“Determining the key factors of the innovation gap between EU countries”

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DETERMINING THE KEY FACTORS OF THE INNOVATION GAP BETWEEN EU COUNTRIES

Abstract

Innovation plays a crucial role in ensuring economic growth and competitiveness of national economies, creating conditions for their sustainable development. By focusing on supporting innovation, the EU is particularly helping to accelerate the development of those member states that lag far behind the EU average. This requires the selection of the indicators reflecting the development of innovation that determine the differences between member countries to the greatest extent. Therefore, the aim of the study is to identify the key factors of the innovation gap (FIG) between EU countries based on a comparison of indicators characterizing the national innovation systems (NIS).

For this purpose, 22 relative indicators were selected from the indicators included in the Global Innovation Index to form an array of empirical data. At the first stage, the EU countries were divided into four clusters using the k-means method. At the second stage, using the decision tree method, a group of indicators was identified that together distinguish the obtained clusters to the greatest extent and, accordingly, determine the differences between EU countries and can be considered as FIG, namely: "Researchers", "GERD financed by business", "Joint venture/strategic alliance deals", "Software spending", and "High-tech manufacturing". This allows individual member states to prioritize the development of those indicators (i.e. FIG) that most determine their position in the EU and therefore improve their NIS. At the EU level, this will contribute to the complementarity of the NIS, overcome differences between member states and increase the overall level of convergence in innovation.

Keywords innovations, national innovation system, indicators, clustering, classification analysis, factors of innovation gap between countries, innovation policy, convergence

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INTRODUCTION

In the modern economy, innovations are recognized as a preferred factor for the growth and competitiveness of national economies, creating conditions for sustainable socio-economic development and public well-being. The aggravation of economic, social, resource, and environmental problems in recent years necessitates various transformations and transition to new production and economic models, which, along with rapid technological changes, increases the importance of innovations that will ensure overall prosperity in the future.

The EU, which is one of the world's economic centers, focuses on building an innovative, competitive economy capable of competing with dynamically developing global players and gaining leadership. This requires the unity of all twenty-seven member states around a common course of socio-economic development, ensuring synchronized progress of member states to improve the EU's overall position in the global economic space. The commitment of EU member countries to progress is closely linked to innovations based on excellence, openness, high standards, human potential development, ideas for protecting the planet, and other principles

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of sustainable development. In this context, it is expected to ensure a high level of activity and achievements in the field of innovation, building efficient national innovation systems (hereinafter referred to in the singular and plural forms as NIS). To consolidate the EU member states, it is natural to reduce their differentiation in innovation, increase the level of convergence across the union, and agree on development strategies. This is especially important for lagging member states to ensure accelerated development and increase their contribution to the global competitiveness of the whole association.

The EU implements appropriate policies to overcome the so-called innovation gap among member countries, which requires assessing and comparing the level of innovation development. Given the complexity of modern NIS, which are described by a large set of different indicators, an effective solution to this problem requires, among other things, identifying the specific factors that cause the innovation gap. Standard statistical monitoring and existing comparative analysis and ranking approaches (e.g., European Innovation Scoreboard, EIS) do not allow for this to be fully realized, as they are not designed to identify links between factors that may indicate such differentiation. Considering the experience of analytical research, it is advisable to use Data Mining methods, namely cluster and classification analysis, which, in combination, allow identifying hidden patterns in large data sets, to determine the factors of differentiation between certain objects.

1. LITERATURE REVIEW

The EU unites a group of highly developed countries in the world that have powerful NIS, belonging to the global leaders in the field of innovations (WIPO, 2022), as well as a number of countries that act as moderate and emerging innovators. (European Commission, 2023). Empirical studies confirm the comprehensive socio-economic significance of innovations and their positive correlation with economic growth indicators in practically all EU countries (Vetsikas et al., 2017; Maradana et al., 2019). The mandatory focus on innovation in the EU is proclaimed in the context of transitioning to sustainable development, for which the synchronicity of progress among all member countries is of utmost importance (Szopik-Depczyńska et al., 2018; Shkarupa et al., 2020; Petrushenko et al., 2021; Oharenko et al., 2021; Kostakis & Tsagarakis, 2022; Filatova et al., 2023).

The objectives of ensuring global competitiveness in the EU have acquired collective significance, special content, and reached a supranational level, emphasizing increased attention to innovative activities (Ciocanel & Pavelescu, 2015; Kral & Janoskova, 2023; Kartika et al., 2023). First and foremost, this concerns high-tech industries, where competition and changes in global exports are directly linked to innovative factors. Recognizing these sectors as the main drivers of economic growth and employment, the EU actively supports the implementation of innovations to strengthen its overall competitive positions in the global markets (Braja & Gemzik-Salwach, 2020). The issues of competitiveness, linked to adapting to systemic changes, are closely intertwined with new trends in production transformation, including the transition to the "green economy" (Melnyk, 2016; Apak & Atay, 2015; Boros et al., 2023) and digitalization (Marti & Puertas, 2023), where the innovation gap becomes a crucial prerequisite, hindering the progress of the entire union. At the global level, the EU competes with powerful and rapidly developing players, particularly the USA and China. The issues of competitiveness are linked to the problem of global leadership and directly concern the sphere of innovations. Comparing positions in the global markets for high-tech goods and services reveals Europe's relative weakness. Therefore, the EU strives to increase its economic power and level of competitiveness in the global markets, which depends on successes in the field of innovations (Marčeta & Bojnec, 2020; Melnyk, 2022).

To increase its level of competitiveness and achieve global leadership, the EU needs synchronized strengthening and implementation of the innovative potential of individual member countries. In this context, international comparisons allow identifying leaders and outsiders among the EU countries, determining the strengths and weaknesses of each country, and accordingly identifying the components of the NIS that need improvement and the parameters that need to be enhanced to improve their positions. This will contribute to bridging the gaps between countries at the level of the entire union.

Given the history of expansion and the natural diversity of the EU's economic landscape, the problem of inequality between countries is significant and persistent. This is particularly evident in the field of innovations, which ultimately determines economic outcomes and societal well-being. Moreover, this necessitates the identification of the FIG among countries within the EU, i.e., the reasons for their differentiation and inequality, which allows us to understand the differences in NIS and identify ways to bring countries closer together in terms of qualitative and quantitative parameters of the innovation field. In particular, this can be the basis for accelerated development of those countries that lag far behind the average level in the whole union (Zabala-Iturriagagoitia et al., 2021). Given the specificity of the innovation phenomenon and NIS, the key problem is the evaluation of prerequisites and the measurement of innovation activity outcomes. This evaluation requires encompassing a broad set of components of innovative potential and the effects of its utilization. Consequently, it necessitates summing up a wide range of various specialized parameters that characterize NIS based on the areas of its functioning (Barbero et al., 2021). Instead, this makes it difficult to assess the level of innovation development of countries in general, the effectiveness of the NIS and, even more so, relevant comparisons between countries.

In global practice, a certain established set of indicators has been formed to characterize the structure, dynamics, and effectiveness of NIS, which are used to assess the level of innovation development of a particular country. These characteristics are utilized in official statistics, and various configurations are used to calculate composite indices. For different assessment tasks and international comparisons, multi-criteria analysis methods are applied (Paredes-Frigolett et al., 2021; Carayannis et al., 2018; Hamdan & Hussein, 2020; Dubyna et al., 2023; Vávrová & Přečková, 2023), but it also cannot provide answers to all the questions that are necessary for the development of innovation policy. Taking this into account, the EU has developed new approaches to statistical monitoring, comprehensive indicators for assessing the level and effectiveness of innovation activity, which are essential for comparing countries and making managerial decisions (Janger et al., 2017). At the same time, an assessment is carried out regarding the degree of achieving specific strategic goals of the EU related to innovations as a prerequisite for growth, competitiveness, or certain transformations. Additionally, attention is focused on changes in the level of convergence among Union countries, based on overcoming the innovation gap. For this purpose, specialized analytical approaches are mainly used, such as national and regional innovation scoreboards, comprehensive indices, and rankings.

The NIS of different countries significantly differ from one another, which complicates the comparison of their potential (input indicators) and performance (output indicators). Multi-criteria comparison of the structure of innovation systems among EU countries, considering their heterogeneity, allows highlighting their unique characteristics, strengths, and weaknesses, while also raising the question of the possibility of integrating the NIS themselves (Cirillo et al., 2019). As for the EU, it is necessary and appropriate to compare the NIS between member states to understand the correlation, state, and assessment of the dynamics of development of the innovation systems of the member states, and to determine the directions of their effective interaction (mutual complementation). The innovation performance of the EU and other global players can also be compared to position them competitively, set benchmarks and build up certain parameters to overcome Europe's lagging behind (Jurickova et al., 2019).

To assess and compare NIS in the EU, a large system of statistical monitoring of innovative activities has been established, and an annual EIS is being prepared. Based on the summary of a set of indicators, the EIS calculates the Summary Innovation Index, which allows for the ranking of member states, which are divided into four groups (Innovation leaders, Strong innovators, Moderate innovators, Emerging innovators). This is a relative comparison of the level of innovation development of EU countries (as well as several other European countries and global players), evaluating the performance and variability of their NIS.

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This allows individual countries to identify the problems in the field of innovation that are causing them to lag behind the leaders, enabling the formulation of a more effective innovation policy (Bielińska-Dusza & Hamerska, 2021; Zabala-Iturriagagoitia et al., 2021).

EIS has undoubtedly become a powerful approach to statistical monitoring and a useful tool for developing innovation policy (Borrás & Laatsit, 2019). However, it provides only a superficial assessment of the EU's differentiation in innovation, while its underlying causes, i.e., the architecture of leadership and lagging behind, remain unclear. At the same time, addressing this issue is crucial for bridging the innovation gap among EU countries, the significant magnitude and persistence of which are confirmed by official EU statistics and other international innovation indices. At the same time, it is precisely the focus on bridging the innovation gap that largely determines the content of the EU's innovation policy measures, whose overall objective is to promote convergence among member countries, supporting them while considering different levels of development and individual challenges. The solution to this task, by the way, involves expanding the role of the EU and strengthening its innovation policy (Kowalski et al., 2021), which requires an appropriate analytical framework.

Intra-EU comparisons are particularly valuable for member states that are lagging behind. A significant challenge for them is to approach the average level of innovation indicators within the union, narrowing the gap with leading and strong innovator countries. To achieve this, outsider countries need to enhance and accelerate the development of their NIS, aligning their efforts with the overall direction of the EU (Sandu et al., 2015; Švarc & Dabić, 2021). In the context of resource scarcity, this requires identifying priority areas for improving the NIS (indicators), which should be focused on to effectively improve the position.

A separate area of international comparisons within the EU is to identify the differences between candidate countries and member states, which is particularly relevant in the field of innovation. Considering the economic and transformative significance of innovation, assessing this differentiation helps narrow the gaps between candidate countries and the average level of indicators among EU member states, creating conditions for full integration. Comparing and utilizing the experience of EU countries allows candidate countries not only to develop their innovation potential and align with the overall development course of the EU but also to determine the optimal functional positions of their R&D systems within the entire union (Aytekin et al., 2022).

Earlier it was said about the objective need to compare the EU with other global players, with respect to which competition is vital. Such comparisons make it possible, when defining the architecture of global innovation leadership, to identify the strengths and weaknesses of individual players, determine the importance of certain factors as triggers of progress, and highlight priority areas for change in the current context. This helps the EU to keep pace with the dynamic technological and structural changes that are unfolding in the world today and will determine the balance of power in the economy of the future (Forge et al., 2013; Vilaplana, 2020; Kowalski, 2020). The assessment of the innovation gap between the EU, the USA, and China is used to develop the innovation systems of member countries, increase high-tech exports, and facilitate technology transfer (Marxt & Brunner, 2013).

In recent years, various international analytical rankings have gained wide popularity, becoming an integral part of monitoring and an important basis for making management decisions. In the field of innovations, the most authoritative is the Global Innovation Index (GII), which is prepared by Cornell University, INSEAD, and WIPO (Brás, 2023). The GII assesses various dimensions of countries' innovation systems, their innovation competence and competitiveness. The primary data that form the basis for the GII calculation can be used in a certain set for other comparative studies, expressing cause-and-effect combinations in the field of innovation (Yu et al., 2022; Huarng & Yu, 2022).

Thus, there is a real need for the EU to identify the main FIG of its member states, and overcoming them will accelerate convergence, strengthen global competitiveness, and ensure overall socio-economic progress. This is also an important task from the perspective of both the EU as a whole and individual member states to improve the NIS and increase the effectiveness of innovation policy, especially for countries that are lagging behind.

2. AIM

Based on the comparison of indicators characterizing the NIS, this study aims to identify the key factors of innovation gap between EU countries.

3. METHODS

The EU, as an international organization built on supranational integration, aims to promote the development of science and technology. It implements measures to support research and innovations, improving conditions for their dissemination in the economy and implementation. Specifically, the EU develops infrastructure and funds R&D, including the Framework Programmes for Research and Technological Development, and creates mechanisms for international cooperation in research and innovation at all levels (e.g., the European Research Area, the Innovation Union). The EU focuses its policy on supporting innovation activities at the sectoral level, coordinating and complementing innovation policies at the level of member countries. At the supranational level in the field of innovation, the goal is to achieve convergence, which involves aligning indicators of innovation activities encompassing all elements of R&D systems. This concerns, first and foremost, the improvement of the performance of those countries that are significantly lagging behind , Moderate and Emerging innovators according to the EIS, which is necessary to improve the EU's global position.

The innovation gap between countries is understood as a generalization of their differences in specific indicators that characterize the field of innovation and NIS. Reducing the level of differentiation (gap) in specific indicators leads to convergence. The key factors of innovation gap (FIG) are those indicators that are most related to the differences between all countries in a given set, i.e., they are the main cause of inequality and determine the level of differentiation between countries.

The latest data characterizing the field of innovations across 132 countries worldwide are provided by the aforementioned GII, which encompasses 81 indicators. Considering the different scales and difficulties of comparing the innovation systems of EU countries, a group of 22 primary relative indicators was selected from the general list of indicators included in the GII to illustrate the proposed approach (the indicators calculated for the measurement of the GII were not selected). These indicators primarily characterize the prerequisites for innovation generation and only partially the effectiveness of NIS. A comprehensive assessment of the innovation performance of countries requires a somewhat different range of outcome indicators, which is not carried out in this study.

The list of indicators selected to characterize the EU's innovation field is presented in Table 1.

Table 1. List of key indicators characterizing the innovation systems of EU countries (2022)

Source: Compiled by the authors based on WIPO (2022).

Variable	Indicators
x_1	Expenditure on education, % GDP
x_2	Tertiary enrolment, %gross
x_3	Graduates in science and engineering, %
x_4	Researchers, FTE/mln pop. *
x_5	Gross expenditure on R&D, % GDP
x_6	Venture capital investors, deals/bn PPP$* GDP
x_7	Venture capital recipients, deals/bn PPP$* GDP
x_8	Knowledge-intensive employment, %
x_9	Firms offering formal training, %
x_{10}	GERD* performed by business, % GDP
x_{11}	GERD* financed by business, %
x_{12}	GERD* financed by abroad, % GDP
x_{13}	Joint venture/strategic alliance deals/bn PPP$* GDP
x_{14}	Patent families/bn PPP$* GDP
x_{15}	Intellectual property payments, % total trade
x_{16}	High-tech exports, % total trade
x_{17}	Patents by origin/bn PPP$* GDP
x_{18}	PCT* patents by origin/bn PPP$* GDP
x_{19}	Scientific and technical articles/bn PPP$* GDP
x_{20}	Citable documents H-index
x_{21}	Software spending, % GDP
x_{22}	High-tech manufacturing, %

Note: * FTE/mln pop. – full-time equivalent per million population; bn PPP$ – billion US dollars purchasing power parity; GERD – gross expenditure on research and development; PCT – Patent Cooperation Treaty.

When evaluating the selected set of indicators, it is necessary to note that they are heterogeneous, specific, and collectively allow for the coverage of various

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characteristics of the National Innovation System (NIS) of a specific country. There are no duplicate or mutually exclusive indicators. Possible interrelationships and mutual influences among these indicators are not considered in this study. Equal significance is attributed to the influence of all the selected indicators on the NIS. From a change perspective, all indicators have the same direction towards maximizing, without saturation or minimum requirement. In general, it can be said that the obtained set of indicators meets the conditions of consistency, comprehensiveness, and diversity in describing the properties of the complex object – the National Innovation System (NIS), and therefore, it can be used for assessing the level and determining the FIG among EU countries.

The comparison of indicators characterizing the innovation systems of EU countries and the identification of factors causing their innovation gap is intended to be carried out in two stages based on addressing two basic Data Mining objectives – clustering and classification.

The first stage involves dividing the set of EU countries into clusters, which means creating relatively homogeneous groups.

The indicators presented in Table 1 form a feature space for clustering. Prior to clustering the data array, it is necessary to assess the clustering possibilities, which can be done using 3D visualization, particularly with a specialized tool available on the scientific web portal *ScienceHunter*. After that, it is advisable to determine the optimal number of clusters using two tools – dendrogram and specific indices (Sum of Squared Errors Index, Davies-Bouldin Index, Trace Index, Calinski-Harabasz Index, Dunn Index, PBM Index). The corresponding tools are also available on the mentioned web portal.

Given the nature of the data, the widely recognized *k-means* method (with the *Euclidean distance* metric) is proposed for clustering, which is commonly used in economic research and is effective when data objects form sufficiently compact clusters that are well separated from each other. The calculation methodology for the k-means method is well-known and does not require additional explanations in this article. The tools for performing the relevant calculations are available on the ScienceHunter web portal.

The second stage involves determining, based on classification analysis, the indicators that contribute the most to the differentiation of the obtained clusters (classes). For classification, the data will be mathematically processed using the logic-combinatorial method "decision trees" (Vasylenko & Shevchenko, 1979) as it allows for the identification of relatively small combinations of indicators with maximum, if possible absolute, discriminating power, indicating the most significant differences between clusters and, accordingly, differentiation between countries. Considering the essence of the classification objective, the indicators that strongly differentiate the clusters can be considered as the FIG among countries.

The basis for classification is the sampling set, formed by an array of empirical data constructed from Table 1, with countries divided into clusters (classes) obtained during the clustering process in the first stage. The assessment of the discriminative capability (quality) of the sampling set and each of the indicators included in it, followed by the identification of the FIG, is carried out using the relevant tools available on the *ScienceHunter* web portal. The discriminative capability of the FIG is determined using the following formula:

$$V\left(x_{i1},\dots,x_{ij}\right)=\frac{1}{k}\sum_{\Delta\in\Gamma}\max_{Y}\left(\frac{m_{\Delta Y}}{m_Y}\right), \tag{1}$$

where k is the number of classes (clusters), m_Y is the number of objects belonging to class (cluster) Y, $\Delta=t_{i1},t_{i2},\dots,t_{ij}\left(0\le t_{ij}\le k_{ij}-1\right)$, $j=1,\dots,\Gamma$ means the arbitrary set of parameter values $x_{i1},\dots,x_{ij}\left(1\le\Gamma\le n\right)$, $m_{\Delta Y}$ denotes the number of sampling sets of the m class, for which the relation $x_{ij}=t_{ij}\left(j=1,\dots,\Gamma\right)$ is performed, t_{ij} are the values of parameters x_{ij} in the set of Δ, Γ means variety of all sets of parameter values $x_{i1},\dots,x_{ij}$. When there is a complete separation (difference) between classes, this evaluation takes on the maximum value of 1 (Vasylenko & Shevchenko, 1979). It is essential to note that such an evaluation is directly calculated from the sampling set. If multiple groups of indicators with sufficiently high discriminative capability are identified, which can be considered as part of the FIG, two approaches can be applied: First, selecting one primary group with the maximum discriminative capability, and second, creating a unified list of characteristics from these groups based on repetitions.

4. RESULTS

After processing the empirical data represented as a feature space based on the prepared list of indicators (Table 1) and conducting the corresponding calculations, the set of 27 EU member countries was divided into four clusters (determined as the optimal number of clusters). The results of clustering of EU countries are presented in Table A1. Clustering provides broad possibilities for analysis. First, this is an assessment of the level of innovation development of each country relative to each other and, accordingly, to each of the resulting clusters of countries, considering, for example, the arithmetic mean. In terms of the geography of innovations in the EU, the obtained clusters characterize the concentration of innovation potential in certain groups of countries (different regions of Europe). Additionally, innovation centers can be identified within these clusters (for example, leading countries), and specific indicators can explain the distribution of particular resources or activities that require further investigation. These obtained clusters can be further compared with the assessments of the EIS (European Commission, 2023). Each of the clusters of EU countries has its own distinctive features, namely:

- Cluster I is formed by countries such as Denmark, Finland, and Sweden, in other words, it brings together some of the most successful EU countries that demonstrate the highest level of science, education, and the technology sector, and are leaders in transformations related to sustainable development. This accounts for their corresponding high positions in the field of innovation, localized in Northern Europe. This is confirmed by the EIS where Sweden, Finland, and Denmark belong to the highest category of "innovation leaders" and occupy the top three positions in the ranking.

- Cluster II is predominantly formed by countries from Western Europe, namely Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands, as well as Portugal and Slovenia. These countries have a balanced, sustainable economy, a well-developed technological sector, and an innovative system. Many of them are EU leaders in innovation and modern economic development trends. According to the EIS, Netherlands and Belgium belong to the category of "innovation leaders", while Austria, Ireland, Luxembourg, Germany, and France belong to the second level – "strong innovators" (however, Cyprus from this group did not enter cluster II, presumably due to relatively low indicators of innovation potential). Portugal and Slovenia are classified as "moderate innovators" in the EIS. From a geographical perspective, cluster II obtained in this study clearly indicates that the "core" of the EU's innovation economy is concentrated in Western Europe.

- Cluster III is formed by relatively successful countries from different regions of Europe, namely, the Czech Republic, Estonia, Greece, Hungary, Lithuania, Poland, Slovakia, and Spain. These countries have a reasonably developed economy, predominantly positive dynamics, and significant achievements in the field of innovations. However, they need to allocate more resources to the development of their innovation systems, focusing on the key FIG that will be further selected. According to the EIS, the Czech Republic, Estonia, Lithuania, Greece, and Spain are appropriately classified as "moderate innovators," while Hungary, Poland, and Slovakia belong to the lower-level group of "emerging innovators" (these countries are increasing their innovation potential, which has determined their placement in cluster III in this study).

- Cluster IV is formed by countries with relatively low indicators in the field of innovations, namely, Bulgaria, Croatia, Cyprus, Italy, Latvia, Malta, and Romania. From a geographical perspective, the cluster encompasses countries from Southern, Central, and Eastern Europe, which have recently become members of the EU and are lagging behind in building a modern innovation system. These countries need the highest dynamics, primarily in terms of the indicators that will be selected as FIG, and, accordingly, the greatest

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support from the EU. According to the EIS, Cyprus belongs to the group of "strong innovators" (probably due to relatively high-performance indicators, whereas this research focuses on potential indicators), while Italy and Malta belong to the group of "moderate innovators" (likely for similar reasons as Cyprus). Bulgaria, Croatia, Latvia, and Romania are classified into the expected groups of "emerging innovators".

After dividing the EU member states into clusters (classes) based on indicators characterizing the field of innovations, the second stage involved data classification processing. The quality check of the entire training dataset, meaning its overall resolution capacity, showed a maximum of 100%. Therefore, combinations of indicators should be selected, whose resolution capacity is close to absolute. As a result of using the corresponding computational tools available on the *ScienceHunter* web portal, two combinations of indicators with the highest resolution capacity were obtained, i.e., FIG, with a maximum of four indicators in each combination: *first* – $x_{4,}$ $x_{11,}$ x_{13} i x_{22} (resolution capacity – 92.89%); *second* – $x_{4,}$ $x_{13,}$ x_{21} i x_{22} (resolution capacity – 93.21%). Considering that three indicators are present in both combinations, obviously being the most significant, eliminating duplication, the obtained indicators were combined into a single list, namely:

- x_4 "Researchers" *(FTE/mn pop.)* – this indicator assesses the number of professionals (full-time employment per million population) engaged in research and development activities and actively involved in improving or developing concepts, theories, models, technologies, instruments, software, or work methods, essentially contributing to the creation of new knowledge. This factor is extremely important, as it characterizes the potential for R&D and, accordingly, the ability to generate new knowledge in terms of human resources;
- x_{11} "GERD financed by business" *(%)* – this indicator assesses gross R&D expenditures funded by commercial enterprises as a percentage of total gross R&D expenditures, reflecting the relative scale of the resources and activities involved. The significance of this indicator lies in its characterization of the level of business involvement in the field of innovation, its overall innovative activity, and the generation of new knowledge through R&D for further transformation into innovations;
- x_{13} "Joint venture/strategic alliance deals" *(bn PPP$ GDP)* – this indicator assesses the number of deals related to the creation of joint ventures/strategic alliances per billion dollars of GDP (PPP-adjusted). It characterizes the relative intensity of cooperation among companies in terms of the scale of deals in the form of joint ventures (where companies create a single legal entity through a merger) and strategic alliances (where companies work together without creating a legal entity), for example, in the development and market promotion of innovations. Companies combine their potentials, which increases the likelihood of successful implementation of innovative projects;
- x_{21} "Software spending" (% GDP) – this indicator estimates total software costs, which include the cost of purchased or leased software packages, such as operating systems, database systems, programming tools, utilities, and applications as a percentage of GDP (this does not include expenses related to in-house software development or software development for users under outsourcing arrangements). This indicator is of utmost importance in the context of the emerging digital economy, which necessitates and opens up a significant new field for implementing innovations related to digital transformations;
- x_{22} "High-tech manufacturing" *(%)* – this indicator assesses the level of development of the modern high-tech sector by determining the share of the total volume of high-tech and medium-high-tech products in the total output of the manufacturing industry. For this purpose, the OECD classification "Definition of Technology Intensity" is used based on the International Standard Industrial Classification and data from the United Nations Industrial Development Organization (INDSTAT-2 and INDSTAT-4 databases). The indicator is critically important as high-tech manufacturing is a special source of economic growth, generating the highest GDP multiplication. In the context

Table 2. Minimum (min), average (aver.) and maximum (max) values of the indicators identified as FIG for the obtained clusters of EU countries

Indicator (FIG)	Value of indicators											
	Cluster I			Cluster II			Cluster III			Cluster IV		
	min	aver.	max	min	aver.	max	min	aver.	max	min	aver.	max
x_4	7527,40	7716,67	7930,40	4769,10	5285,47	5911,70	3109,20	3704,59	4358,10	952,90	2058,34	2671,80
x_{11}	54,30	58,77	62,40	50,10	57,89	64,50	34,00	44,41	52,90	24,30	43,59	58,70
x_{13}	0,20	0,23	0,30	0,00	0,08	0,20	0,00	0,01	0,10	0,00	0,09	0,40
x_{21}	0,50	0,50	0,50	0,10	0,46	0,60	0,10	0,34	0,60	0,10	0,26	0,60
x_{22}	44,60	47,23	48,80	16,30	43,93	58,50	17,00	39,90	61,50	15,00	28,31	43,50

of the Fourth Industrial Revolution, high-tech manufacturing is characterized by active implementation of innovations, intensifies science and education, creates preconditions for the growth of the service sector, and thus acts as a "locomotive" for the development of innovations in the economy.

The selected set of indicators explains the reasons for differentiation and innovation gap among the EU countries, which means the barriers to achieving convergence. This contributes to a deeper understanding and enables the appropriate quantitative assessment of the innovation gap, for example, based on the calculation of minimum, average, and maximum values (Table 2).

It is important to focus on understanding the following. First, due to the wide range of vectors for the development of National Innovation Systems (NIS) and limited resources available to countries, there is a need for targeted concentration of resources on key areas, which are precisely determined by FIG. These indicators can be considered as a priority and should be increased primarily through the appropriate concentration of resources and efforts, which will allow a particular country to improve its position in this aggregate more effectively. Second, the identified FIG give a general idea of the structure of "innovativeness" of individual countries, show the architecture of leadership in a given set of countries, allow identifying comparative advantages and determining the possible specialization of certain countries, and assess the compatibility of their NIS at the EU level. However, in the context of studying the innovation gap between EU countries, the selection of a specific set of key indicators is only a working hypothesis. This initial stage should be followed by a fundamental analysis of why these indicators have become differentiating factors, what is the specificity of each of them in specific countries and in the EU as a whole, what underlying patterns they reflect, etc. Only then is it possible to achieve a deep understanding of the situation for strategic decision making.

5. DISCUSSION

The obtained research results can be used in the management practice of improving the NIS and for shaping innovation policy at the level of member states and the EU as a whole, as well as serve as a basis for various analytical and scientific studies. The use of the proposed methodology in dynamics makes it possible to form a mechanism for parametric adjustment of goals and target indicators of innovation policy, identify breakthrough points to eliminate the weaknesses of a particular NIS, thus acting at the forefront of problems and within the framework of the real external situation.

The proposed methodology is especially important for EU countries that follow the leaders and significantly lag behind, as well as for EU institutions seeking to ensure convergence among member countries and achieve sustainability of overall progress. For countries that need to improve their positions, this methodology allows a clear understanding of the problems and limitations of their innovation systems and helps them focus on enhancing priority parameters. As a result, it establishes a connection between innovation policy and the current context, ensuring its adaptability to respond to the changing situation within the EU countries collectively. For the systematic adjustment of innovation policy at the national level, it is necessary to establish corresponding managerial mechanisms and tools to influence NIS based on specific indicators. The application of the meth-

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odology for selecting FIG as priority development directions in the field of innovation can become a part of specialized strategic programs aimed at overcoming the lagging position of a particular country and implementing specific scenarios for accelerating the development of innovation systems in different countries.

At the EU level, the presented methodology for identifying the FIG can be applied not only to ensure the convergence of countries in the field of innovation, but also to determine the advantages of their specialization and, accordingly, the areas of cooperation, complementarity, and integration of the innovation systems of the member states. The obtained results can strengthen the basis for justifying supranational support measures for individual countries to target the improvement of NIS indicators in a particular group of countries to achieve appropriate collective change. In addition, the proposed combination of cluster and classification analysis makes it possible to describe the EU's innovation landscape and spatial problems in terms of innovation development, complementing the current statistical monitoring system. In addition to recommendations on supranational support for innovation, the proposed methodology can be used to compare the EU with other global players, which will allow for a better understanding of the directions of intensifying its innovation development to be at the forefront of technology and strengthen competitiveness.

The resulting clustering of EU countries and the identified FIG are an objective but static study. The dynamic approach involves systematic, for example, annual (in particular, at the beginning and end of the year) repetition of the cluster-classification analysis, which will allow assessing relevant changes and identifying trends in the countries' innovation systems. If the proposed approach is used annually, the selected indicators can be considered as triggers for tactical transformations of the NIS. The presented methodology for finding FIG can also be used for national regions at the scale of countries or the EU as a whole in specific sectors of innovation (digital, environmental, social innovation, etc.). For EU candidate countries, this approach allows for comparisons with EU member states and identifies the main areas for approximation to the EU's innovation performance, which can be seen as the basis for a policy of catch-up development.

CONCLUSION

Considering that innovations are the key driver of sustainable economic growth and development and play a crucial role in increasing competitiveness and societal well-being, the EU aims to strengthen the innovative economy in all member states. This implies ensuring their convergence, bridging the so-called innovation gap to achieve overall progress, which is based on the identification of key FIG.

To address this objective, a set of 22 indicators characterizing the innovation systems of EU countries has been formed, primarily focusing on their potential for generating innovations. Additionally, an array of empirical data was used for calculating the GII. The developed methodology involves the use of data mining techniques and includes two stages. At the first stage, clustering was performed (*k-means* method, *Euclidean distance* metric), as a result of which the EU countries were divided into four clusters (classes), representing a relative characteristic of the level of development of their NIS. At the second stage, a classification analysis (the *decision tree* method) was performed, which resulted in the identification of a group of indicators that most strongly divide the obtained clusters and can be considered as FIG, namely, "Researchers", "GERD financed by business", "Joint venture/strategic alliance deals", "Software spending", and "High-tech manufacturing". These indicators determine innovation leadership in the EU as a whole to the greatest extent and can therefore be seen as priorities for improvement. The obtained results provide broad analytical opportunities for improving the NIS, serve as a basis for shaping the innovation policy of member states and making tactical management decisions at the EU level. Future research in this area is planned to identify the factors of the innovation gap between the EU and other global players, to expand the range of analyzed indicators, especially through the parameters of innovation performance, and to develop a methodology for long-term assessment of NIS development based on the proposed approach.

AUTHOR CONTRIBUTIONS

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APPENDIX A

Table A1. Clusters of EU countries by indicators characterizing their innovation systems (2022 data)

Source: Obtained by the authors through calculations.

Clusters	Countries	Indicators (numbering according to Table 1)																					
		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}
I	Denmark	6,8	81,8	23	7692,2	3,0	0,3	0,1	48,7	40,6	1,8	59,6	0,2	0,2	4,7	0,8	5,8	10,6	4,2	65,6	51,3	0,5	48,3
	Finland	6,3	93	27,9	7527,4	2,9	0,2	0,1	47,2	50,2	2,0	54,3	0,4	0,2	6,0	1,0	4,6	12,7	6,5	55,5	42,6	0,5	44,6
	Sweden	7,6	77,3	27,0	7930,4	3,5	0,3	0,1	56,7	61,9	2,6	62,4	0,3	0,3	6,8	2,9	7,8	10,9	7,3	57,7	59,5	0,5	48,8
Average for cluster I		6,9	84,0	26,0	7716,7	3,1	0,3	0,1	50,9	50,9	2,1	58,8	0,3	0,2	5,8	1,6	6,1	11,4	6,0	59,6	51,1	0,5	47,2
II	Austria	5,2	86,5	30,6	5751,6	3,2	0,2	0,1	43,5	42,6	2,2	50,1	0,5	0	3,5	0,8	7,3	9	3	40,6	44,2	0,5	45,8
	Belgium	6,4	80,1	17,6	5750,1	3,5	0,2	0,1	49,6	57,8	2,5	64,3	0,5	0,1	2,5	0,8	8,3	5,5	2,1	42,2	53,8	0,6	44,2
	France	5,4	68,4	25,9	4926,2	2,4	0,2	0,1	47,4	67,9	1,6	56,7	0,2	0,1	3,0	1,5	11,2	7,7	2,2	25,5	78,6	0,5	52,1
	Germany	5,0	73,5	35,8	5393,1	3,1	0,2	0,1	45,7	68,4	2,1	64,5	0,2	0,1	5,2	1,0	11,7	15	3,6	27,7	87,4	0,5	56,8
	Ireland	3,4	75,2	26,4	4769,1	1,2	0,2	0,1	47,3	59,8	0,9	62,8	0,2	0,1	2,1	20,2	9,0	2,2	1,5	20,5	34,9	0,6	58,5
	Luxembourg	3,6	18,4	19,2	4920,3	1,1	1,4	0,1	63,6	66,1	0,6	51,3	0	0,2	4,3	4,0	0,5	7,1	4,2	20,7	11,6	0,2	16,3
	Portugal	4,7	67,9	27,8	5214,8	1,6	0,1	0	42,7	29,0	0,9	52,2	0,1	0	0,6	0,9	3,9	2,7	0,7	53,4	33,1	0,6	30,5
	Slovenia	4,9	77,9	28,6	4932,3	2,1	0	0	47,5	44,0	1,6	61,5	0,3	0	1,1	0,6	6,5	4,4	1,1	59,7	18,8	0,1	41,4
	Netherlands	5,4	87,1	18,8	5911,7	2,3	0,3	0,1	52,4	54,1	1,5	57,6	0,2	0,1	4,4	7,9	13,0	8,5	3,8	44,2	69,8	0,5	49,8
Average for cluster II		4,9	70,6	25,6	5285,5	2,3	0,3	0,1	48,9	54,4	1,5	57,9	0,2	0,1	3,0	4,2	7,9	6,9	2,5	37,2	48,0	0,5	43,9
III	Czech Republic	4,3	65,6	25,9	4127,9	2,0	0,1	0	40,6	43,6	1,2	35,6	0,6	0	0,5	0,8	23,8	2,0	0,6	37,6	30,4	0,3	60,1
	Estonia	5,3	74,2	27,5	3846,1	1,8	0,7	0,4	48,2	40,7	1,0	49,1	0,2	0,1	0,6	0,3	2,9	1,6	1,0	46,9	17,9	0,2	30,6
	Greece	3,6	148,5	27,3	4010,4	1,5	0,1	0	31,7	21,6	0,7	40,2	0,2	0	0,4	0,4	3,1	1,7	0,3	42,8	33,8	0,6	18,1
	Hungary	4,6	52,4	15,5	4358,1	1,6	0	0	38,9	29,3	1,2	52,9	0,2	0	0,4	1,1	14,9	1,7	0,3	26,6	29,6	0,3	59,8
	Lithuania	3,9	72,0	26,0	3728,5	1,2	0,2	0,1	45,3	27,5	0,6	34	0,3	0	0,3	0,2	6,8	1,3	0,4	29,4	13,0	0,1	17,0
	Poland	4,6	69,2	19,4	3292,2	1,4	0	0	41,4	21,7	0,9	50,7	0,1	0	0,3	1,2	6,4	3,5	0,3	28,0	36,8	0,3	34,1
	Slovakia	4,0	46,4	22,2	3164,3	0,9	0	0	37,6	43,3	0,5	43,7	0,1	0	0,1	0,7	8,8	1,5	0,2	26,9	17,0	0,3	61,5
	Spain	4,2	92,9	20,8	3109,2	1,4	0,1	0	35,5	55,2	0,8	49,1	0,1	0	0,6	1,4	4,4	1,8	0,8	38,8	61,7	0,6	38,0
Average for cluster III		4,3	77,7	23,1	3704,6	1,5	0,2	0,1	39,9	35,4	0,9	44,4	0,2	0,0	0,4	0,8	8,9	1,9	0,5	34,6	30,0	0,3	39,9
IV	Bulgaria	4,1	73,4	19,5	2402,3	0,9	0	0	33,4	20,0	0,6	37,6	0,3	0	0,2	0,6	5,6	1,8	0,2	16,5	15,4	0,2	23,6
	Croatia	3,9	67,7	28,5	2220,0	1,2	0	0	36,4	26,2	0,6	37,6	0,3	0	0,1	1,1	4,2	1,2	0,3	40,5	17,3	0,1	24,5
	Cyprus	5,7	88,5	13,1	1706,1	0,8	1,3	0,1	38,0	39,7	0,4	36,4	0,2	0,2	0,9	1,3	0,9	1,9	1,4	58,2	12,3	0,2	15,9
	Italy	4,3	66,1	22,7	2671,8	1,5	0	0	35,8	12,6	0,9	55,9	0,1	0	1,7	0,8	6,8	6,0	1,3	33,9	68,7	0,6	39,5
	Latvia	4,2	94,9	19,3	2158,8	0,7	0,1	0,1	44,5	52,9	0,2	24,3	0,2	0	0,3	0,2	9,2	2,0	0,6	21,6	9,2	0,1	15,0
	Malta	4,7	64,9	17,2	2296,5	0,7	0,6	0,1	46,2	49,9	0,4	58,7	0	0,4	1,6	6,1	4,3	3,1	1,9	24,8	6,9	0,3	36,2
	Romania	3,3	51,4	29,1	952,9	0,5	0	0	27,2	20,5	0,3	54,6	0,1	0	0,1	0,9	7,1	1,5	0	15,3	18,9	0,3	43,5
Average for cluster IV		4,3	72,4	21,3	2058,3	0,9	0,3	0,0	37,4	31,7	0,5	43,6	0,2	0,1	0,7	1,6	5,4	2,5	0,8	30,1	21,2	0,2	28,3