difficult task and requires active actions taken by individual countries. There is therefore a need for constant monitoring of progress in this area. This allows for the optimization of decision-making processes. This study contributes to the discussion of the innovation level of EU member states and identifies the key drivers that differentiate EU countries in this respect. Member states should promote an innovation policy based on innovation components that will enable them to develop dynamically and improve their competitiveness in the international market by increasing their innovation level. Further research should focus on an in-depth analysis of the effectiveness of actions taken by the EU to strengthen innovation activities.

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