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Evaluating the National Innovation Systems of EU Countries through Innovation Indicators

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Abstract

The innovative capacity of a nation is crucial for effectively achieving the sustainable development goals. The European Union exemplifies leadership in this domain through the implementation of comprehensive technological, financial, and regulatory strategies at the supranational, national, and regional governance levels. These practices provide invaluable insights for developing countries seeking to enhance their innovation processes. Moreover, the EU represents a unique case for analysing national innovation systems (NIS) due to its diverse policies and the differing levels of integration among its member states. The research was based on the analysis of complex innovation indicators and indices, which have gained wide recognition and are used for benchmarking. To determine the key factors that shape a country's innovation potential, we undertake graph visualisation and techniques of structural analysis of the European Innovation Scoreboard, and propose an alternative methodology to assess the innovation potential by constructing the European Index of Innovation Potential. This analysis enables the evaluation and comparison of innovation capabilities, simultaneously validating the innovative achievements of leading nations and providing a strategic framework for identifying potential directions to enhance innovation opportunities. Building on these findings, and incorporating alternative analytical approaches, a new methodological framework has been developed for assessing the innovation capabilities of EU countries. This framework aims to delineate the strengths and weaknesses of their national innovation ecosystems. By utilising cluster and taxonomic analysis, it maps EU countries in terms of their innovation potential and achievements. Strategic recommendations have been formulated based on these results to craft national strategies and roadmaps for fostering innovative ecosystems and leveraging innovation as a means to achieve more sustainable development.

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1. Introduction

The realisation of the sustainable development goal relies heavily on innovations, encouraging competitive advantages, and enhancing economic transformations both at the corporate and national levels, systematising their growth in governmental policies. Countries present different particularities of the innovation policy, as a consequence of the differences in innovative potentials and prerequisites, requesting a variety of approaches to encourage innovation. In addition, countries with an alike condition level can display distinct efficiency of innovation policies, indicating diversity with respect to national innovation systems and their development paths.

Innovation indices are increasingly used to assess the performance of national innovation systems. In the course of the past two decades, there is an increasing trend in employing these indices to compile rankings, conduct comparative policy analyses, and policy-making for selected activities. Specifically, the European Innovation Scoreboard (EIS), developed by the European Commission, serves both to assess and compare the innovation potential of the European Union countries and as a tool for continuous monitoring and periodic reporting on research, development, and innovation achievements.

The complex nature of innovation processes and their results necessitates the utilisation of composite indices which mix different sets of individual indicators. However, even if the indices supply useful ratings and values, they cannot define what determines an innovation in being successful or the manner in which innovations are conveyed in the economic potential of a country. They also prove inappropriateness in setting out policies and actions to generate, disseminate, and pt innovations in practice. A more comprehensive comparative analysis is needed to analyse the factors influencing index changes in individual EU countries, to assess specific national innovation systems, and to examine the relationship between innovation potential and innovation results.

2. Problem Statement

Innovations play a vital role in modern sustainable socioeconomic development both in times of war and peace. As our cooperation with GFCC on driving innovation in times of crisis has revealed, the way to get out of a crisis and grow competitiveness goes through innovations, and the deeper the crisis, the more incremental innovations should be (GFCC, 2023). The efficient use of any resource, including natural ones, with simultaneous economic growth is evident only when innovations are put into practice, as updated by Namazi and Mohammadi (2018) and Wilson and Vellinga (2022). For most countries, innovations that trigger a circular economy and sustainable entrepreneurship lead to improved quality of life and social welfare

(Manea et al., 2021). While green transformations take time, the ongoing digital transformations could significantly enhance competitiveness through skills development (Ligonenko et al., 2022).

Many researchers are trying to identify the best set of indicators, their normalisation, and weighting schemes in order to rank countries by innovation and entrepreneurial performance. Grupp and Schubert (2010) showed that different traditional methods, such as equal weighting, Benefit of the Doubt weighting, or principal component analysis weighting, could yield results that are radically different. Sotirelis et al. (2020) offered a Multiple Criteria Decision Aid approach to improve the ranking introduced on the EIS. As Corrente et al. (2023) have argued, a set of composite innovation indicators is the best choice for now, and EIS is one of them. So, the multiple-criteria decision-making approach would be the one to be used in order to rank or benchmark countries' innovation performance. A synthetic index obtained from the arithmetic mean of the 21 EIS indicators to build a ranking was offered by Salazar-Elena and Zabala-Iturriagagoitia (2022) to overcome the problem of the large number of indicators required to measure the complex phenomenon of regional innovation systems. Moreover, Fabri et al. (2023) offer to use a fuzzy-set qualitative approach to highlight the interlinkages among EIS innovation measures.

Various international institutions have started to collect innovation system indicators and build rankings and indices to make their policies sounder and more reasonable. Examples include Science, Technology, and Innovation Scoreboard by OECD, Global Innovation Index by WIPO, European Innovation Scoreboard and European Research Area Scoreboard by EC, as well as Bloomberg Innovation Index etc., which differ by sets and coverage of innovation system indicators. These tools vary in their sets and coverage of innovation system indicators, highlighting an ongoing need for refinement. Therefore, a better set of innovation determinants and outputs has been offered by Hamidi and Berrado (2018). EC has initiated a Regional Innovation Scoreboard to take a deeper look at innovations on a regional level (EC, 2023). The development of international innovation system monitoring facilities creates the foundation for research and policy development. For example, Ivanová and Čepel (2018) have used the Global Competitiveness Index as a basic data source to find that Visegrad countries could be found in the same cluster by economic development but in different clusters by innovation performance. This allowed Fabri et al. (2023) to conclude that the development of an innovation system is based primarily on the nonlinear relationship between indicators.

In the last two decades, various researchers allocated efforts to develop the innovation structure by the provision of a universal methodological reasoning that most stakeholders can utilise. The launch of the EIS in 2000 was the milestone of the strategic advancement, many indicators being capable for usage in their existent form or through an intricate methodology. In the first place, the evaluation of EIS indicators was made by researchers through basic analytical techniques, the elements of emphasis being trends, structures, and correlations. Katz (2006) provided scale-adjusted indicators and models. In the case of complex systems, for instance an innovation system, Data Envelopment Analysis (DEA) can be used to reveal the interaction between multiple inputs and outputs in the absence of a universally accepted methodology. In addition, Androulidaki et al. (2022) observed various divergences within the EU and put them into a methodological, political, and economic context. More recently, the input-output approach has gained popularity among innovation system researchers. Zofio et al. (2023) used it in combination with a functional approach to identify innovation system bottlenecks.

Simultaneously, other researchers have sought to assess the performance of the innovation system with the use of EIS indicators. Although the first attempts, such as the widely cited paper by Zabala-Iturriagagoitia et al. (2007), showed promise as they used data envelopment analysis methodology to combine previous quantitative and qualitative analyses to improve systemic policymaking, later it was questioned by practice and policymakers. The DEA has become a popular tool for assessing innovation efficiency in the EU (Meda et al., 2023). Complementary to the DEA, cluster analysis had been successfully exploited to identify innovation efficiency improvability by Wilson and Vellinga (2022). The well-known factor analysis is helpful to investigate the innovation system value added and its impact on technological transformations (Antoniuk & Cherkas, 2018).

Quality improvement in an innovation system emerges out of many other drawbacks which are found by researchers when they have access to credible data. Zygmunt (2022) has found that in some EU countries patents, R&D personnel, and innovation performance of SMEs have much lower levels of correlation due to underdeveloped knowledge networks. Coutinho and Au-Yong-Oliveira (2023) revealed that for Portugal many European innovation indicators have a negative impact on innovations, while creativity makes an outstanding impact. Both developed and developing countries rely on government support to make the innovation system work for a sustainable future (Novillo-Villegas et al., 2022).

Meanwhile, the understanding of the innovation system has moved towards an innovation ecosystem, so the system has become even more complex. Consequently, research in this field should employ a clear vision of its aims and targets in order to make the best use of EIS and other data sources. The next level of complexity we see when combining economic processes, actors, and trends with past indicators and their forecasts. This is highlighted by Ogrean and Herciu (2022), who observe that Romania has big expectations to use innovations for smart specialisation to boost the economic development of the nation's regions and their competitiveness. Our efforts to systematise relationships within the European innovation ecosystem gives us the reason to insist on the necessity to include the institutional dimension into the analysis of innovation systems at any scale or level (Antonyuk & Zaremskyi, 2018).

Clustering has become one of the most widely used methods for grouping countries, mapping, and identifying their innovation system models. This approach is well documented in studies by Orlovska and Morozova (2021), Dworak et al. (2021), and Hajighasemi et al. (2022). However, there has been no research where clustering has been combined with multiple inputs and outputs in order to increase precision and address specific issues more effectively.

3. Research Questions / Aims of the Research

The purpose of the research is to conduct an in-depth analysis of the effectiveness of NIS in EU countries to identify strategic priorities that support their competitive leadership. The specific tasks of this study include:

- analysing and systematising EIS indicators to distinguish between preconditions and resources necessary for innovative development, and the achieved outcomes and impacts for evaluating the effectiveness of NIS;
- positioning countries featured in the EIS within a matrix defined by input factors and outcomes, developing an index to measure the effectiveness of the innovation system's potential implementation, and ranking the countries based on this index;
- clustering countries based on their innovation input factors and identifying the most influential differentiators.

4. Research Methods

The research data are based on the European Innovation Scoreboard 2023 database (EC, 2023). The index covers four primary types of activities, each subdivided into three dimensions, encompassing a total of 32 independent indicators. The internal structure of the EIS was analysed using Network Graph Analysis, a robust tool for extracting insights from complex, interconnected data. Aimed at revealing hidden patterns, connections, and relationships, it has found wide application in many different domains (Barabasi, 2016). In this study, the nodes within the graph represent indicators, while the connections show aggregation links that are important in building complex indices within the EIS framework. To identify clusters of indicators and organise their grouping, graph-colouring techniques were used to visually distinguish various segments of the graph. This approach effectively highlights different categories of nodes, producing a clear and informative visualisation that facilitates the interpretation of the underlying data. The visualisation was created using the Gephi software.

Based on the experience gained from the Global Innovation Index (WIPO, 2023), a unique structuring of EIS indicators was developed to assess the competitive potential of national innovation systems. The indicators were organised into two main components of the innovation process: conditions and resources (InnovINPUT) and outcomes and impacts (InnovOUTPUT). The groups of indicators are detailed in Table 1.

Given that the EIS indicators are multidimensional, a taxonomic analysis methodology has been employed to generate comprehensive evaluations. This method includes standardising primary indicators, constructing a reference vector by classifying indicators into stimulators and destimulators relative to the assessment object, calculating deviations from this benchmark, and computing the taxonomic indicator. The detailed step-by-step algorithms for this process are presented in many studies, including those by Pociecha (2008), Sej-Kolasa (2009), and Boichenko et al. (2022).

Table 1. Grouping EIS indicators for evaluating the national innovation systems

Components of InnovINPUT	Indicators of InnovINPUT	Components of InnovOUTPUT	Indicators of InnovOUTPUT
INPUT 1 Human resources	1.1.1 New doctorate graduates	**OUTPUT1** Innovators	3.1.1 SMEs introducing product innovations
	1.1.2 Population with tertiary education		3.1.2 SMEs introducing business process innovations
	1.1.3 Population involved in lifelong learning	**OUTPUT2** Intellectual assets	3.3.1 PCT patent applications
INPUT 2 Digitalisation	1.3.1 Broadband penetration		3.3.2 Trademark applications
	1.3.2 Individuals with above basic overall digital skills		3.3.3 Design applications
	2.3.1 Enterprises providing ICT training	**OUTPUT3** Attractive research systems	1.2.1 International scientific co-publications
	2.3.2 Employed ICT specialists		1.2.2 Scientific publications among the top 10% most cited
INPUT 3 Linkages	3.2.1 Innovative SMEs collaborating with others		1.2.3 Foreign doctorate students as % of all doctorate students
	3.2.2 Public-private co-publications	**OUTPUT4** Employment impacts	4.1.1 Employment in knowledge-intensive activities
	3.2.3 Job-to-job mobility of HRST		4.1.2 Employment in innovative enterprises
INPUT 4 Finance and support	2.1.1 R&D expenditure in the public sector	**OUTPUT5** Sales impacts	4.2.1 Exports of medium and high technology products
	2.1.2 Venture capital expenditures		4.2.2.Knowledge-intensive services exports
	2.1.3 Direct and indirect government support of business R&D		4.2.3 Sales of new-to-market and new-to-firm innovations
	2.2.1 R&D expenditure in the business sector	**OUTPUT6** Environmental sustainability	4.3.1 Resource productivity
	2.2.2 Non-R&D innovation expenditures		4.3.2 Air emissions by fine particulates
	2.2.3 Innovation expenditures per person employed		4.3.3 Environment-related technologies

Source: grouped by the authors based on the EIS (EC, 2023).

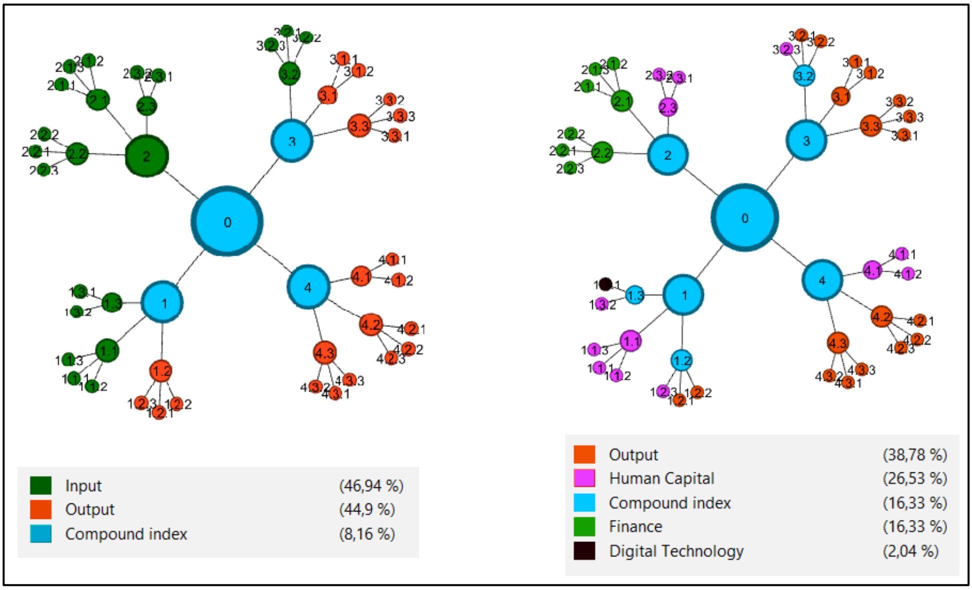
Following the structuring process, the development potential of the EU National Innovation Systems was assessed using matrix positioning. This evaluation was further complemented by a cluster analysis of EU countries' innovation activities based on InnovINPUT category indicators, performed using STATISTICA 10.0 software. Ward's method was chosen for hierarchical clustering analysis, in which the objective function calculates the sum of squared distances between each object and the mean of the cluster. The result was clusters of approximately equal sizes, with the differentiation criteria being indicators standardised by scaling them to a uniform factorial measurement scale. This was supplemented by the use of the k-means method, which maximises the initial distances between clusters.

5. Findings

5.1 Network Graph Analysis

Our detailed analysis has revealed significant heterogeneity in the structure of the EIS (Figure 1).

Figure 1. Graph representation of the structure of the EIS



Source: developed by the authors.

The InnovINPUT and InnovOUTPUT components each account for approximately half of its composition. However, three out of the four sub-indices cannot be distinctly classified as inputs or outputs. Consequently, employing the index for strategic decision-making should be based on a more thorough analysis of its component values. Indicators related to the "Human Capital" category constitute 26.53% of the overall index structure, underscoring the importance of this factor. In contrast, digitalisation processes are only represented by the "Broadband penetration” indicator, which does not adequately reflect the impact of information and communication technologies on the innovation processes typical of the digital economy, as shown by Antoniuk et al. (2021). This highlights the necessity to re-evaluate the composition of the indicators to increase their relevance.

5.2 Benchmark of the National Innovation Systems

To effectively benchmark the potential of NIS across EU countries, a nine-quadrant matrix has been developed. This matrix facilitates the interpretation of the consistency between InnovINPUT and InnovOUTPUT taxonomic indicators (Figure 2). The boundaries of each quadrant are established by dividing the potential range of the taxonomic indicator (from 0 to 1) into three equal segments. The identifiers assigned to countries within specific quadrants – linguistic assessments of their current positions – reflect expert judgments on the competitive potential of the NIS, its current development level, and its prospects for further growth.

Figure 2. Innovation potential matrix InnovINPUT – InnovOUTPUT

OUTPUT	+++	Unforeseen	Follower	Leader
	++	Unexpected	Average	Chaser
	+	Emerging	Potential	Unrealised
		+	++	+++
		INPUT		

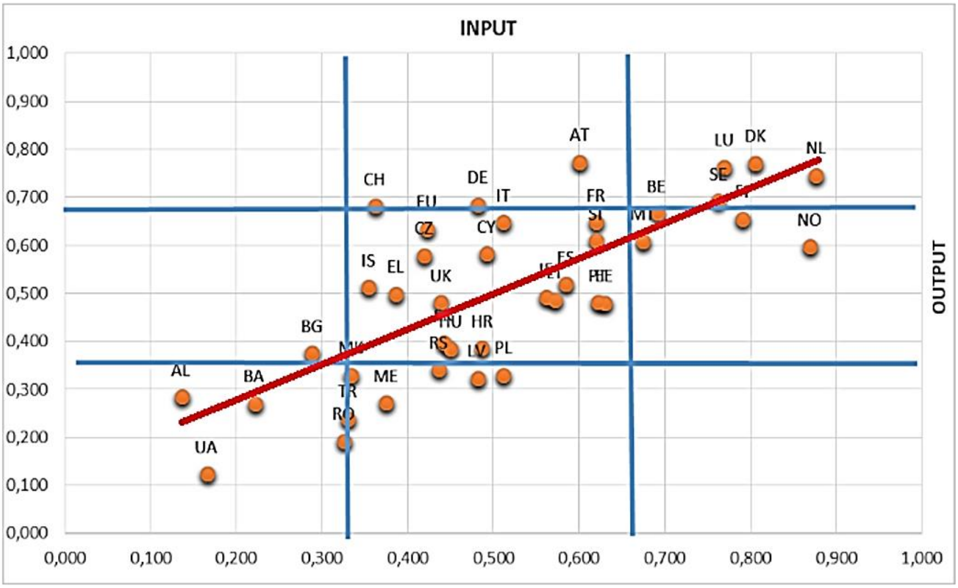
Source: developed by the authors.

The positioning of countries within this nine-quadrant matrix (Figure 3) provides detailed insights into their current states and future development prospects. It also forms a foundational basis for developing strategic recommendations for groups of countries within each quadrant. Countries located in the quadrants above the matrix diagonal should prioritise the development of INPUT components, which are essential for building competitive NIS. In contrast, those in the quadrants below the diagonal should focus on improving OUTPUT components, which reflect the realisation of NIS potential. This strategic prioritisation will facilitate quicker advancement to more favourable quadrants of the matrix, thereby accelerating the country's progress toward becoming a leader in NIS development.

For a quantitative assessment of the effectiveness of forming and realising innovation potential, we suggest calculating the European Index of Innovation Potential (EIIP) using the taxonomic indicators InnovINPUT and InnovOUTPUT (see Equation 1):

$$EIIP = InnovINPUT * InnovOUTPUT \qquad (1)$$

Figure 3. Positioning countries within the matrix InnovINPUT - InnovOUTPUT



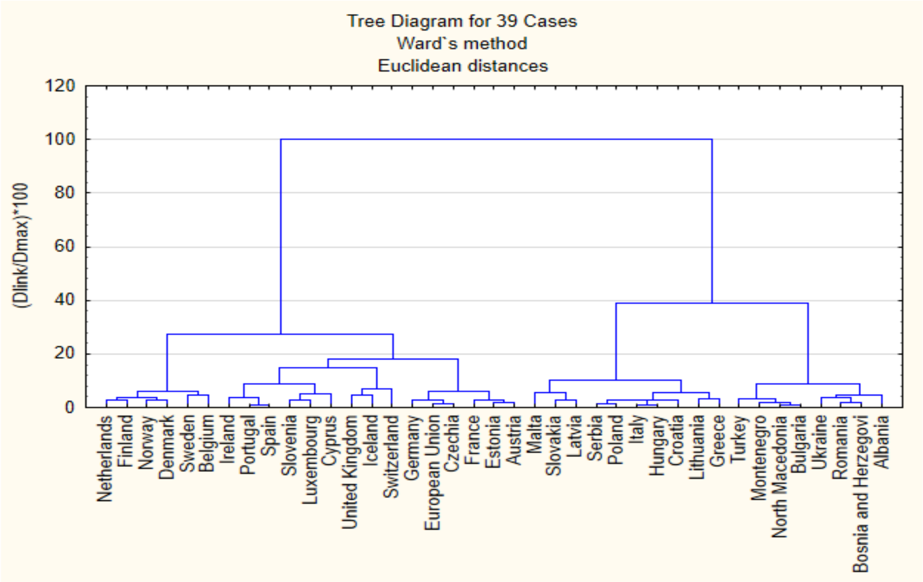
Source: developed by the authors.

The results of the calculations are given in Appendix 1. Six countries top the ranking, each with an EIIP index value above 0.5. Among these, the Netherlands, Denmark, Luxembourg, and Sweden are Innovation Leaders. Norway and Finland are Chasers, possessing high but not fully realised innovation potential, as their innovative achievements are rated as average. Emerging innovators are Albania, Bosnia and Herzegovina, Romania, and Ukraine. These countries currently have limited innovation potential and achieve lower outcomes and impacts from innovative activities compared to other European nations. The experience of Bulgaria is noteworthy, as it uniquely entered the “Unexpected” quadrant, similar to the countries in the “Follower” quadrant. Notably, the level of innovation results and impacts in these countries surpasses their initial innovation potential.

5.3 Analysis of the Input Factors Influencing Innovation Potential

To refine the input factors that significantly influence the effectiveness of NIS, a cluster analysis was conducted using the InnovINPUT indicators. Employing Ward's method and k-means, six clusters were identified (Figure 4).

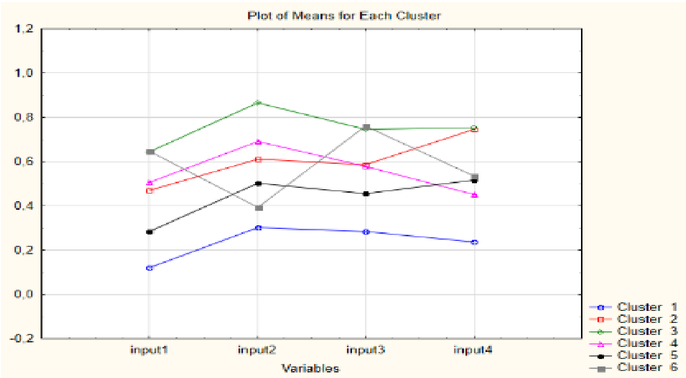
Figure 4. Distribution of countries by clusters based on input factors



Source: developed by the authors.

The calculated Euclidean distances between the clusters are significant, indicating a clear distinction between them. Clusters 3 (Belgium, Denmark, Finland, Netherlands, Norway, Sweden) and Cluster 6 (Iceland, Switzerland, United Kingdom) exhibit the highest indicators. However, in terms of the average value of the Input 2 “Digitalisation” indicator, which contributes the most significantly to the classification, Cluster 6 ranks among the lowest (Figure 5). Ukraine, along with Albania, Bulgaria, Bosnia and Herzegovina, North Macedonia, Romania, Turkey, and Montenegro, forms a cluster of countries with currently unrealised innovation potential (Cluster 1).

Figure 5. Average values of input factors by the clusters, calculated using the k-means method



Source: developed by the authors.

6. Conclusions

The EIS provides a comprehensive comparative analysis of the NIS of EU countries and their regional neighbours by monitoring and evaluating a wide range of factors, offering valuable insights for policymakers and stakeholders. It highlights significant differences in Europe's NIS with respect to their long-term competitive potential. This study analyses the effectiveness of EU countries' NIS to justify the need for targeted strategies aimed at enhancing innovation capacity, contribute to economic growth, and support the achievement of the SDGs.

The main idea of our paper is that understanding the volume and quality of input factors – including human resources, digitalisation, linkages, finance, and support – is important for developing place-based innovation policies. We propose an alternative methodology to assess innovation potential by constructing the EIIP, which uses the taxonomic indicators InnovINPUT and InnovOUTPUT. Positioning countries within the InnovINPUT-InnovOUTPUT matrix, as well as ranking them according to the EIIP, forms a sound basis for developing NIS development roadmaps. These roadmaps aim to refine or enhance policies in areas where countries show insufficient performance according to specific taxonomic indicators. This includes input policies such as developing human capital, advancing digitisation, enhancing collaboration, and providing financial and institutional support. Output policies should focus on encouraging the growth of entrepreneurial innovators, facilitating the creation of intellectual and scientific assets, promoting employment in innovative sectors, supporting the production and sale of innovative products, and advancing environmental sustainability.

The results of the cluster analysis have confirmed that the leading countries in NIS development are those with significant success in both quantitative and qualitative terms to ensure INPUT factors. Specifically, Belgium, Denmark, Finland, Netherlands, Norway, and Sweden have been identified as key examples. Given that the analysis highlighted Digitalisation as the primary driver in clustering countries based on development preconditions and resources, we prioritise the creation of a Digitalisation Policy and Roadmap for countries with unrealised innovation potential. Implementing such a policy will significantly stimulate the advancement of both the INPUT and the OUTPUT components.

The study revealed limitations in the NIS dimensions included in the EIS, which prompts us to suggest adding new aspects to the analysis of innovation systems at any level concentrating more on institutional environment and digitalisation processes. The expansion of digital infrastructure, along with the implementation of Industry 4.0 technologies, ICT diffusion processes, and smartisation, not only accelerates innovation, but also contributes to the achievement of the SDGs. We argue that a comprehensive digital transformation of the NIS is crucial to enhance the innovation capacity of European countries. In the future, this approach will enable a more detailed assessment of the competitive potential of NIS and its implementation, aiming to ensure the innovation leadership of the EU countries and Ukraine by 2030.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT4 solely to improve the readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Appendix

Country rankings based on NIS competitive potential

Country	INPUT	OUTPUT	EIIP	Matrix Identifier	Cluster
Netherlands	0,876	0,746	0,654	Leader	3
Denmark	0,806	0,772	0,622	Leader	3
Luxembourg	0,770	0,764	0,588	Leader	4
Sweden	0,762	0,693	0,528	Leader	3
Norway	0,870	0,597	0,519	Chaser	3
Finland	0,790	0,656	0,518	Chaser	3
Austria	0,600	0,774	0,464	Follower	2
Belgium	0,691	0,668	0,461	Chaser	3
Malta	0,675	0,609	0,411	Chaser	4
France	0,620	0,648	0,402	Average	2
Slovenia	0,619	0,610	0,378	Average	4

Country	INPUT	OUTPUT	EIIP	Matrix Identifier	Cluster
Italy	0,512	0,648	0,332	Average	5
Germany	0,482	0,685	0,330	Follower	2
Spain	0,584	0,519	0,303	Average	4
Estonia	0,630	0,480	0,302	Average	2
Portugal	0,622	0,482	0,300	Average	4
Cyprus	0,492	0,582	0,286	Average	4
Lithuania	0,572	0,486	0,278	Average	5
Ireland	0,562	0,493	0,277	Average	4
Switzerland	0,362	0,683	0,247	Follower	6
Czechia	0,419	0,579	0,243	Average	2
United Kingdom	0,439	0,481	0,211	Average	6
Greece	0,386	0,499	0,193	Average	5
Croatia	0,487	0,386	0,188	Average	5
Iceland	0,354	0,513	0,182	Average	6
Slovakia	0,442	0,398	0,176	Average	5
Hungary	0,450	0,385	0,173	Average	5
Poland	0,512	0,330	0,169	Potential	5
Latvia	0,481	0,324	0,156	Potential	5
Serbia	0,436	0,342	0,149	Average	5
North Macedonia	0,334	0,330	0,110	Potential	1
Bulgaria	0,288	0,375	0,108	Unexpected	1
Montenegro	0,375	0,271	0,102	Potential	1
Turkey	0,330	0,240	0,079	Potential	1
Romania	0,325	0,193	0,063	Emerging	1
Bosnia and Herzegovina	0,221	0,271	0,060	Emerging	1
Albania	0,136	0,285	0,039	Emerging	1
Ukraine	0,166	0,124	0,020	Emerging	1

Source: developed by the authors.