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STATISTICAL ASSESSMENT OF THE IMPLEMENTATION OF SUSTAINABLE DEVELOPMENT GOAL 9 IN THE EUROPEAN UNION COUNTRIES

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Purpose: The development of modern infrastructure, support for sustainable industry, and the promotion of innovation and new technologies are the main objectives of SDG 9. The aim of the article is to provide a synthetic assessment of the level of SDG 9 implementation in these three areas by the 27 EU countries in 2023.
Design/methodology/approach: The value of the synthetic measure reflecting the level of SDG 9 implementation was calculated using two selected linear ordering methods: the zeroed unitarization method and the TOPSIS method. The study used a set of indicators from Eurostat assigned to SDG 9. These indicators are a key tool for monitoring progress in achieving the goals, enabling analyses at international, national, and regional levels. The findings are presented in tabular form.
Findings: Based on the conducted research, EU country rankings were constructed, and countries were grouped according to similar levels of SDG 9 implementation. The results showed that the leaders in implementing SDG 9 were Sweden, Denmark, Belgium, and Germany, while Bulgaria, Romania, Latvia, and Portugal ranked lowest. Both applied linear ordering methods produced similar rankings of EU countries with regard to SDG 9 implementation, as confirmed by the Spearman's rank correlation coefficient at the level of 0.8993.
Research limitations/implications: In this study, only fully complete indicators related to Sustainable Development Goal 9, as provided by Eurostat, were utilized. The selection of variables for cross-country analyses presents a considerable challenge, as differences in data collection methods and reporting standards may limit comparability. For this reason, the choice of variables in the article was primarily determined by the availability, consistency, and completeness of statistical data in the Eurostat database. Ensuring an appropriate and comprehensive set of variables is crucial, as any gaps or inadequacies in the dataset may influence the reliability, validity, and overall interpretability of the research findings.
Practical implications: The research results provide a general overview of the studied phenomenon and offer policymakers valuable diagnostic information that enables the monitoring of progress and the identification of areas requiring intervention. Countries lagging in the implementation of Goal 9—particularly in Central, Eastern, and Southern Europe—may benefit from support programs tailored to their specific contexts, the development of digital

infrastructure, and investments in education and human capital development. The study's conclusions can also support the effective allocation of EU funds and resources in order to maximize their impact and ensure that all Member States are able to fully achieve the objectives set out in the 2030 Agenda, including SDG 9. These actions may therefore contribute to ensuring sustainable development across the entire European Union.
Originality/value: The originality of the article lies in the authors' individual approach to the chosen research issues. An original selection of research methods was made, including the ordering of individual countries and their grouping, thereby enriching the research methodology. The obtained results may serve as a basis for broadening knowledge in this area, preparing and subsequently applying more advanced research assumptions and methods, as well as expanding research conclusions. The added value of the study is the proposed original research procedure, which may be applied to analyses of other Sustainable Development Goals within the EU or in individual Member States.
Keywords: sustainable development, Sustainable Development Goals (SDGs), SDG9, European Union countries, zero unitarization method, TOPSIS methods.
Category of the paper: Research paper.

1. Introduction

One of the key challenges of the global economy in the 21st century is the implementation of development policies based on the concept of sustainable development. The Member States of the European Union have actively participated in international debates concerning the assumptions of this model, an important outcome of which was the adoption, on 15 September 2015, by the United Nations General Assembly of the resolution entitled *Transforming our world: the 2030 Agenda for Sustainable Development* (The 2030 Agenda, 2015).

Within the framework of the 2030 Agenda, UN Member States agreed on the Sustainable Development Goals (SDGs), which serve as the basis for verifying progress towards the overarching objective of sustainable development. Seventeen goals were defined and described as "integrated and indivisible, global in nature and universal". These goals encompass 169 specific targets, to which measurable quantitative and qualitative indicators were assigned. The responsibility for monitoring and reporting the degree of their implementation rests with national governments. Initially, the concept of sustainable development focused on reducing the negative impact of economies on the natural environment. Later, it emphasized the balance between the three main dimensions: environmental protection, social progress, and economic growth. The implementation of the individual Sustainable Development Goals is expected to contribute to improving the overall level of development, taking into account economic, social, and environmental aspects (Raczkowska, 2024).

The European Union approaches sustainable development holistically, which means that the principles and programs derived from it must be integrated into all EU policies and projects. The European Commission monitors the implementation of individual sustainable development strategy goals, while Eurostat publishes the results of this monitoring. The practical realization of the provisions of the EU sustainable development strategy would not be possible without the financial guarantees embedded in the community's budget (Jantoń-Drozdowska, Juskowiak, 2023).

The concept of sustainable development has been the subject of reflection by researchers representing various fields of science. Among them, scholars in economics and management sciences play a particularly significant role. However, attention should be drawn to the continuously increasing number of scientific publications addressing this issue. In the 1980s, the number of new publications indexed in the Scopus database with the expression "sustainable development" included in the abstract did not exceed 60 per year; in the 1990s, the figure rose to around 600 annually; whereas in 2022-2023, more than 20,000 publications were added (Raczkowska, 2024).

One of the areas covered by the 2030 Agenda is SDG 9, which concerns building resilient infrastructure, promoting sustainable industrialization, and fostering innovation. As noted by Jantoń-Drozdowska and Juskowiak (2023), achieving this goal requires the development of sustainable and durable infrastructure that supports economic growth and human well-being, the promotion of sustainable industrialization, the modernization of infrastructure, and the upgrading of industry towards sustainability and innovation—both internationally and nationally.

The research presented in this article was aimed at a comprehensive examination of the level of SDG 9 implementation in the EU Member States. The objective of the study was therefore to assess the degree of SDG 9 implementation by the 27 EU countries in 2023. To analyze disparities in the level of implementation, indicators from the Eurostat database describing this goal were applied.

The article attempts to answer the following research questions:

- Which EU countries are the leaders, and which occupy the lowest positions in the EU rankings with respect to the synthetic measure of SDG 9 in 2023?
- Which EU countries formed groups characterized by high, medium-high, medium-low, and low levels of SDG 9 implementation?
- What is the degree of consistency between the EU country rankings regarding SDG 9 implementation obtained using two selected linear ordering methods, namely the zeroed unitarization method and the TOPSIS method?

The implementation of the article's research objectives required its division into several parts. In the first part, a literature review was conducted with respect to the areas covered by SDG 9. This was followed by the presentation of methodological assumptions and the indicators considered as characterizing this goal. An important part of the article consists of the results and the discussion of the conducted research. The final part presents a short analysis of the findings.

2. Pillars of SDG 9: Resilient Infrastructure, Sustainable Industrialization, and Innovation

The main pillars of SDG 9 are the construction of stable infrastructure, the promotion of sustainable industrialization, and the fostering of innovation. As noted by Fura et al. (2025), developed and modern infrastructure can improve residents' living standards and contribute to a country's economic development. Infrastructure provides the basic physical systems, assets, and structures that are essential for maintaining vital societal functions, health, security, and the economic and social well-being of people. Adequate infrastructure is closely linked to the achievement of social development, economic growth, and environmental goals. Poor access to basic infrastructure reduces opportunities for employment, education, and healthcare, thereby compromising quality of life and creating barriers to business activity. Progress in railways, roads, water systems, irrigation systems, electrical power, sanitation, and information technologies is visibly connected to economic growth and enables the attainment of many other goals that depend on it.

In times of intense uncertainty, a resilient infrastructure system reduces vulnerability, minimizes the consequences of threats, accelerates responses and recovery, and facilitates adaptation to disruptive events (Cabrita et al., 2023; NIAC, 2020). The development of stable, accessible, high-quality infrastructure helps prevent social exclusion due to lack of connectivity and can also have a positive impact on the natural environment. Building resilient infrastructure therefore requires thinking and acting for future generations (Cabrita et al., 2023).

The UNDRR (2022) identifies six interconnected principles for resilient infrastructure:

- Continuously learning – highlighting the challenges in understanding infrastructure resilience due to the internal complexity and external hyperconnectivity of related systems and sectors.
- Proactively protected – ensuring preparedness for hazards, acknowledging that infrastructure is exposed to various known and unknown risks, and that the nature of these hazards is constantly evolving.
- Environmentally integrated – working proactively and positively with the natural environment, both biological (flora and fauna) and physical (land, air, water).
- Socially engaged – actively involving people and communities so they understand how they can help prevent and respond to disruptions.
- Shared responsibility – encouraging collaborative approaches to sharing data, knowledge, and expertise.
- Adaptively transforming – changing the ways in which infrastructure systems operate or the outputs they are intended to deliver.

"Industrialization" is a broad term for a set of economic and social processes related to finding more efficient ways of creating value. Industrialization is often an indirect result of adequate and resilient infrastructure, generating jobs with positive impacts on social and economic life (Cammarano et al., 2022). While industrialization has brought economic prosperity, it is also responsible for adverse ecological effects such as pollution (air, water, and land), forest degradation, and biodiversity loss (Cabrita et al., 2023). This is particularly evident in former post-communist countries, which share a common history, similar economic structures, levels of development, and energy profiles. The centrally planned economies of these countries heavily invested in energy-intensive, high-emission heavy industries, creating a unique energy culture based on the availability of cheap resources such as coal, crude oil, and natural gas (Pach-Gurgul, Ulbrych, 2019).

According to Ulbrych (2020), sustainable industrial development should be understood as fostering growth in manufacturing capacity and competitiveness, creating employment, and improving environmental performance. Other scholars (Nkoa, Fonguen-Kong-Nogh, 2024) add that industrial development should be based on ambitious, multilateral, and international frameworks for financing new technologies, energy transition, and so-called green industrialization to support low-income economies.

Innovation and technological progress are essential for achieving economic and employment growth, as well as for finding lasting solutions to environmental challenges such as improved resource and energy efficiency. The use of new technologies supports the development of a knowledge economy and leads to further inventions that enhance living conditions in areas such as medicine, transportation, production, and energy use. Innovation and creativity are vital for making more efficient and effective use of resources and are key mechanisms for achieving the SDGs (Cabrita et al., 2023). Investment in research and development, along with the growth of human capital, contributes to fostering innovation (Beck-Krala, Duda, 2014). Thanks to innovation and technological progress, inclusive and sustainable industrial development supports environmental goals, including increased resource and energy efficiency (Worrell et al., 2008).

3. Methodological Assumptions

The calculation of the synthetic measure value using linear ordering methods involves several stages (Nowak, 1990):

I. Selection of diagnostic variables.

At this stage, variables are verified according to substantive, formal, and statistical criteria. For the statistical assessment, measures of variability and correlation are applied.

Most often, the classical coefficient of variation, defined by the following formula, is adopted as the measure of variability:

$$v_j = \frac{s_j}{\bar{x}_j} \quad (j=1,2, ...,m) \tag{1}$$

where:

s_j – standard deviation of variable X_j,

$\bar{x}_j$ – arithmetic mean of variable X_j.

From the set of potential diagnostic variables, those that meet the following condition are eliminated:

$$\left| v_j \right| \leq v^* \tag{2}$$

where: v^* – the critical value of the coefficient of variation.

The critical value is most often assumed at the level of 0.1. In the literature, it is accepted that the variable then does not possess discriminative ability, and thus has little informational value (Panek, 2009; Nowak, 1990).

For the assessment of variable correlation, the inverted correlation matrix method proposed by Malina and Zeliaś (1998) may be applied. This method consists of:

1. Calculating the matrix $\boldsymbol{R}$ of Pearson's linear correlation coefficients between the variables:

$$\boldsymbol{R} = \begin{bmatrix} 1 & r_{12} & \cdots & r_{1m} \\ r_{21} & 1 & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & 1 \end{bmatrix} \tag{3}$$

where: r_{jk} – Pearson's linear correlation coefficient between variables X_j and Xk.

2. Determining the inverse matrix of $\boldsymbol{R}$:

$$\mathbf{R}^{-1} = \left[r^{(ij)} \right] \tag{4}$$

where: $r^{(ij)}$ $(i, j = 1, 2, ..., m)$ – the elements of the inverse matrix $\boldsymbol{R}^{-1}$.

The diagonal elements of the inverse matrix are significantly greater than one in cases of excessive correlation of a given variable with the remaining variables. In such cases, variables for which the following condition is satisfied are subject to elimination:

$$\left| r^{(jj)} \right| > r^* \tag{5}$$

where:

$r^{(jj)}$ – the diagonal element of the inverse matrix $\boldsymbol{R}^{-1}$,

r^* – the critical value of the diagonal elements of the inverse matrix $\boldsymbol{R}^{-1}$, most often set at the level of 10.

After conducting the statistical verification of variables, the set of so-called diagnostic variables remains.

II. Application of Selected Linear Ordering Methods.

In the study assessing EU countries with respect to the implementation of SDG 9, two linear ordering methods are applied: the min–max method, also known as the zero unitarization method, and the TOPSIS method. The first belongs to the so-called non-pattern methods, while the second is classified as a pattern method of linear ordering. Both methods make it possible to obtain the value of a synthetic measure, which is a function of many variables. This, in turn, enables the comparison of countries in terms of a so-called complex phenomenon, i.e., one described by several variables.

The methodological assumptions of both methods are presented below.

The min-max method (zero unitarization) requires several stages (Kukuła, 2000):

- Construction of the so-called observation matrix:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{6}$$

- Determining the nature of the variables. Variables can be classified as stimulants or destimulants. Stimulants are features whose high values are desirable from the adopted point of view, while low values are undesirable. Destimulants, on the other hand, are features for which low values are desirable from the perspective of the studied phenomenon, whereas high values are considered undesirable (Hellwig, 1968).
- Normalization of variable values, i.e., making them comparable by means of formulas:

For stimulants:

$$z_{ij} = \frac{x_{ij} - \min\limits_{i}\{x_{ij}\}}{R_j} \tag{7}$$

For destimulants:

$$z_{ij} = \frac{\max\limits_{i}\{x_{ij}\} - x_{ij}}{R_j} \tag{8}$$

- Determining the value of the synthetic measure using the following formula:

$$MS_i = \frac{1}{m}\sum_{j=1}^{m} z_{ij} \tag{9}$$

where:

MS_i – synthetic measure for the i-th object,

z_i – normalized values of the variables,

m – number of variables.

The TOPSIS method was developed by Hwang and Yoon (1981) and is widely used due to its flexibility in both theoretical and practical analyses. It enables decision-making in complex multi-criteria problems while taking into account various aspects of the studied phenomena (Roszkowska, 2011). This method includes steps defined by formulas (6-8) and additionally by formulas (10-14):

– Determining the coordinates of the model units – the development pattern (A^{+}) and the anti-pattern (A^{-}):

$$A^{+} = (\underset{i}{max}(z_{i1}), \underset{i}{max}(z_{i2}), \ldots, \underset{i}{max}(z_{im})) = (z_1^{+}, z_2^{+}, \ldots, z_m^{+}) \quad (10)$$

$$A^{-} = (\underset{i}{min}(z_{i1}), \underset{i}{min}(z_{i2}), \ldots, \underset{i}{min}(z_{im})) = (z_1^{-}, z_2^{-}, \ldots, z_m^{-}) \quad (11)$$

– Calculation of the Euclidean distances of each object from the pattern z^{+} and the anti-pattern z^{-}using the following formulas:

$$d_i^{+} = \sqrt{\sum_{j=1}^{m}\left(z_{ij} - z_m^{+}\right)^2} \quad (12)$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{m}\left(z_{ij} - z_m^{-}\right)^2} \quad (13)$$

– Determination of the synthetic measure value:

$$MST_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \quad (14)$$

The synthetic measure MST_i takes values in the range [0;1]. An object is considered more advanced in terms of the analyzed complex phenomenon the closer the value of the synthetic measure is to one; that is, the smaller the distance of a given object from the pattern and, consequently, the greater its distance from the anti-pattern.

After calculating the values of the synthetic measures MS_i and MST_i for the objects, it is possible to classify the countries into similar groups according to the following scheme (Nowak, 1990):

Group 1: $MS_i \geq \overline{MS}_i + S_i$ high level

Group 2: $\overline{MS}_i + S_i > MS_i \geq \overline{MS}_i$ medium-high level

Group 3: $\overline{MS}_i > MS_i \geq \overline{MS}_i - S_i$ medium-low level (15)

Group 4: $MS_i < \overline{MS}_i - S_i$ low level

where:

$\overline{MS}_i$ – the mean value of the synthetic measure,

S_i – standard deviation of the synthetic measure.

The use of this scheme made it possible to identify groups of countries with a similar level of SDG 9 development in 2023.

4. SDG 9 Indicators

Sustainable development indicators for the European Union are developed by a reliable institution, Eurostat, in cooperation with national statistical offices of the member states and other EU institutions.

In this study, a ready-made set of Eurostat indicators assigned to SDG 9 was used. These indicators serve as a key tool for monitoring progress in achieving the goals, enabling analyses at the international, national, and regional levels (Raczkowska et al., 2024).

The following variables were proposed to assess the implementation of Sustainable Development Goal 9:

X1 – Gross domestic expenditure on R&D by sector [sdg_09_10],
X2 – R&D personnel by sector [sdg_09_30],
X3 – Patent applications to the European Patent Office by applicants' / inventors' country of residence [sdg_09_40],
X4 – Share of buses and trains in inland passenger transport [sdg_09_50],
X5 – Share of rail and inland waterways in inland freight transport [sdg_09_60],
X6 – Air emission intensity from industry [sdg_09_70],
X7 – Tertiary educational attainment by sex [sdg_04_20],
X8 – Gross value added in environmental goods and services sector [sdg_12_61],
X9 – High-speed internet coverage, by type of area [sdg_17_60].

The values of the variables were obtained from Eurostat via the website: https://ec.europa.eu/eurostat/data/database.

Within the research and development & innovation area, the following four indicators were analyzed: Gross domestic expenditure on R&D (X1), Research and development personnel (X2), Patent applications to the European Patent Office by applicants' country of residence (X3), and Tertiary education attainment of the population (X7).

In the sustainable industry area, two indicators were analyzed: Air emission intensity from industry (X6) and Gross value added in the environmental goods and services sector (EGSS) (X8).

In the sustainable infrastructure area, the following indicators were considered: Share of buses and trains in passenger transport (X4), Share of railways and inland waterways in inland freight transport (X5), and Broadband Internet coverage (X9).

Variables X1-X5 and X7-X9 are stimulants, while only variable X6 is a destimulant.

The variables were also checked for completeness. Missing data for Cyprus and Malta regarding variable X5 led to its removal from the set of indicators.

The calculated values of the coefficient of variation for the proposed variables across the 27 EU countries ranged from 18.5% for variable X9 to 234.4% for variable X6. Therefore, the variables met the criterion of an appropriate level of variability.

The application of the inverse correlation matrix method made it possible to assess the correlations between the variables (Table 1).

Table 1.
Inverse matrix

	X1	X2	X3	X4	X6	X7	X8	X9
X1	**6.882**	-6.203	-1.236	-0.527	0.051	0.094	0.852	-0.102
X2	-6.203	**7.582**	0.582	0.109	-0.248	-0.222	-1.905	0.204
X3	-1.236	0.582	**1.452**	0.338	0.244	0.172	-0.106	-0.044
X4	-0.527	0.109	0.338	**1.381**	0.544	0.391	-0.037	-0.094
X6	0.051	-0.248	0.244	0.544	**1.304**	0.292	0.162	-0.252
X7	0.094	-0.222	0.172	0.391	0.292	**1.340**	-0.311	-0.353
X8	0.852	-1.905	-0.106	-0.037	0.162	-0.311	**1.975**	-0.168
X9	-0.102	0.204	-0.044	-0.094	-0.252	-0.353	-0.168	**1.152**

Source: Author's own elaboration.

The data presented in Table 1 indicate that the examined variables are not strongly correlated with each other and therefore do not replicate similar information.

5. Results

Using the proposed linear ordering methods, i.e., the zero unitarization method and TOPSIS, rankings of EU countries in terms of SDG 9 implementation were constructed. Applying Scheme 15, the EU countries were also classified into groups with a similar level of achievement of the examined goal. The results are presented in Table 2.

Table 2.
Ranking of EU Countries by Synthetic Measure Values in 2023

	Country	MS_i	Group	Country	MST_i	Group
1	Sweden	0.734	I. high level	Sweden	0.641	I. high level
2	Denmark	0.698		Germany	0.634	
3	Belgium	0.691		Denmark	0.612	
4	Germany	0.670		Austria	0.602	
5	Austria	0.669		Finland	0.598	
6	Netherlands	0.658		Belgium	0.594	
7	Luxembourg	0.657		Netherlands	0.566	
8	Finland	0.643		Luxembourg	0.537	II. medium-high level
9	France	0.591	II. medium-high level	France	0.503	
10	Ireland	0.580		Ireland	0.454	
11	Spain	0.511		Hungary	0.438	

Cont. table 2.

12	Slovenia	0.465	III. medium-low level	Spain	0.423	III. medium-low level
13	Estonia	0.459		Slovenia	0.410	
14	Poland	0.453		Portugal	0.408	
15	Hungary	0.448		Estonia	0.388	
16	Malta	0.429		Czechia	0.380	
17	Czechia	0.419		Malta	0.380	
18	Italy	0.414		Poland	0.379	
19	Cyprus	0.401		Italy	0.364	
20	Slovakia	0.399		Romania	0.361	
21	Lithuania	0.386		Slovakia	0.352	
22	Greece	0.369		Bulgaria	0.302	IV. low level
23	Croatia	0.368		Croatia	0.299	
24	Latvia	0.345	IV. low level	Greece	0.294	
25	Portugal	0.341		Cyprus	0.292	
26	Romania	0.322		Latvia	0.279	
27	Bulgaria	0.320		Lithuania	0.267	

Source: Author's own elaboration.

The results obtained using the two linear ordering methods – the zeroed unitaryzation method and the TOPSIS method – allow for a comparison of the positions of European countries in terms of SDG9 implementation in 2023.

A high level of the analyzed composite phenomenon, according to the zeroed unitaryzation method, was achieved by eight countries: Sweden, Denmark, Belgium, Germany, Austria, Netherlands, Luxembourg, and Finland. Three countries – France, Ireland, and Spain – were classified in the group with a medium-high level of SDG9 implementation. The largest group, consisting of 12 countries, showed a medium-low level of SDG9 implementation. Latvia, Portugal, Romania, and Bulgaria occupied the lowest positions in the EU country ranking.

The TOPSIS method similarly orders EU countries in terms of SDG9 implementation. Some shifts between groups were observed for certain countries. The largest changes concerned the following countries: Portugal (25th place according to the zeroed unitaryzation method, but 14th place in TOPSIS – an increase of 11 positions), Romania (26th place vs. 20th place), Bulgaria (27th place vs. 22nd place), Cyprus (19th place vs. 25th place), and Lithuania (21st place vs. 27th place – a drop of 6 positions).

The consistency of the rankings obtained using the zeroed unitaryzation and TOPSIS methods was also assessed using Spearman's rank correlation coefficient. The obtained value of 0.8993 indicates a high similarity between the rankings generated by both methods.

6. Discussion

The implementation of the Sustainable Development Goals (SDGs) outlined in the 2030 Agenda requires coordinated actions in three key areas: social, economic, and environmental. Effective achievement of these goals necessitates continuous monitoring, which allows for an objective assessment of progress. In recent years, particular attention in the scientific community has focused on Goal 9 (SDG 9), concerning the development of infrastructure, industry, and innovation, as well as the possibilities for its practical implementation.

The analysis of the research results presented in this article indicates that the level of SDG 9 implementation in European Union countries is not uniform. The highest performance was observed in northern, particularly Scandinavian, countries, while the lowest levels were recorded in southern European countries, especially those that joined the EU in 2004 or later, such as Romania and Bulgaria. Poland falls into the group of countries with a medium-low level of SDG 9 implementation. The results obtained are consistent with findings from other authors, despite the use of different research methods.

An example of such analyses is the study by Fura et al. (2025), who assessed the level of digital transformation in the areas of industry, innovation, and infrastructure in 27 EU countries in 2015 and 2020. The authors developed an aggregated indicator, the Digital Transformation Assessment Indicator (DTAI), measuring countries' progress in achieving SDG 9. The results showed that the highest values were observed in Scandinavian countries and highly developed nations such as Austria, Germany, and the Netherlands, both in 2015 and 2020. The lowest indicators were recorded in Romania, Greece, Malta, Cyprus, and Portugal. The study confirmed that the greatest challenges in implementing SDG 9 occur in Central, Eastern, and Southern European countries, while the leaders remain the Scandinavian and Western European states. Among the new EU members, Slovenia achieved a high ranking, while among former Eastern Bloc countries, Lithuania ranked highest (in the present study — Hungary). Romania and Bulgaria consistently occupied the lowest positions.

A similar topic was addressed by Burhan (2024), who analyzed the implementation of SDG 9 in EU countries and Turkey (2020) using an integrated MCDM approach, combining objective criterion weighting with VIKOR and MAIRCA techniques. Excluding Turkey, Sweden achieved the highest score, while Greece and Croatia scored the lowest.

Another significant study was conducted by Brodny and Tutak (2023), who evaluated the level of sustainable development in the EU-27 countries (SDG 9) based on 14 specific indicators between 2015 and 2020. They employed MCDM methods (TOPSIS, WASPAS, EDAS) to construct the indicator and used Entropy, CRITIC, and standard deviation (SD) methods to determine weights. Analysis using non-parametric Spearman's tau and Kendall tests examined the relationships between SDG 9 and economic, environmental, energy, and digitalization indicators. The results confirmed substantial differences between EU countries. The highest levels of SDG 9 achievement were observed in Denmark, Germany, Luxembourg, the Netherlands, Finland, and Sweden, while the lowest were in Bulgaria, Greece, Portugal, and Lithuania. The study also allowed for a temporal comparison between the "old" and "new" EU member states.

The consistency of the above findings with previous studies (Szopik-Depczyńska et al., 2018; Stanujkic et al., 2020; Hametner, Kostetckaia, 2020; Ozkaya et al., 2021; Kuc-Czarnecka et al., 2023) confirms the reproducibility of the results. These authors, using various research methods, indicated that the leaders in implementing SDG 9 are countries in Northern Europe (Sweden, Denmark, Finland) and Western Europe (Germany, the Netherlands, Belgium), while the lowest positions are occupied by Southern European countries, such as Greece, Croatia, Bulgaria, and Romania.

7. Conclusions

Innovation, industrialization and infrastructure development (issues included in Goal 9 of Agenda 2030) are closely intertwined and play an important role in building sustainable economic prosperity for societies around the world. They are therefore a fundament for ensuring sustainable and peaceful development of the world (Brodny, Tutak, 2023).

A comparative analysis of EU countries in terms of SDG 9 implementation in 2023 indicates that the highest performance is achieved by the Nordic countries, including the Scandinavian Peninsula states such as Sweden, Denmark, and Finland, as well as Western European countries, including Germany, Belgium, and the Netherlands. In contrast, Eastern European countries, such as Romania, Bulgaria, and Greece, exhibit the lowest values of the analyzed indicators. The development model of these economies requires a comprehensive transformation toward sustainable growth, which will necessitate ongoing dialogue and close cooperation among all stakeholders directly or indirectly involved in this process. In this context, managers can identify best practices in individual countries, make informed strategic decisions, and implement corrective actions.

The applied research methods, namely the zero unitaryzation method and the TOPSIS method, produced similar rankings of EU countries in terms of SDG 9 implementation, as indicated by the high Spearman rank correlation coefficient.

The conducted analysis and obtained research results provide a significant contribution to deepening the understanding of SDG 9 implementation under the 2030 Agenda in European Union member states, encompassing issues of innovation, industrial development, and infrastructure. These findings can serve as a solid foundation for formulating long-term development strategies for the European Union, as well as for shaping public policies that support digital transformation, the adoption of modern technologies in the industrial sector, and the expansion of digital and transport infrastructure. Consequently, these actions can contribute to enhancing the global competitiveness of the European economy.

The research results also provide policymakers with valuable diagnostic information, enabling them to monitor progress and identify areas requiring intervention. Countries lagging in SDG 9 implementation—particularly in Central, Eastern, and Southern Europe—can benefit from support programs tailored to their specific needs, including digital infrastructure development and investments in education and human capital. Such actions can contribute to ensuring the sustainable development of the entire European Union.

Furthermore, the study's conclusions can support the effective allocation of EU funds and resources to maximize their impact and ensure that all member states have the opportunity to fully achieve the goals outlined in the 2030 Agenda, including Sustainable Development Goal 9. Thus, the obtained results constitute a valuable source of knowledge that can support decision-making processes and the design of targeted actions in key areas of SDG 9.

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