https://doi.org/10.38104/vadyba.2025.1.07

Vadyba
Journal of Management
2025, № 1 (41)
ISSN 1648-7974

A COMPARATIVE ANALYSIS OF THE INNOVATION PERFORMANCE OF THE VISEGRAD COUNTRIES

Sergey Vinogradov[1], Balázs Nagy[2]
[1]Budapest Metropolitan University & MOME Foundation, Future Potentials Observatory, [2]MOME Foundation, Future Potentials Observatory

Abstract
This study conducts a comparative evaluation of the innovation performance of the Visegrad Group countries − Czechia, Hungary, Poland, and Slovakia − through a dual-framework analysis based on the European Innovation Scoreboard (EIS) 2024 and the Global Innovation Index (GII) 2024. To assess how efficiently each country transforms innovation-related inputs into outputs, the research employs Data Envelopment Analysis (DEA), a non-parametric method widely used for performance benchmarking. Both input-oriented and output-oriented DEA models are applied under the assumption of variable returns to scale, enabling the assessment of relative innovation efficiency and the identification of countries that operate close to or far from the efficiency frontier. Despite their shared historical and socio-economic characteristics, the findings reveal notable disparities in innovation efficiency among the Visegrad countries. Slovakia emerges as the most efficient, demonstrating strong performance in both input- and output-oriented models, which indicates a well-balanced and effectively managed innovation system. Poland follows with high input-oriented efficiency scores, suggesting prudent resource utilization, although there remains potential to enhance innovation output. Czechia, while achieving strong results in absolute innovation indicators, ranks lower in DEA-based efficiency due to relatively high output-oriented inefficiency, indicating underperformance in converting inputs into impactful results. Hungary consistently ranks at the bottom across both models, highlighting significant challenges in translating innovation investments into measurable outcomes and signaling the need for improvements in system effectiveness. These findings are placed in the context of previous studies on innovation performance in Central and Eastern Europe. Earlier research has often focused on input intensity or output volume, but few have combined efficiency analysis across multiple global indices. The findings of the study support prior conclusions that innovation systems in the Visegrad countries are unevenly developed, and that structural inefficiencies − such as limited innovation collaboration, low levels of venture capital investment, or weak commercialization processes − are central to the performance gaps. The results also provide actionable insights for policy design. Slovakia and Poland can serve as benchmarks within the region for balanced and efficient innovation systems. Czechia may benefit from targeted interventions to improve output transformation mechanisms, while Hungary requires a more comprehensive overhaul of its innovation ecosystem, with emphasis on fostering public-private cooperation and knowledge diffusion. By combining the strengths of two leading innovation measurement frameworks and the analytical power of DEA, this study contributes to a more nuanced understanding of innovation performance.
KEY WORDS: Global Innovation Index (GII), European Innovation Scoreboard (EIS), Data Envelopment Analysis (DEA).
JEL classification: O31, O32, O57, C67, R58

Introduction

International comparative analyses are essential for evaluating national innovation systems, as they help identify differences and performance gaps between countries. These analyses can support policy development and guide the identification of potential improvements. In global, multi-continent comparative analyses, the problem of different economic development and cultural factors may arise, which can limit the direct comparability of countries' performance. Therefore, analyses comparing areas with similar levels of economic development are better suited to supporting the development of countries' innovation ecosystems. In this study, we examine such a homogeneous group of countries, the Visegrad Group, whose member countries – Czechia, Hungary, Poland, Slovakia – share a history spanning several centuries and face similar challenges nowadays.

Innovation performance within the Visegrad Group countries has been the focus of numerous studies that explore various aspects of national and regional innovation systems. These analyses often underline the structural and contextual factors that shape innovation capacity and efficiency in Central and Eastern Europe.

Several scholars have emphasized the role of social and relational capital in fostering innovation. For instance, Będzik and Gołąb (2020, 2021) highlight the critical importance of trust, cooperation, and social capital as enablers of innovation activities. Their findings suggest that beyond quantitative inputs, the quality of institutional and collaborative environments plays a key role in shaping innovation outcomes.

Adding to this perspective, Kowalski, Kuberska, and Mackiewicz (2023) stress the role of collaboration and clustering, pointing out that cluster organizations can significantly enhance innovation performance through coordinated knowledge exchange and resource pooling, particularly in the Visegrad context.

In terms of quantitative performance assessment, Ivanová and Žárská (2023) examine the relationship between R&D expenditures and aggregate innovation index scores, concluding that there is a notable research gap in the analysis of how sub-indicators influence overall innovation indices. This insight underlines the need for more granular analyses that go beyond aggregate rankings.

Hudec and Procházdková (2015) contribute to the methodological discourse by employing a Cobb-Douglas production function with R&D costs as inputs and patent counts as outputs to evaluate regional innovation

efficiency in the Visegrad countries. Their findings suggest that, in addition to capital regions, several Polish and Czech regions exhibit high efficiency, supporting the idea that regional dynamics may diverge from national trends.

In a similar vein, Wibisono (2023) introduces the idea of R&D personnel as an additional category of knowledge input, advocating for more comprehensive models of innovation efficiency that account for human capital alongside financial inputs.

Despite the shared historical background and structural similarities of the Visegrad countries, their innovation trajectories differ significantly. Jabłońska (2020, p. 31) notes that while these countries share some institutional similarities, the structure and dynamics of R&D expenditures vary considerably, and their regional innovation potential remains below the EU average. These findings underscore the value of intra-regional comparisons, as pursued in the present study.

Moreover, Hintošová et al. (2020, p. 106), in their examination of the Summary Innovation Index (SII) and foreign direct investment (FDI), reveal that only outward FDI contributes significantly to innovation performance in the Visegrad countries. This suggests that domestic innovation ecosystems may not fully benefit from inward investment flows, pointing to systemic inefficiencies.

Kowalska et al. (2018) compare multiple composite indices—including the SII, GII, and Global Competitiveness Index—and observe that the Visegrad countries are increasingly diverging in innovation performance, with Czechia emerging as a clear frontrunner. They argue that these trends call for more complex and detailed analyses to understand the underlying efficiency differences and national innovation strategies.

Building on these contributions, the present study addresses a specific gap in the literature: the lack of integrated efficiency analysis using both the European Innovation Scoreboard (EIS) and the Global Innovation Index (GII) within a Data Envelopment Analysis (DEA) framework. While many of the previous studies offer valuable insights into innovation outputs, inputs, or contextual enablers, few examine how efficiently innovation systems convert resources into results across both regional and global benchmarking tools.

Most prior research has focused on individual indicators or innovation rankings, typically examining the European Innovation Scoreboard (EIS) or the Global Innovation Index (GII) separately. In contrast, comprehensive efficiency assessments that integrate both frameworks remain scarce. This study aims to fill this gap by employing a DEA-based dual-model approach that incorporates both EIS and GII data, thereby providing a more detailed and comparative perspective on the innovation efficiency of the Visegrad countries.

The primary aim of this study is to assess and compare the innovation performance and efficiency of the Visegrad Group countries – Czechia, Hungary, Poland, and Slovakia – within both regional and global contexts. Specifically, the research:

- Applies a dual-framework approach, using data from the European Innovation Scoreboard (EIS) 2024 and the Global Innovation Index (GII) 2024, to provide a comprehensive picture of national innovation systems in the Visegrad region.
- Evaluates the relative innovation efficiency of these countries through Data Envelopment Analysis (DEA), utilizing both input-oriented and output-oriented models under variable returns to scale, in order to identify efficiency gaps in the transformation of innovation inputs into outputs.
- Benchmarks the Visegrad countries against the EU-27 average, highlighting their position within the broader European innovation landscape and identifying best practices and underperforming areas.
- Explores structural factors and contextual differences that may explain variations in innovation efficiency among the Visegrad countries, drawing on previous empirical research and national innovation profiles.

Theoretical framework

The theoretical foundation of this study lies at the intersection of national innovation systems (NIS) theory and efficiency analysis in innovation performance measurement.

The concept of National Innovation Systems (Freeman, 1987; Lundvall, 1992) emphasizes the role of institutions, policies, and interactions among firms, universities, and government bodies in shaping a country's capacity to generate, diffuse, and apply innovations. Innovation performance is thus viewed as a systemic outcome resulting from the coordinated functioning of various components, including R&D investment, human capital, infrastructure, and institutional quality. The NIS framework provides a holistic lens through which the innovation capabilities of countries can be evaluated and compared.

To operationalize and assess innovation performance, international benchmarking tools such as the European Innovation Scoreboard (EIS) and the Global Innovation Index (GII) have been developed. These indices synthesize numerous indicators into composite scores that reflect both the input conditions (e.g., funding, education, research) and output results (e.g., patents, exports, firm innovation) of national innovation systems. While widely used in policy and academic circles, these indices typically provide descriptive rankings rather than analytical insights into how efficiently countries convert innovation inputs into outputs.

To bridge this gap, the present study adopts Data Envelopment Analysis (DEA)—a non-parametric, frontier-based method introduced by Charnes, Cooper, and Rhodes (1978)—as the analytical core of the theoretical framework. DEA is designed to evaluate the relative efficiency of decision-making units (DMUs)—in this case, countries—by comparing the ratio of multiple innovation outputs to multiple inputs. By applying both input-oriented and output-oriented DEA models under the assumption of variable returns to scale (VRS), the study is able to identify countries that lie on the innovation efficiency frontier, as well as those that underperform given their resource endowments.

This dual-framework approach enables a more nuanced interpretation of innovation performance than absolute scores alone. It integrates systemic thinking from NIS theory with methodological rigor from DEA-based efficiency analysis, thus offering a novel contribution to the literature on comparative innovation studies.

In the context of the Visegrad countries – Czechia, Hungary, Poland, and Slovakia – this framework allows for a comprehensive evaluation that accounts not only for their shared historical and institutional legacies but also for the divergence in how effectively each nation utilizes its innovation resources. By combining insights from innovation systems theory and efficiency measurement, the study provides an evidence-based foundation for policy recommendations aimed at improving innovation performance and competitiveness in the region.

Methodology

This study employs a comparative analysis of the innovation performance of the Visegrad Group countries (Czechia, Hungary, Poland, and Slovakia), using data from two internationally recognized innovation indices: the European Innovation Scoreboard (EIS) 2024 published by the European Commission, and the Global Innovation Index (GII) 2024 released by the World Intellectual Property Organization (WIPO). These indices provide harmonized, publicly accessible innovation input and output indicators that enable cross-country comparisons.

From the EIS, four main areas − Framework Conditions, Investments, Innovation Activities, and Impacts −were analyzed. These were further grouped into input and output categories based on the definitions of the GII. Specifically, the Framework Conditions and Investments dimensions were categorized as inputs, while Innovation Activities and Impacts were treated as outputs.

In the case of the GII, innovation performance is divided into two sub-indices: Innovation Inputs and Innovation Outputs, which include a broad set of indicators such as Institutions, Human Capital & Research, Infrastructure, Business Sophistication, Knowledge & Technology Outputs, and Creative Outputs. Country-level data for all EU Member States were extracted from the 2024 editions of the two indices.

To evaluate the efficiency of innovation systems, we applied Data Envelopment Analysis (DEA), a non-parametric linear programming technique widely used for performance benchmarking (Mason & Wagner, 1994). DEA is especially well-suited to evaluate the relative efficiency of decision-making units, which in this case are countries, based on multiple inputs and outputs (Bae et al., 2019).

Two DEA models were applied in the analysis:

1. Input-oriented efficiency model under Variable Returns to Scale (VRS): This model assesses the extent to which a country can reduce its innovation-related inputs while maintaining the current level of outputs (Kočišová, 2015). Efficiency scores in this model range from 0 to 1, where a score of 1 indicates full efficiency−meaning no further input reduction is possible without compromising output levels.
2. Output-oriented efficiency model under VRS: This model evaluates how much a country could potentially increase its innovation outputs using the same level of inputs. A score of 1 indicates full efficiency, whereas values above 1 reflect inefficiency, implying that the country could produce greater innovation outputs without increasing its current level of inputs. Therefore, an output-oriented efficiency score greater than 1 is commonly understood as an indication of inefficiency and can be interpreted as a measure of output-oriented inefficiency.

The efficiency scale is calculated as the ratio of input-oriented to output-oriented efficiency scores. A value <1 indicates that the country is not operating at an optimal scale.

This dual approach enhances the robustness of the analysis and provides nuanced insights into the specific strengths and weaknesses of each country's innovation system. By considering both input and output perspectives, policymakers can better understand the leverage points for improving innovation performance, whether by optimizing resource allocation or enhancing the impact of innovation activities.

The ability of DEA to simultaneously evaluate multiple inputs and outputs renders it a highly effective tool for capturing the complexity of innovation systems (Golany et al., 1990). Moreover, as a non-parametric method, DEA does not require the specification of a functional form between inputs and outputs, allowing the data itself to define the efficiency frontier (Park et al., 2017).

The DEA was conducted separately for the datasets derived from the EIS and the GII, providing two complementary views on the innovation efficiency of EU Member States. Additionally, a scale efficiency score was calculated as the ratio of input-oriented to output-oriented efficiency, highlighting whether countries operate at an optimal scale.

All DEA calculations were carried out using standard linear programming algorithms, and the results were interpreted in the context of the structural characteristics of national innovation systems.

The calculations were performed using the DEA package in R software.

Results and Discussion

In this chapter, the results of the countries are presented only at the level of the dimensions defined in the analyses, while specific indicators within each dimension are highlighted, as these may account for the performance differences between countries. Based on the results of the European Innovation Scoreboard (Table 1), Czechia clearly stands out among the examined countries, outperforming the other three in each of the four main measurement areas.

For the other three countries, the ranking is less straightforward. While Hungary's overall result is better than those of Poland and Slovakia, there are specific areas where it lags behind these countries. In field of Framework Conditions, Hungary surpasses Poland and Slovakia, primarily due to its strong performance in the Attractive Research System and digitalization development.

However, it falls behind in the Human Resources dimension, which is attributable to the poor performance in the Population with tertiary education indicator. For Poland and Slovakia, their performance in the Attractive Research System dimension drags their results down, largely due to weak scores in the Share of Foreign doctorate students indicator.

In the Investments dimension, Slovakia lags behind the other countries, particularly in Finance and support, which is driven by low public sector R&D expenditure, limited Venture Capital Expenditures, and low R&D support. In contrast, Czechia performs favourably in the Innovation activities field, although Poland also achieves strong results here, as reflected in the Intellectual Assets dimension. Poland's positive outcome in this area is largely attributed to its high Design applications value, and it also leads the group in the Trademark applications indicator. Hungary's heterogeneous performance is also notable. Although it performs well in the Linkages dimension −particularly in Public-private co-publications and Job-to-job mobility of HRST (Human Resources in Science and Technology)− its innovation performance among SMEs (notably in business process innovation) lags behind. Additionally, Hungary's low Design Applications value in the Intellectual assets dimension negatively impacts its overall result.

An interesting pattern emerges in the Impacts area, where Slovakia achieves a strong performance despite weaker results in other areas. Two indicators from the Sales impacts dimension (Exports of medium and high technology products and Sales of new-to-market and new-to-firm innovations) stand out, placing Slovakia ahead of the other three countries. In the field of Employment impacts, Czechia stands out among the countries, which is mainly due to the high value of Employment in innovative enterprises.

Table 1. Results of the Visegrad countries based on the dimensions of the European Innovation Scoreboard

	CZ	HU	PL	SK
Framework conditions	**0.413**	**0.344**	**0.313**	**0.327**
Human resources	0.366	0.232	0.351	0.382
Attractive research system	0.361	0.340	0.165	0.223
Digitalisation	0.562	0.518	0.477	0.398
Investments	**0.574**	**0.448**	**0.412**	**0.333**
Finance and support	0.513	0.495	0.376	0.285
Firm investments	0.678	0.414	0.366	0.346
Use of information technologies	0.511	0.428	0.535	0.385
Innovation activities	**0.380**	**0.291**	**0.336**	**0.240**
Innovators	0.497	0.236	0.237	0.237
Linkages	0.323	0.345	0.274	0.206
Intellectual assets	0.358	0.272	0.464	0.276
Impacts	**0.617**	**0.477**	**0.396**	**0.540**
Employment impacts	0.573	0.339	0.334	0.318
Sales impacts	0.667	0.601	0.448	0.648
Environmental sustainability	0.596	0.445	0.384	0.579

Note: The values for each dimension represent the unweighted arithmetic mean of the normalised indicator values. Similarly, the values of the four main areas (Framework conditions, Investments, Innovation activities, Impacts) are calculated as the unweighted arithmetic mean of the normalised dimension values.
Source: calculations based on data from European Commission (2024)

Based on the results of the Global Innovation Index on Innovation Input (Table 2), there is a slight difference between the countries studied. According to the Input Sub-Index, Czechia and Hungary scored better than Poland and Slovakia. One of the strengths of Czechia is its Institutional and Regulatory environment, but it also performs well in the field of Ecological sustainability, which belongs to the Infrastructure pillar. However, the results for Czechia in this Sub-Index are notably hindered by the Market sophistication area, particularly in the dimensions of Credit and Investment.

Hungary's strengths include, for example, the Business sophistication pillar. Within this, the Foreign Direct Investment (FDI) inflows indicator is particularly favourable, placing Hungary at the top among all countries. Additionally, Hungary ranks among the top 10 countries in the Public research-industry co-publications index. Despite these strengths, Hungary's performance in the Investment area under Market Sophistication, similar to Czechia, remains a weakness. This can be attributed to the moderate role of venture capital (VC) in the economy.

In the case of Poland, the standard deviation of values across the Input Sub-Index pillars is the smallest. However, its ranking position varies significantly depending on the pillar. The Institutions and Market sophistication areas are weaknesses for Poland, due to a lack of political stability and underperformance in credit access compared to other countries in the report.

Slovakia achieved the weakest performance in inputs. Its significant lag compared to other countries is apparent

in the fields of education and R&D. Additionally, Slovakia underperformed in the field of Innovation linkages within the Business sophistication pillar, mainly due to insufficient cooperation and joint initiatives among economic actors.

Based on the Innovation Output Sub-Index results, Czechia's advantage over the other countries becomes significant. This superiority is primarily due to its high level of Knowledge diffusion.

Table 2. Results of the Visegrad countries based on the dimensions of the Global Innovation Index

	CZ	HU	PL	SK
Innovation input	**47.56**	**45.31**	**40.98**	**39.04**
Institutions	67.46	52.18	44.92	47.84
Human capital and research	43.69	42.95	42.63	34.64
Infrastructure	54.04	51.05	45.77	47.94
Market sophistication	30.09	34.05	33.55	32.24
Business sophistication	42.52	46.30	38.01	32.52
Innovation output	**40.52**	**33.84**	**33.03**	**29.58**
Knowledge and technology outputs	42.71	35.58	28.01	31.40
Creative outputs	38.34	32.09	38.06	27.77

Note: The values of the two Sub-Indices (Innovation input, Innovation output) represent the unweighted arithmetic mean of their respective dimensions.
Source: WIPO (2024)

The DEA (Data Envelopment Analysis) results for EU countries, based on the European Innovation Scoreboard (EIS) 2024 and Global Innovation Index (GII) 2024, assess efficiency by analyzing innovation input and output scores.

Countries with a DEA efficiency score of 1.000− calculated as the ratio of input-oriented to output-oriented efficiency based on EIS 2024 data−serve as benchmarks, representing the optimal transformation of innovation inputs into outputs. These countries include Bulgaria, Cyprus, Denmark, Italy, and Romania (Table 3).

Countries with lower input-oriented efficiency scores demonstrate inefficient use of innovation inputs. Portugal (0.526) is the least efficient, indicating that its innovation investments yield disproportionately low outputs. Similarly, Spain (0.570), France (0.618), and Sweden (0.622) exhibit low efficiency, suggesting the need for improved resource utilization.

Countries with higher output-oriented efficiency scores (>1.0) exhibit greater inefficiencies in generating innovation output. Portugal (1.697) and Hungary (1.492) have the highest inefficiency, indicating that their innovation outputs are not proportional to their investments.

Some countries demonstrate moderate input efficiency and reasonable output efficiency, meaning they are neither fully efficient nor highly inefficient. Examples include Germany (0.829 input-, 1.046 output-oriented efficiency), Finland (0.662 input-, 1.057 output-oriented efficiency), and Ireland (0.764 input-, 1.075 output-oriented efficiency). These countries maintain a relatively balanced innovation ecosystem, where innovation inputs and outputs are more proportionally aligned.

Among the Visegrad countries, Slovakia performs the best in terms of DEA efficiency. With an input-oriented efficiency score of 0.806, it is closer to the efficient frontier compared to the other three. Although the output-oriented score of 1.227 still reflects inefficiencies in innovation output generation, Slovakia's relatively higher efficiency scale (0.657) indicates moderately balanced input-output relationships, making it the most efficient innovator within the group. Hungary and Poland face the greatest challenges, especially in converting innovation inputs into tangible outputs. Hungary has an input-oriented efficiency score of 0.656 and a high output-oriented inefficiency score of 1.492, while Poland scores 0.683 on input efficiency and 1.436 on output efficiency− both ranking among the lowest in the EU. Czechia performs slightly better, with an input-oriented efficiency of 0.696, but it also struggles with high output inefficiency, reflected in its output-oriented score of 1.356.

The Visegrad countries, as a group, underperform relative to the EU-27 average in innovation efficiency. Slovakia is the only country in the group approaching EU average efficiency, making it a regional benchmark.

Table 3. DEA Efficiency Results Based on Innovation Input and Output Scores from EIS 2024

Country	Input-oriented efficiency	Rank	Output-oriented efficiency	Rank	Efficiency scale	Rank
Austria	0.767	13	1.053	8	0.728	8
Belgium	0.688	18	1.061	10	0.649	13
Bulgaria	1.000	1	1.000	1	1.000	1
Croatia	0.791	11	1.250	19	0.633	14
Cyprus	1.000	1	1.000	1	1.000	1
Czechia	0.696	17	1.356	22	0.513	21
Denmark	1.000	1	1.000	1	1.000	1
Estonia	0.649	22	1.235	18	0.526	20
Finland	0.662	20	1.057	9	0.626	15
France	0.618	25	1.278	21	0.484	23
Germany	0.829	7	1.046	7	0.792	7
Greece	0.984	6	1.015	6	0.970	6
Hungary	0.656	21	1.492	25	0.440	25
Ireland	0.764	14	1.075	12	0.711	9
Italy	1.000	1	1.000	1	1.000	1
Latvia	0.774	12	1.272	20	0.608	17
Lithuania	0.698	16	1.373	23	0.508	22
Luxembourg	0.699	15	1.130	14	0.619	16
Malta	0.813	8	1.193	15	0.682	10
Netherlands	0.639	23	1.089	13	0.587	18
Poland	0.683	19	1.436	24	0.475	24
Portugal	0.526	27	1.697	27	0.310	27
Romania	1.000	1	1.000	1	1.000	1
Slovakia	0.806	9	1.227	17	0.657	12
Slovenia	0.800	10	1.201	16	0.666	11
Spain	0.570	26	1.520	26	0.375	26
Sweden	0.622	24	1.062	11	0.585	19

Source: authors' calculations based on innovation input and output scores from EIS 2024

Countries with an input-oriented efficiency of 1.000 and an output-oriented efficiency of 1.000 based on GII 2024 innovation input and output scores achieve an efficiency scale of 1.000, making them benchmark performers. These countries—Bulgaria, Cyprus, Germany, Romania, and Sweden—effectively convert innovation inputs into outputs and operate at an optimal scale (Table 4).

Countries with low input-oriented efficiency scores (below 0.8) demonstrate inefficient utilization of innovation inputs, indicating that they do not effectively leverage their innovation resources. Notable examples include Estonia (0.764, ranked 27th), Austria (0.772, ranked 26th), Luxembourg (0.774, ranked 25th), and Lithuania (0.777, ranked 24th). To enhance innovation performance, these countries should focus on optimizing resource allocation and improving input management to achieve better output conversion.

Countries with high output-oriented efficiency scores (>1.3) demonstrate significant inefficiencies in generating innovation outputs, indicating that their current innovation efforts do not fully translate into measurable results. Notable examples include Lithuania (1.525, ranked 27th), Latvia (1.504, ranked 26th), Slovenia (1.394, ranked 25th), and Hungary (1.312, ranked 24th).. A higher output-oriented efficiency score suggests that these countries have the potential to increase innovation output without requiring additional inputs, highlighting inefficiencies in their innovation performance.

A moderate balance between input and output efficiency (scores around 0.8–0.9) reflects relatively effective innovation performance. Countries such as Italy (0.966 input-, 1.016 output-oriented efficiency), Netherlands (0.957 input-, 1.029 output-oriented efficiency), France (0.937 input-, 1.057 output-oriented efficiency), and Slovakia (0.966 input-, 1.176 output-oriented efficiency) demonstrate a well-structured innovation ecosystem, where innovation investments and outputs are proportionally aligned.

Table 4. DEA Efficiency Results Based on Innovation Input and Output Scores from GII 2024

Country	Input-oriented efficiency	Rank	Output-oriented efficiency	Rank	Efficiency scale	Rank
Austria	0.772	26	1.257	20	0.614	22
Belgium	0.784	23	1.262	22	0.621	21
Bulgaria	1.000	1	1.000	1	1.000	1
Croatia	0.925	11	1.251	18	0.739	13
Cyprus	1.000	1	1.000	1	1.000	1
Czechia	0.888	13	1.142	10	0.777	11
Denmark	0.832	20	1.150	11	0.723	16
Estonia	0.764	27	1.254	19	0.609	24
Finland	0.842	17	1.128	9	0.746	12
France	0.937	10	1.057	8	0.886	8
Germany	1.000	1	1.000	1	1.000	1
Greece	0.924	12	1.262	21	0.732	14
Hungary	0.856	15	1.312	24	0.653	20
Ireland	0.829	21	1.170	12	0.709	17
Italy	0.982	6	1.016	6	0.966	6
Latvia	0.851	16	1.504	26	0.566	26
Lithuania	0.777	24	1.525	27	0.510	27
Luxembourg	0.774	25	1.264	23	0.612	23
Malta	0.833	18	1.214	16	0.687	18
Netherlands	0.957	8	1.029	7	0.930	7
Poland	0.942	9	1.179	15	0.799	10
Portugal	0.832	19	1.229	17	0.677	19
Romania	1.000	1	1.000	1	1.000	1
Slovakia	0.966	7	1.176	14	0.821	9
Slovenia	0.816	22	1.394	25	0.585	25
Spain	0.858	14	1.175	13	0.730	15
Sweden	1.000	1	1.000	1	1.000	1

Source: authors' calculations based on innovation input and output scores from GII 2024

Based on the GII, Slovakia and Poland lead the Visegrad group in terms of DEA-measured innovation efficiency, indicating that their systems effectively utilize resources and maintain a good balance between input and output. Slovakia achieved an input-oriented efficiency score of 0.966, an output-oriented score of 1.176, and an efficiency scale of 0.821, the highest among the Visegrad countries. Similarly, Poland recorded a strong input efficiency of 0.942, with an output efficiency of 1.179 and a scale efficiency of 0.799, reflecting a stable and relatively efficient innovation system.

Czechia follows closely, with an input efficiency of 0.888, output efficiency of 1.142, and efficiency scale of 0.777, suggesting good performance overall but still some room for improving output generation, particularly in turning inputs into high-impact innovation results.

Hungary, on the other hand, lags behind its Visegrad peers, with an input-oriented efficiency of 0.856, a notably high output-oriented inefficiency score of 1.312, and a low efficiency scale of 0.653. This highlights significant shortcomings in converting innovation investments into measurable outputs and signals the need for targeted policy interventions to enhance commercialization, knowledge transfer, and innovation productivity.

Slovakia and Poland lead the Visegrad region in DEA-based innovation efficiency and both exceed the EU average in input utilization. Czechia remains a moderately efficient innovator, with good input efficiency but modest output performance, suggesting opportunities for enhancement in innovation impact and diffusion. Hungary underperforms in both models, indicating structural inefficiencies and a need for policy reforms to strengthen the conversion of innovation efforts into tangible results.

There is a general positive correlation between efficiency scores in EIS 2024 and GII 2024 (Fig. 1), meaning that countries efficient within the EU tend to perform well globally. However, some discrepancies exist, where certain countries are more efficient within the EU framework (EIS) but less efficient in a global comparison (GII), and vice versa.

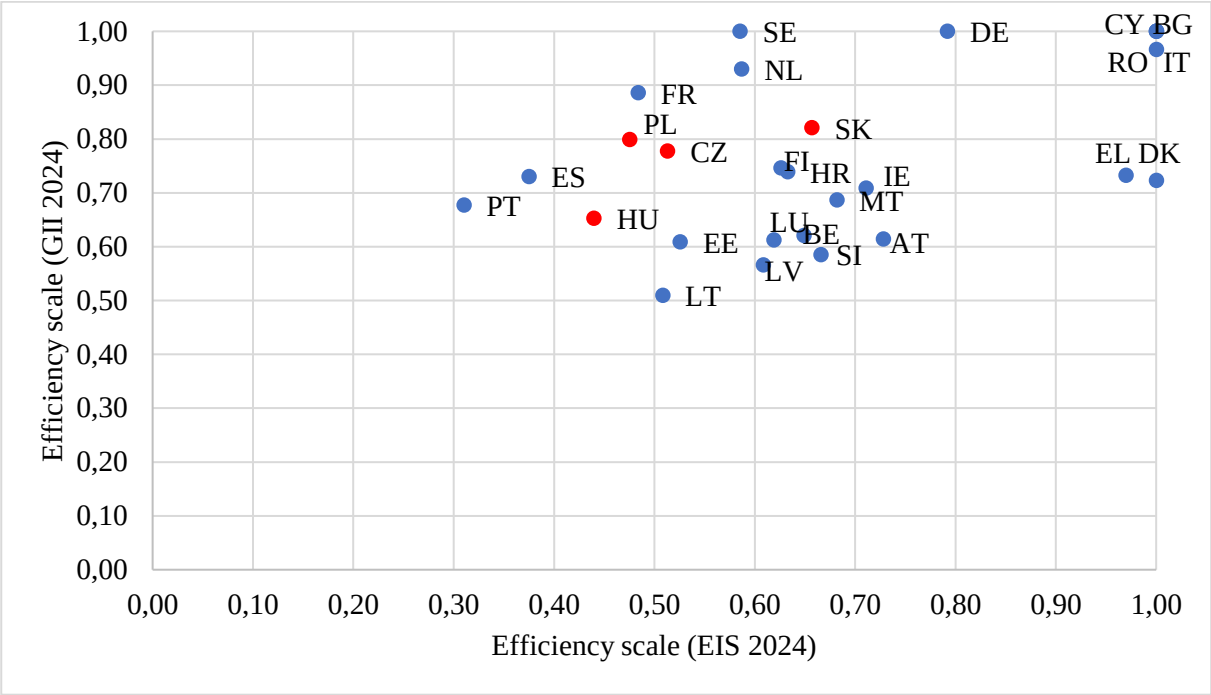

Fig. 1. Relationship Between Efficiency Scores Based on EIS 2024 and GII 2024
Source: authors' calculations based on innovation input and output scores from EIS 2024 and GII 2024

Benchmark Countries (Top-Right Quadrant) such as Cyprus (CY), Bulgaria (BG), Romania (RO), and Italy (IT) achieved an efficiency scale of 1.00 in both EIS 2024 and GII 2024. These countries are considered fully efficient in both models, meaning they optimally convert innovation inputs into outputs across both innovation measurement frameworks.

Denmark (DK) and Greece (EL) have a high-efficiency scale in EIS 2024 (close to 1.00) but a lower efficiency scale in GII 2024. This suggests that while these countries perform well in innovation efficiency according to EIS 2024, they exhibit lower efficiency in the global innovation context as per GII 2024.

Germany (DE), Sweden (SE), and the Netherlands (NL) have high-efficiency scores in GII 2024 but moderate efficiency in EIS 2024. This implies that these countries are efficient from a global innovation perspective but face some inefficiencies when measured within the EU framework.

Slovakia is the best-performing Visegrad country in terms of combined innovation efficiency. Its high efficiency score based on the GII (0.821) indicates that Slovakia is highly effective at converting innovation inputs into outputs on a global scale. While its EIS efficiency score is somewhat lower (0.657), it still surpasses the other Visegrad countries, reflecting strong innovation efficiency in both regional and international contexts.

Poland shows stronger innovation efficiency globally than within the EU. This may suggest that Poland's innovation outputs are better recognized or measured in the broader global context, possibly due to structural differences in the GII methodology. However, the lower EIS efficiency indicates potential weaknesses in how innovation policies function within the EU framework.

Conclusions

The DEA results reveal significant disparities in innovation efficiency across EU countries. Some countries (Bulgaria, Cyprus, Germany, Italy, Romania, and Sweden) efficiently utilize innovation inputs, while others exhibit inefficiencies in resource allocation or output generation.

Certain countries (Croatia, Latvia, Lithuania, Slovakia, Slovenia) perform well in input-oriented efficiency but lag in output efficiency, indicating a need to enhance the effectiveness of innovation investments. Conversely, countries with high output inefficiencies have untapped potential to increase innovation output without additional resources.

The comparison of DEA results based on EIS 2024 and GII 2024 highlights that some countries (Denmark, Greece) are efficient in an EU context but less competitive globally, while others (Germany, Sweden, and the Netherlands) perform well on a global scale despite inefficiencies within the EU framework.

The DEA analysis provides valuable insights into the efficiency of national innovation systems. Policymakers should leverage these findings to enhance innovation performance, close efficiency gaps, and strengthen competitiveness both within the EU and globally.

The DEA-based analysis of innovation performance, using input and output data from both the European Innovation Scoreboard (EIS) 2024 and the Global

Innovation Index (GII) 2024, reveals significant differences in innovation efficiency among the Visegrad Group countries—Czechia, Hungary, Poland, and Slovakia.

Slovakia emerges as the most efficient innovator in the group. It demonstrates strong input-oriented efficiency in both indices (0.806 in EIS and 0.966 in GII), coupled with relatively moderate output inefficiency, resulting in the highest efficiency scale among the four countries (0.657 in EIS and 0.821 in GII). These findings indicate that Slovakia not only utilizes its innovation inputs effectively but also operates at a near-optimal scale. This aligns with earlier findings by Hudec & Procházková (2015), who also identified high regional efficiency in several Slovak and Polish regions, particularly in terms of patent outputs relative to R&D expenditures.

Poland shows a mixed profile: while it lags in terms of raw innovation output (as seen in the GII and EIS rankings), it ranks second in DEA efficiency among the V4, with strong input-oriented scores (0.683 in EIS and 0.942 in GII). This suggests that Poland manages its innovation resources efficiently, though the quality or economic impact of its outputs may be lower. This corresponds with the findings of Kowalski et al. (2023), who emphasized the importance of improving the linkages between business and science to enhance innovation effectiveness in Poland.

Czechia performs well in absolute innovation rankings and shows balanced but moderate efficiency in DEA results (0.696 input efficiency in EIS, 0.888 in GII). However, it exhibits noticeable output inefficiency (1.356 in EIS and 1.142 in GII), indicating that despite having a solid innovation infrastructure, the country is not fully translating inputs into high-impact results. Previous research, including Ivanová and Žárská (2023), highlights that sub-indicator dynamics—such as R&D spending efficiency—are often underexplored, and Czechia might benefit from such micro-level adjustments to enhance performance.

Hungary consistently ranks as the least efficient Visegrad country in both DEA models. It shows low input efficiency (0.656 in EIS, 0.856 in GII) and very high output inefficiency (1.492 in EIS, 1.312 in GII), resulting in the lowest efficiency scale scores (0.440 and 0.653). These findings suggest serious structural inefficiencies in Hungary's innovation system, particularly in converting inputs (e.g., funding, infrastructure) into outputs such as patents, high-tech exports, or innovation-driven growth. This is consistent with Jabłońska (2020), who reported low innovation potential in Hungarian regions despite moderate levels of investment, and with Hintošová et al. (2020), who found that only outward foreign direct investment showed a meaningful contribution to innovation performance, suggesting limited domestic innovation dynamics

Limitations

The DEA results are highly sensitive to the chosen innovation input and output indicators from GII 2024 and EIS 2024. Alternative input-output combinations could lead to different efficiency rankings. Aggregated innovation input and output scores mask variations within individual components, making it difficult to identify which specific factors (e.g., R&D expenditure, human capital, patents) drive efficiency or inefficiency. Countries with different innovation structures, industries, or policy frameworks are evaluated on a single efficiency scale, which may not fully capture the nuances of their innovation ecosystems.

Acknowledgement

The research underpinning this study was conducted in the first half of 2024 with the support of MOME Foundation, Future Potentials Observatory.

References

Bae, J.-H., Chung, Y., Lee, J., & Seo, H. (2019). Knowledge spillover efficiency of carbon capture, utilization, and storage technology: A comparison among countries. *Journal of Cleaner Production*, 246, 119003. https://doi.org/10.1016/j.jclepro.2019.119003

Będzik, B., Gołąb, S. (2020): Selected determinants of innovation potential in the agricultural sector in the visegrad countries. *Zagadnienia Ekonomiki Rolnej/ Problems of Agricultural Economics* 3(364) 2020, 162-179

Będzik, B., Gołąb, S. (2021): Social Capital and Innovation in the Countries of the Visegrad Group. *Konference Hradec Economic Days*, Proceedings Paper.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision-making units. *European Journal of Operational Research*, 2(6), 429–444.

European Commission: Directorate-General for Research and Innovation. (2024). *European Innovation Scoreboard 2024*. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/779689.

Freeman, C. (1987). *Technology Policy and Economic Performance: Lessons from Japan*. Pinter Publishers.

Golany, B., Learner, D. B., Phillips, F., & Rousseau, J. J. (1990). Managing service productivity: The data envelopment analysis perspective. *Computers Environment and Urban Systems*, 14(2), 89. https://doi.org/10.1016/0198-9715(90)90015-l

Hintošová, A. B., Bruothová, M., & Vasková, I. (2020). Does Foreign Direct Investment Boost Innovation? The Case of the Visegrad and Baltic Countries. *Quality Innovation Prosperity*, 24(3), 1–18. https://doi.org/10.12776/qip.v24i3.1519

Hudec, O., Procházková, M. (2015). Visegrad Countries and Regions: Innovation Performance and Efficiency. *Quality Innovation Prosperity*, 19(2), 55–64. https://doi.org/10.12776/qip.v19i2.593

Ivanová, E., Žárská, V. (2023). R&D expenditure as a determinant of the aggregate innovation index in the V4 countries. *Innovative Marketing*, 19(2), 87–100. https://doi.org/10.21511/im.19(2).2023.08

Jabłońska, M. (2020). Comparative Analysis of R&D in the Visegrad Group Countries in the Years 2004–2018. *Comparative Economic Research – Central and Eastern Europe*, 23(4), 7–23. https://doi.org/10.18778/1508-2008.23.26%0A

Kočišová, K. (2015). Application of the DEA on the measurement of efficiency in the EU countries. *Agricultural Economics (Zemědělská Ekonomika)*, 61(2), 51. https://doi.org/10.17221/107/2014-agricecon

Kowalska, A., Kovarnik, J., Hamplova, E., Prazak, P. (2018). The Selected Topics for Comparison in Visegrad Four Countries. *Economies*, 6(3), 50

Kowalski, A. M., Kuberska, D., & Mackiewicz, M. (2023). The role of cluster organisations in stimulating cooperation between business and science. Experience from the Visegrad Group countries. *Argumenta Oeconomica*, 2(51), 197–212. https://doi.org/10.15611/aoe.2023.2.10

Lundvall, B.-Å. (1992). *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. Pinter.

Mason, G., Wagner, K. (1994). Innovation and the Skill Mix: Chemicals and Engineering in Britain and Germany. *National Institute Economic Review*, 148(1), 61. https://doi.org/10.1177/002795019414800106

Park, J., Kim, J.-Y., & Sung, S.-I. (2017). Performance Evaluation of Research and Business Development: A Case Study of Korean Public Organizations. *Sustainability*, 9(12), 2297. https://doi.org/10.3390/su9122297

Wibisono, E. (2023): Knowledge input and innovation in Visegrad Group (V4) regions: A spatial econometric approach. *Bulletin of Geography. Socio-economic Series*, 59(59)

World Intellectual Property Organization (WIPO) (2024). *Global Innovation Index 2024: Unlocking the Promise of Social Entrepreneurship*. Geneva: WIPO. 10.34667/tind.50062

RECEIVED: 10 October 2024 ACCEPTED: 02 December 2024 PUBLISHED: 10 March 2025

Sergey VINOGRADOV is an associate professor and head of the Institute of Methodology at Budapest Metropolitan University, where he teaches statistical methodology to bachelor's, master's, and doctoral students. He is former researcher at MOME Foundation, Future Potentials Observatory and Ludovika University of Public Service. He has authored or co-authored over 70 scientific journal articles, with 23 of them cited in Scopus. His current research interests include work environments that foster innovation and the examination of soft factors influencing national competitiveness in the era of digitalization and Industry 4.0. E-mail: szvinogradov@metropolitan.hu, ORCID ID: 0000-0002-6242-3063

Balázs NAGY is a lecturer at Pázmány Péter Catholic University (Budapest) and former researcher at MOME Foundation, Future Potentials Observatory and Ludovika University of Public Service. His research interests include competitiveness, regional and territorial disparities, and economic policy. E-mail: nagybalazs0224@gmail.com, ORCID ID: 0000-0002-1229-4021