VERİMLİLİK DERGİSİ
JOURNAL OF PRODUCTIVITY

Sustainability in Industry, Innovation and Infrastructure: A MCDM Based Performance Evaluation of European Union and Türkiye for Sustainable Development Goal 9 (SDG 9)

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ABSTRACT
Purpose: The aim of this study is to perform two distinct cross-country evaluations including European Union (EU) countries and Türkiye, focusing on Sustainable Development Goal 9 (SDG 9): Industry, innovation and infrastructure. The study aims to obtain rankings that display the relative standings of countries and identify areas for potential enhancement.
Methodology: An integrated objective criteria weighting, VIKOR, and MAIRCA based Multi-Criteria Decision Making (MCDM) approach has been employed.
Findings: Based on the first analysis, high speed internet coverage (HSI) and the share of rail and inland waterways in inland freight transport (SRI) were prominent criteria, and in the MCDM analysis, Sweden displayed the highest performance, while Greece and Croatia showed the lowest performance. In the second analysis, which included Türkiye, tertiary educational attainment (TEA) criteria stood out; while, Sweden maintained its leading position. Türkiye initially had poor performance in the early years but later improved, reaching a mid-level position among 26 countries by 2020. However, a significant decline in performance was observed in the last two years. In addition, during the handled period Türkiye witnessed a decline in both the number of patent applications and the share of buses and trains in inland passenger transport. Thereby, novel policies and incentives could be formulated to overcome these issues.
Originality: Two distinct cross-country analyses were conducted in accordance with the SDG 9 by adopting the most recent data and an integrated methodology. Within this context, EU countries were compared both among themselves and with Türkiye, and valuable findings were presented.
Keywords: Sustainable Development Goals, SDG 9, Objective Criteria Weighting, VIKOR, MAIRCA.
JEL Codes: C60, O30, R11.

Sanayi, İnovasyon ve Altyapıda Sürdürülebilirlik: 9. Sürdürülebilir Kalkınma Hedefi (SKH 9) Açısından Avrupa Birliği ve Türkiye'nin ÇKKV Temelli Performans Değerlendirmesi

ÖZET
Amaç: Bu çalışmanın amacı, Avrupa Birliği ülkeleri ve Türkiye için iki farklı değerlendirme yapmak ve Sürdürülebilir Kalkınma Hedefi 9 (SKH 9): Sanayi, inovasyon (yenilikçilik) ve altyapı üzerinde odaklanarak ülkelerin göreceli performanslarını ve potansiyel iyileştirme alanlarını sergileyen sıralamalar elde etmektir.
Yöntem: Bu çalışmada bütünleşik nesnel kriter ağırlıklandırma, VIKOR ve MAIRCA temelli Çok Kriterli Karar Verme (ÇKKV) yaklaşımı benimsenmiştir.
Bulgular: İlk analizde yüksek hızlı internet kapsamı ile kara taşımacılığında demiryolları ve su yollarının payı öne çıkan kriterler olarak belirlenirken, ÇKKV analizinde İsveç'in en yüksek performansı, Yunanistan ve Hırvatistan'ın ise en düşük performansı gösteren ülkeler olduğu görülmüştür. İkinci analizde Yükseköğrenim Eğitim Düzeyi en önemli kriter olarak belirlenirken, yine İsveç lider konumunu korumuştur. Ele alınan dönemin ilk yıllarında kötü bir performans gösteren Türkiye, sonrasında ilerleme kaydetmiş, 2020 yılında 26 ülke arasında orta düzeyde bir konuma ulaşmıştır. Öte yandan son iki yılda Türkiye'nin genel performansı ve patent başvurularının sayısı ile karayolu ve demiryolu taşımacılığındaki otobüs ve tren payında bir düşüş yaşandığı görülmüş olup, bu doğrultuda yeni politika ve teşvikler geliştirilebilir.
Özgünlük: Çalışmada en güncel veriler ve bütünleşik bir metodoloji benimsenerek 9. sürdürülebilir kalkınma hedefi doğrultusunda iki ayrı ülkeler arası analiz yapılmış, bu bağlamda Avrupa Birliği ülkeleri hem kendi içinde hem Türkiye ile karşılaştırılmış ve elde edilen önemli bulgular paylaşılmıştır.
Anahtar Kelimeler: Sürdürülebilir Kalkınma Hedefleri, SKH 9, Objektif Kriter Ağırlıklandırma, VIKOR, MAIRCA.
JEL Kodları: C60, O30, R11.

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DOI: 10.51551/verimlilik.1333767
Research Article |Submitted: 27.07.2023 |Accepted: 13.10.2023
Cite: Burhan, H.A. (2024). "Sustainability in Industry, Innovation and Infrastructure: A MCDM Based Performance Evaluation of European Union and Türkiye for Sustainable Development Goal 9 (SDG 9)", *Verimlilik Dergisi,* Productivity for Innovation (SI), 21-38.

1. INTRODUCTION

Sustainable development (SD) which has gained widespread popularity as an objective for many societies in the 21st century, can be portrayed as the means to achieve a wide array of positive and desirable goals. The initial definition of the notion of SD was introduced in the Brundtland Report of 1987 by the World Commission for Environment and Development (WCED), as the endeavor to fulfill the requirements of the present generation while protecting the interests and well-being of future generations (WCED, 1987). In 2015, the United Nations (UN) General Assembly introduced the 2030 development agenda titled "Transforming Our World: The 2030 Agenda for Sustainable Development" including 17 Sustainable Development Goals (SDGs) (UN, 2015). This agenda and the designated SDGs hold significant importance as the global population is projected to increase from the current 8 billion to 8.55 billion by 2030 (UN, 2022). Thereby, it can be clearly stated that SD, which is inherently linked with innovation, creativity, and productivity, will form the foundation for supporting the world population. In addition, the SDGs introduce these 17 non-legally binding objectives to address economic, social, and environmental aspects of sustainability; nevertheless, it was anticipated that governments will assume responsibility and create country-level plans to attain them. These main indicators involve a broad spectrum of topics, ranging from poverty, inequality, health, industry, innovation, climate action, and others. Furthermore, it is also stated that, in certain instances, the fulfillment of one SDG target is a prerequisite for the attainment of another SDG (Le Blanc, 2015). However, it is also a well-known fact that neglecting the interconnectedness of SDGs and adopting a fragmented approach to target fulfillment may lead to unintended adverse outcomes for countries. For instance, it is stated that prioritizing energy access through coal usage to boost the access to energy (SDG 7) could compromise SDG 13 and SDG 14 (climate action and life below water goals respectively) (Nilsson et al., 2016). Therefore, through harmonious and synergistic actions that minimize trade-offs, the SDG agenda is considered to have the potential to fulfill its objectives effectively.

On the other hand, as not all UN indicators were relevant in the European Union (EU) context, the union determined its SDG indicators which align with various EU policy initiatives (EU, 2023a). The implementation of the SDGs within the EU has been influenced by these several significant policy documents such as 2016's "Next Steps for a Sustainable European Future: European Action for Sustainability", the "Towards a Sustainable Europe by 2030" report of 2019, in addition to strategy and target plans such as the "European Green Deal" in 2019, "Circular Economy Action Plan" of March 2020, and the 2030 Climate Target Plan, etc. (EU, 2023a). In this respect, the EU also presented the first instance of a voluntary review in July 2023, which includes comprehensive and item-by-item evaluation of the collaborative endeavors undertaken by the EU in pursuit of the implementation of the SDGs (EU, 2023b). According to this review report, it is stated that since 2015, the EU has exhibited advancements in all SDGs, albeit not consistently and as per the latest available data in the Eurostat portal, it is mentioned that the EU excelled in ensuring sustainable employment and economic growth, alleviate poverty, and promoting peace (EU, 2023b). Moreover, as economies strive for SD, industrialization has progressed in various nations. While it plays a significant role in fostering economic growth, its consequences vary according to a country's level of development. For instance, in developed economies, industrial growth hinges on the adoption of cutting-edge technologies and mitigate the impact of industrial activities on ecosystems and the climate; on the other hand, for developing economies, industrialization entails transitioning from traditional sectors to a modern industry centered on infrastructure, technology and innovation (Kynčlová et al., 2020). Hence, it can be clearly stated that the primary concern for many countries centers on interlinking industry, innovation, and infrastructure to successfully accomplish SDGs, as it is seen that the innovation brought by the technological progressions of the Fourth Industrial Revolution (Industry 4.0) have profoundly transformed countries and society, (Frankelius, 2009; Silvestre and Ţîrcă, 2019). Additionally, a crucial aspect in the advancement of economies involves establishing a stable infrastructure involving various transportation modalities such as roads, railways, waterways, airways, etc. (Yin, 2019; Stoenoiu, 2022). However, although infrastructure plays a pivotal role for nations, it is noted that the incorporation of state-of-the-art technologies into planning, development, and implementation of the infrastructures lags behind other sectors, whereas limited or inadequate access to infrastructure, encompassing transportation, energy, and information and communication technology (ICT) is perceived as an obstacle to development (Bose et al., 2019). Thereby, it can be stated that regarding both domestic and international links, infrastructure assumes a crucial role in fostering investment generation and attraction, supporting economic development and advancement, and facilitating global integration (Haghshenas and Vaziri, 2012; Zhou, 2012; Alonso et al., 2015).

However, as technologies are not exogenous to environmental and social structures, their impact is also particularly evident. Furthermore, recent events, including the COVID-19 pandemic, global supply chain interruptions, and the energy crisis resulting from Russia's military attacks against Ukraine, have significantly affected the well-being of millions of households, impeding business activities, and revealed vulnerabilities in current social protection and healthcare systems (EU, 2023b). It is also stated that these crises have further intensified the effects of the Fourth Industrial Revolution on employment, competition, trade, digitization, skills, and it has also brought attention to the separation between global economic and environmental systems and the capacity of society to cope with challenges (Schwab and Zahidi, 2020). In this context, it can be asserted that SDGs provide a comprehensive and multidimensional perspective on the development and well-being of nations (Pradhan et al., 2017). Moreover, in line with the above mentioned aspects, one particular SD goal, SDG 9, attracts significant attention. With 8 sub-targets (9.1 to 9.5 and 9.A to 9.C) included, SDG 9 can be succinctly summarized as fostering the development of durable and eco-friendly infrastructure, promoting inclusive and environment-conscious industrialization, and acknowledging the crucial role of research and innovation in addressing social, economic, and environmental challenges (EU, 2023a). Furthermore, the EU SDG 9 includes 9 indicators (6 main, 3 multi-purpose indicators) namely, gross domestic expenditure on research and development (R&D), R&D personnel, patent applications to the European Patent Office (EPO), tertiary educational attainment, share of busses and trains in inland passenger transport, share of rail and inland waterways in total freight transport, air emission intensity from industry, gross value added in the environmental goods and services sector and high speed internet coverage (EU, 2023a). By considering the recently published voluntary review, between 2015 and 2022, the EU's innovation performance witnessed a 9.9% increase; while, expenditure on R&D showed modest growth, rising from 2.02% to 2.26% between 2011 and 2021 (EU, 2023b). Furthermore, over the past 15 years, there was a notable increase of 10,000 patent applications from within the EU submitted to the EPO, while the proportion of individuals aged 25 to 34 with a university degree or equivalent rose from 28.9% to 42.0% (EU, 2023a). Additionally, during the same period, the air emissions intensity of the EU's manufacturing sector declined by 36.4%, noteworthy improvements in high capacity network connectivity were observed in the EU in recent years, however, the share of buses and trains in inland passenger transport decreased to 12.8% in 2020, down from 17.5% in 2019 (EU, 2023a).

When evaluated from the perspective of Türkiye, it is specified in the current 11th National Development Plan (NDP) for 2019-2023 that cultivating SD and promoting inclusive growth require a well-coordinated implementation of efficient economic policies to ensure a stable economy, alongside social policies that foster harmony within society (PSB, 2019a). By considering the SDG 9, available official reports and latest statistics indicate that, in Türkiye, the proportion of R&D expenditure in gross domestic product (GDP) rose from 0.51% in 2002 to 1.40% in 2021 (TSI, 2023b). Moreover, in 2021, 93.0% of enterprises utilized fixed broadband connections, and during the 2018-2020 period, 38.5% of enterprises with ten or more employees were classified as innovation-active (TSI, 2021a; TSI, 2021b). In addition, it is stated that total greenhouse gas (GHG) emissions for the year 2021 exhibited a 7.7% increase compared to the previous year, while based on the 2017 data, the railway's contribution to domestic freight transportation was 4.1%, and its share in passenger transportation was 1% (PSB, 2020; TSI, 2023a). As of 2022, Türkiye 's existing railway network spanned around 13,000 km, with anticipated substantial expansions in the length of electrified and signalized tracks through ongoing projects (TSI, 2023c). Aside from the NDPs and strategic plans of pertinent public institutions, crucial policies and strategies concerning SDG 9 encompass the 2023 Türkiye Export Strategy, Information Society Strategy, National Broadband Strategy, Energy Efficiency Strategy, Combined Transportation Strategy, and action plans (PSB, 2019b).

Furthermore, in the past decade, multi-criteria decision-making (MCDM) methods have gained considerable attention from researchers. As a subfield of operational research, MCDM methods allows decision-makers to make informed choices while considering various and sometimes conflicting criteria, and applied in various areas such as engineering, business, management, also issues of SD (Sousa et al., 2021). In addition, a critical aspect of the MCDM process involves prioritizing the criteria, which is often referred to as the weighting process. This step can be accomplished through subjective weighting, where experts handle the process, or through objective weighting, which relies on the values of the quantities associated with the criteria. However, subjective criteria weighting methods tend to be less preferred due to a variety of factors. These include their time-consuming nature, inherent subjectivity, vulnerability to manipulation, as well as concerns regarding transparency and the potential oversight of critical criteria (Radulescu and Radulescu, 2018; Odu, 2019).

In this context, this study enables assessments of progress towards SDG 9 among both EU countries and Türkiye for 2013-2022 period by utilizing objective criteria weighting approaches and MCDM analysis in which two different methods were compared. By means of the notable and intensive efforts of the EU in tracking and monitoring the SDG indicators, the datasets provided by Eurostat were included in the study. Due to the lack of Cyprus and Malta country data, 25 of the EU countries and all SDG 9 indicators were included in the first analysis. For this initial one, the Criteria Importance Through Intercriteria Correlation (CRITIC) objective criteria weighting method was used because of conflicting criteria. For the second analysis, Türkiye is added to the country list; however, the number of indicators was reduced to 5 because of data constraints. Since there were not any conflicting criteria in this dataset, the Entropy method was used. According to Opricovic (2007) and Taherdoost and Madanchian (2023), the VIKOR method is highly effective in addressing multi-criteria decision-making (MCDM) problems, particularly when dealing with conflicting criteria. Additionally, it stands out for its straightforward ranking process, requiring only a minimal number of steps and eliminating the need for consistency checks. Furthermore, as pointed out by Qahtan et al. (2023), the MAIRCA method has demonstrated greater stability compared to other commonly used MCDM ranking methods and its ability to calculate the probability associated with each alternative can also be stated as the superiority of this method.Therefore, to provide an alternative approach in alignment with the methodologies found in existing literature and facilitate comparative analysis, this study employs both VIKOR and MAIRCA methods in its final phase. Due to the presence of missing values in the dataset, it is essential to regard the calculations for both criteria weighting and country rankings for the year 2022 as projections, since these analyses heavily rely on estimated average values derived from the given time period. Thereby, the objective of this study can be stated as to conduct two distinct cross-country assessments employing a methodology based on objective criteria-weighting and MCDM methods that will facilitate the ranking of countries in the context of SDG 9 in particular and demonstrate their placement in areas of progress. The remainder of the paper is organized as follows: The subsequent section comprises a review of the relevant literature. In the third section, a concise explanation of the employed methodology is presented. Section four encompasses two empirical analyses aimed at obtaining the rankings, along with the corresponding results. The final section provides an overview and brief analysis of these findings.

2. LITERATURE REVIEW

The United Nations (UN) policy framework for sustainable development (SD) endeavors to eradicate poverty, hunger, inequality, and address climate change by the year 2030, utilizing a set of goals known as the SD goals (SDGs). The achievement of these is anticipated to foster development and innovation while ensuring environmental preservation and enhancements in the quality of life for all living beings (Hák et al., 2016). As one of the significant goals, SDG-9 emphasizes the establishment of economies with inclusive industries, stimulating innovation, and ensuring sustainable and resilient infrastructure (Stoenoiu, 2022). In this respect, it can be stated that the impact of these three factors on SD has gained substantial attention in the literature in recent years. In addition, as Sousa et al. (2021) have highlighted the efficient utilization of Multi-Criteria Decision-Making (MCDM) methods in studies focusing on the SDGs in a comprehensive literature review.

Therefore, most related studies, in parallel with the content of this paper, are given as follows: Szopik-Depczyńska et al. (2018) conducted an evaluation of the innovation level among EU countries, utilizing Eurostat's indicators to monitor the progress of SDG 9 of the 2030 Agenda, employing the taxonomic measure of development. The analysis covered the data from 2010 to 2015, revealing that only three countries experienced growth in their innovativeness level: Sweden exhibited the most substantial increase, with an average annual growth of 1.09%, followed by the United Kingdom (0.76%) and Slovakia (0.72%). Hametner and Kostetckaia (2020) undertook a study based on the EU SDG indicator set to evaluate the progress of EU countries towards achieving the SDGs over a 15-year period. The assessment involved analyzing changes over time using both the compound annual growth rate (CAGR) and simple mean (SM) methods. The findings revealed that Sweden, the Netherlands, and Denmark exhibited simultaneous strong sustainable and unsustainable trends across the EU. Furthermore, significant progress was observed in addressing poverty alleviation (SDG 1) and promoting health and well-being (SDG 3). However, developments were less favorable in the economic and environmental dimensions of SD, particularly concerning the goals related to innovation, hence SDG 9. Stanujkic et al. (2020) employed a MCDM method, namely Combined Compromise Solution (CoCoSo), and Entropy to determine the positions of EU countries in relation to the SDGs during the period 2015-2018. Additionally, two more MCDM methods were used to validate the outcomes.The final results indicate that Sweden emerged as the top-performing country in implementing the SDGs, while Romania ranked last. Stoenoiu (2022) conducted an analysis utilizing nine indicators from SDG 9 to assess the performance of eight Eastern European countries in 2013 and 2019. A mathematical model was employed to test the proposed hypotheses and classify the countries based on their progress. The results revealed that Lithuania ranked first in industrialization for both 2019 and 2013, Estonia was the leader in research and innovation for both years, and in terms of infrastructure, Lithuania took the top spot in 2019, which Hungary led in 2013. Brodny and Tutak (2023) undertook an analysis of the EU-27 countries' level of SDG 9 using 14 indicators between 2015-2020. The study employed various MCDM methodologies including Evaluation based on Distance from Average Solution (EDAS), along with objective criteria weighting approaches. The results demonstrated significant variations among the countries in terms of their implementation of SDG 9. Denmark, Germany, Luxembourg, the Netherlands, Finland, and Sweden emerged as the most advanced in this aspect, while Bulgaria, Greece, Portugal, and Lithuania faced substantial challenges in their progress toward SDG 9. Kuc-Czarnecka et al. (2023) conducted an evaluation of the level of SDGs implementation in EU countries and investigated the interrelationships between goals using a composite indicator. The calculation of this indicator was based on an innovative method that incorporated sensitivity analysis (SA) tools and data from the Eurostat database for the year 2020. The results revealed the dominant presence of Scandinavian countries in the top positions, with Sweden securing eight and Denmark earning four (including three as the leader). Notably, the Netherlands stood out, occupying a superior position in terms of the performance of SDG 9.

Regarding studies involving Türkiye, Karaşan and Kahraman (2018) utilized a novel interval-valued neutrosophic EDAS method to assess the prioritization of UN's SDGs for Türkiye and determined the most crucial goal that should be addressed first. The results were also compared with an intuitionistic fuzzy Technique For Order Preference By Similarity To An Ideal Solution (TOPSIS) application and indicated that goals related to poverty were deemed the most significant among the SDGs for Türkiye. However, SDG 9 was ranked 14th out of 15 indicators. Ozkaya et al. (2021) evaluated 40 countries, primarily European, based on 115 science, technology, and innovation (STI) indicators (that are closely related with SDG 9) from 2019. Authors employed various MCDM approaches, and the countries were assessed within 10 dimensions and 115 criteria, which were determined based on data from organizations like the OECD, the World Bank, and the Global Innovation Indices (GIIs). The results revealed that Northern European countries emerged as the leading performers in the rankings based on STI indicators, with Switzerland, the Netherlands, and Germany also securing positions in the top ten. In contrast, Türkiye demonstrated comparatively low values in terms of the included STI indicators. Aytekin et al. (2022) conducted a comprehensive investigation comparing the global innovation efficiency of EU member and candidate countries, which is closely linked to SD and SDG 9. The study utilized the GII and employed Data Envelopment Analysis (DEA) and Efficiency Analysis Technique with Input and Output Satisficing (EATWIOS) methods, analyzing data from the year 2020. The results of the study highlighted the Netherlands, Germany, and Sweden as the top-performing countries in terms of global innovation efficiency. However, Türkiye ranked 20th out of the 32 countries, indicating potential areas for enhancement in its global innovation endeavors. Özarı et al. (2023) conducted a prospective analysis to project the advancement in nations' development by employing a hybrid model, which combined both MCDM and machine learning techniques. Initially, the M-EDAS method was applied to rank selected Asian countries based on their progress towards the SDGs during the years 2017–2020. Subsequently, in predicting the countries' development trajectory for 2019-2020, authors utilized key indicators like gross domestic product (GDP) per capita growth and total unemployment rate, employing the k-NN algorithm. The outcomes from the M-EDAS method revealed Singapore as the most developed country for 2017 and 2018, whereas Japan led the list for 2019 and 2020. On the other hand, Türkiye ranked 11th among 13 countries for 2017 and 2018, and 9th for 2019 and 2020.However, in the following k-NN phase, the predictions were accurate for Hong Kong, the Philippines, Japan, and Singapore. In contrast, the prediction for Türkiye was inaccurate.

Taking into account the works of Szopik-Depczyńska et al. (2018) and Stoenoiu (2022), it can be asserted that the primary objective of the first analysis in this study is to present an updated version using the most recent dataset and employing a distinct methodological approach. Similarly, by utilizing VIKOR and MAIRCA methods, this research offers an alternative analysis compared to the study conducted by Brodny and Tutak (2023), which employed TOPSIS, Weighted Aggregated Sum Product Assessment (WASPAS), and EDAS methods. Regarding the second analysis, which also includes Türkiye and the available dataset, this study aims to investigate Türkiye's current ranking in comparison to the EU countries. Thus, with a specific focus on SDG 9, this study contributes to the research conducted by Ozkaya et al. (2021) and Aytekin et al. (2022), both of which conducted cross-country performance evaluations encompassing European states and Türkiye using different methodologies, which are presented in this research.

3. DATA & METHODOLOGY

3.1. Data

The analysis and evaluation of the implementation of Goal 9 of the Agenda 2030 for sustainable development (SD) in the European Union (EU) countries and Türkiye were conducted using data from Eurostat's SD indicators dataset, specifically focusing on Goal 9: Industry, innovation, and infrastructure (SDG 9). Due to the lack of Cyprus and Malta country data, 25 of the EU countries were included in the analysis. The dataset comprised 9 criteria for the first; and 5 out of 9 for the second analysis. The selected time frame for the study covered years between 2013 and 2022. This timeframe was chosen to assess the years leading up to the 2030 Agenda. The criteria set with abbreviations is given in Table 1.

Table 1. Industry, innovation and infrastructure (SDG 9) criteria

No	*Criteria*	*Abbreviation*
1	Air emission intensity from industry	AEI
2	Gross domestic expenditure on research and development (R&D)	GDE
3	Gross value added in environmental goods and services sector	GVA
4	High-speed internet coverage	HSI
5	Patent applications to the European Patent Office	PA
6	R&D personnel	RDP
7	Share of buses and trains in inland passenger transport	SBT
8	Share of rail and inland waterways in inland freight transport	SRI
9	Tertiary educational attainment	TEA

Source: Eurostat

Firstly, a data preparation and pre-processing approach was conducted to handle missing values in the dataset following the data acquisition step. This phase involved using the Python programming language, and the Scikit-learn library's Simple Imputer class was utilized to address and handle the missing values present in the dataset mostly for 2022.

3.2. Methodology

3.2.1. Criteria Importance Through Intercriteria Correlation (CRITIC) Method

To ascertain the objective weights for the specified criteria, the CRITIC method, proposed by Diakoulaki et al. (1995), employs standard deviation and correlation values. The procedural steps of this method are outlined below (Žižović and Marinković, 2020):

- After establishing the decision matrix, the performance measures in this matrix are subjected to normalization through Equation 1.

$$x_{ij}^T = \begin{cases} \frac{x_{ij}-x_j^-}{x_j^+-x_j^-}, x_j^+ = \max\limits_i x_{ij}, x_j^- = \min\limits_i x_{ij} \\ \frac{x_j^- - x_{ij}}{x_j^+-x_j^-}, x_j^+ = \min\limits_i x_{ij}, x_j^- = \max\limits_i x_{ij} \end{cases} \quad (1)$$

where x_{ij}^T is the normalized value of *i*th alternative on *j*th criterion.

- Standard deviation values are computed for each criterion within the normalized matrix.
- The correlation of each criterion in the normalized matrix is also calculated.
- Using each element of the correlation matrix (r_{jk}), the measure of conflict of a given criterion concerning other criteria is computed using the formula provided below (Equation 2).

$$\sum_{j'=1}^{n}(1 - r_{jk}) \quad (2)$$

- By integrating the two aforementioned measures, the quantity of information contained within criterion j (C_j) is computed as in Equation 3.

$$C_j = \sigma \sum_{j'=1}^{n}\left(1 - r_{jk}\right), j = 1, \ldots, n \quad (3)$$

- To determine the weights of criteria (W_j), the sums of C_j values are computed as in Equation 4.

$$C_k = \sum_{k=1}^{m} C_j \quad (4)$$

- The criteria weights are obtained by the formula given below (Equation 5).

$$W_j = \frac{C_j}{\sum_{k=1}^{n} C_k}, j, k = 1, \ldots, n \quad (5)$$

3.2.2. Entropy Method

The entropy method, developed by C.E. Shannon was originally termed “information entropy” (Shannon, 1948). In essence, entropy serves as a parameter that measures the extent of differentiation between specific criteria (Cavallaro et al., 2016). As the entropy value increases, the entropy weight decreases, indicating that the alternatives are considered less distinguishable with respect to certain criteria (Wang and Lee, 2009). The steps involved in the entropy method are outlined below (Cavallaro et al., 2016; Li et al., 2020):

- The normalization of the decision matrix is carried out using Equation 6.

$$P_{ij} = \frac{x_{ij}}{\sum_i^m x_{ij}} \tag{6}$$

where x_{ij} represents the performance rating or value of the *i*th alternative with respect to the *j*th criterion.

- Entropy values E_j are computed for each criteria by Equation 7.

$$E_j = -k \sum_{j=1}^{n} P_{ij} \ \ln(P_{ij}) \tag{7}$$

where $k = \frac{1}{\ln m}$, *m* is the number of alternatives.

- Calculating the degree of divergence (d_j) value using Equation 8.

$$d_j = 1 - E_j \tag{8}$$

where larger the d_j values, moe important the *j*th criteria.

- Objective weights of the criterion are obtained by Equation 9.

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{9}$$

and the sum of all W_j should be equal to 1.

3.2.3. VIKOR Method

Opricovic and Tzeng (2002) introduced the VIKOR method, which stands for "VIseKriterijumska Optimizacija I Kompromisno Resenje," meaning multi-criteria optimization and compromise solution. This method aids decision-makers in reaching a final decision by identifying compromise solutions, which are feasible options closest to the ideal solution. The steps are given below (Devi, 2011; San Cristóbal, 2011):

- Identify the best (r_j^+) and the worst $\left(r_j^-\right)$ values for all criterion functions (Equation 10), where *j* = 1, 2, ..., n. If the *j*th function represents a benefit (maximization criteria), then,

$$r_j^+ = \max_i r_{ij},\ r_j^- = \min_i r_{ij} \tag{10}$$

otherwise (non-beneficial criteria) the reverse applies.

- S_i and R_i values are calculated by Equations 11 and 12.

$$S_i = \sum_{j=1}^{n} \frac{w_j\left(r_j^+ - r_{ij}\right)}{r_j^+ - r_j^-} \tag{11}$$

$$R_i = \max_j \frac{w_j\left(r_j^+ - r_{ij}\right)}{r_j^+ - r_j^-} \tag{12}$$

where W_j are the criteria weights.

- The Q_i values are obtained by the Equation 13.

$$Q_i = \frac{\vartheta(S_i - S^+)}{S^- - S^+} + (1 - \vartheta)\frac{R_i - R^+}{R^- - R^+} \tag{13}$$

where $S^+ = \min_j S_i$, $S^- = \max_j S_i$, $R^+ = \min_j R_i$, $R^- = \max_j R_i$,

the weight ϑ is assigned to represent the strategy of 'the majority of criteria' (or 'the maximum group utility'), and in this case, it is set as ϑ = 0.5.

- The alternatives are ranked based on their preference order determined by the value of Q_i. The alternative with the smallest Q_i value is identified as the optimal choice if the following two conditions are satisfied:
    1. Acceptable advantage: $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ$, where $DQ = \frac{1}{j-1}$, j is the number of alternatives and $A^{(2)}$ is the second best alternative.
    2. Acceptable stability in decision making: The alternative $A^{(1)}$ must also achieve the highest ranking in terms of S_i and/or R_i. If any of the conditions is not met, a set of compromise solutions is proposed, including:

Alternatives $A^{(1)}$ and $A^{(2)}$ are chosen if only the second condition is not met. Alternatives $A^{(1)}$, $A^{(2)}$, ... $A^{(j)}$ are chosen by the relation $Q(A^{(j)}) - Q(A^{(1)}) < DQ$ for maximum *j* until it is satisfied.

3.2.4. Multi-Atributive Ideal-Real Comparative Analysis (MAIRCA) Method

The MAIRCA method, introduced by Pamučar et al. (2014) primarily relies on the disparity between the ideal and real solutions. The method's steps are outlined below (Trung and Thinh, 2021; Günay and Ecer, 2022):

- Once the decision matrix is constructed, the preference values of alternatives (P_{Aj}) are obtained using Equation 14.

$$P_{Aj} = \frac{1}{m} \text{ and } \sum_{i=1}^{m} P_{Aj} = 1, i = 1, \dots, m \quad (14)$$

where *m* is the number of alternatives.

- Theoretical ranking matrix (K_p) is obtained by Equation 15.

$$K_p = P_{Aj} * W_j \quad (15)$$

where W_j is the weight of the *j^th^* criteria.

- By the use of the normalized decision matrix (x_{ij}^T) in equation (1), and K_p values in equation (15), actual evaluation matrix is computed by Equation 16.

$$K_r = K_{pij} * x_{ij}^T \quad (16)$$

- This is followed by the calculation of the gap matrix (F) as in Equation 17.

$$F = K_p - K_r \quad (17)$$

- Considering the alternatives, the criteria function values are determined using Equation 18.

$$Q_i = \sum_{j=1}^{n} f_{ij} \quad (18)$$

- Finally, the alternatives are ranked based on the ascending order of the Q_i values to determine the best option.

4. EMPIRICAL FINDINGS

This study includes two separate analyses intended for evaluating and comparing the progress towards SDG 9 among EU countries solely, as well as including both EU countries and Türkiye, for the period 2013-2022. The steps of the both analysis is given below in Figure 1.

Figure 1. Steps of the performed analysis

Following the outlined steps in Figure 1, in this study, firstly, the necessary datasets were collected, and missing values were handled. In the Analysis 1, to address conflicting criteria, the CRITIC method was employed to derive the criteria weights. As all criteria were beneficial, weights were calculated by the Entropy method in the Analysis 2. In continuation, the rankings of countries based on SDG 9 criteria for both analysis were determined through the application of both VIKOR and MAIRCA methods. In addition, after each MCDM applications, a sensitivity analysis (SA) including the Equal Weights Method (EWM) is conducted.

To assess the robustness and reliability of outcomes generated by MCDM models, SA serves as a valuable tool. However, it's worth noting that in the literature, the utilization of SA in the context of MCDM models varies, with some researchers incorporating it into their analyses while others do not (Delgado and Sendra, 2004). The literature has introduced a range of approaches, exemplified by Demir and Arslan (2022), which encompass techniques like adjusting criterion weights, altering the order of criteria, and cross-comparing outcomes across various MCDM methods. According to Al Garni and Awasthi (2020), the SA helps collecting valuable insights into the reliability and robustness of the results, ultimately enhancing the transparency and trustworthiness of the decision-making process. Also the EWM in particular present a valid methodology due to its simplicity and transparency and makes it easier to comprehend how alterations in criteria weights influence the decision Kumar et al. (2021). In this context EWM and the cross-comparisons with two different MCDM methods has been applied in this study.

The criteria weighting values derived from the CRITIC method for Analysis 1 are provided in Table 2.

Table 2. Weights of the SDG 9 criteria during 2013-2022

Criteria	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022ᵅ*
AEI	0.092	0.099	0.093	0.090	0.091	0.086	0.086	0.090	0.093	0.093
GDE	0.113	0.110	0.109	0.112	0.105	0.106	0.103	0.106	0.111	0.108
GVA	0.103	0.103	0.104	0.102	0.099	0.103	0.103	0.098	0.106	0.103
HSI	0.127	0.133*	0.135*	0.139*	0.147*	0.152*	0.141	0.129	0.124	0.131
PA	0.081	0.082	0.083	0.083	0.081	0.079	0.079	0.081	0.081	0.082
RDP	0.112	0.109	0.106	0.104	0.104	0.101	0.097	0.099	0.098	0.103
SBT	0.108	0.105	0.111	0.110	0.110	0.116	0.123	0.125	0.110	0.114
SRI	0.131*	0.129	0.131	0.132	0.135	0.133	0.142*	0.154*	0.155*	0.143*
TEA	0.129	0.126	0.124	0.124	0.122	0.119	0.121	0.115	0.119	0.119

* The highest value, ᵅ Projection based on estimated values

Based on the findings presented in Table 2, the analysis reveals that the criteria set obtained close values. However, two criteria, namely high-speed internet coverage (HSI) and the share of rail and inland waterways in inland freight transport (SRI), emerge as the most significant factors among others. Notably, HSI obtained the top ranking from 2014 to 2018, while SRI held the first position from 2019 to 2022, as well as in 2013. Additionally, the criterion of tertiary educational attainment (TEA) stands out as another important factor during the observed period.

In the subsequent stage of the research, the progress towards SDG 9 among EU countries was evaluated and compared using the VIKOR and MAIRCA methods. The outcomes obtained through the VIKOR method are presented in Table 3.

Based on the results, Sweden exhibited the best performance, followed by the Netherlands and Finland. On the other hand, Germany experienced a sharp ascent and secured a position among the top three starting from 2019, while Greece, Ireland, Croatia were the lowest performing ones. Considering the acceptable advantage and stability conditions, with the exception of the year 2021, these conditions were met for all the years. In 2021, all the top-three ranked countries were identified as the best performer, since the first condition was not satisfied.

Based on the outcomes derived from the SA, the top three countries remained largely consistent with the VIKOR application, comprising Sweden, Finland, and the Netherlands. Additionally, Greece and Croatia maintained their positions as the lowest-performing countries. The rankings obtained by the second MCDM application, namely MAIRCA are given in Table 4.

Upon reviewing Table 4, it can be observed that Sweden and Germany consistently secured top rankings throughout the analyzed period. Notably, Denmark held a top-three position between 2015 and 2018, while the Netherlands took over this position in 2019. Croatia and Greece exhibited the poorest performances and were ranked at the bottom two positions.

According to the results obtained from the second SA conducted for the MAIRCA results, the rankings of the countries remained relatively similar throughout the analyzed period, including Sweden, Germany, Denmark, and the Netherlands in top performing level, while Greece and Croatia consistently occupying the lowest positions in the rankings.

Table 3. Country rankings based on the VIKOR method between 2013-2022

Countries	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022$^{\alpha}$
Austria	16	14	16	17	17	17	18	4	5	9
Belgium	18	21	21	22	22	23	5	6	6	6
Bulgaria	17	15	14	15	14	18	14	11	16	18
Croatia	23	24	24	23	23	22	20	19	20	21
Czechia	13	17	15	14	12	10	16	16	14	10
Denmark	8	7	5	4	7	5	9	15	18	11
Estonia	5	5	6	5	5	6	8	8	8	7
Finland	**2***	**2***	**2***	**3***	**3***	4	4	5	4	4
France	9	10	7	8	8	7	12	17	13	13
Germany	10	12	11	11	16	16	**3***	**3***	**1***	**3***
Greece	25	25	25	25	25	25	25	25	25	25
Hungary	12	11	12	12	13	11	13	10	10	14
Ireland	22	22	23	24	24	24	24	24	24	24
Italy	24	23	22	21	21	19	23	22	22	22
Latvia	4	4	4	6	4	**3***	6	7	7	5
Lithuania	11	6	9	9	10	13	19	20	12	17
Luxembourg	6	9	10	10	9	8	11	12	15	15
Netherlands	**3***	**3***	**3***	**2***	**2***	**2***	**2***	**2***	**3***	**2***
Poland	21	20	20	19	18	12	7	13	11	12
Portugal	15	16	17	16	15	15	17	18	19	19
Romania	20	19	19	20	20	21	21	21	21	20
Slovakia	14	13	13	13	11	14	15	14	17	16
Slovenia	7	8	8	7	6	9	10	9	9	8
Spain	19	18	18	18	19	20	22	23	23	23
Sweden	**1***	**1***	**1***	**1***	**1***	**1***	**1***	**1***	**2***	**1***

* Indicating top three countries, $^{\alpha}$ Projection based on estimated values

Table 4. Country rankings based on the MAIRCA method between 2013-2022

Countries	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022$^{\alpha}$
Austria	13	12	12	12	12	13	15	9	8	12
Belgium	11	13	13	13	13	12	5	4	4	9
Bulgaria	23	21	21	21	21	22	19	19	22	23
Croatia	25	25	25	25	25	24	24	24	24	24
Czechia	16	15	15	17	16	16	18	21	21	17
Denmark	5	4	**2***	**2***	**2***	**3***	4	5	6	4
Estonia	6	7	8	8	8	7	10	11	12	8
Finland	4	5	7	6	7	9	9	6	7	7
France	8	8	6	7	6	5	8	7	5	6
Germany	**2***	**3***	**3***	**3***	**3***	**2***	**3***	**2***	**1***	**2***
Greece	24	24	24	24	24	25	25	25	25	25
Hungary	14	16	18	18	17	17	17	15	16	16
Ireland	17	18	22	22	22	23	22	16	17	21
Italy	22	23	23	23	23	21	23	23	20	22
Latvia	**3***	**2***	4	4	5	4	6	10	11	5
Lithuania	12	10	10	11	10	10	14	13	14	13
Luxembourg	9	9	9	9	9	8	7	8	9	10
Netherlands	7	6	5	5	4	6	**2***	**3***	**3***	**3***
Poland	20	20	19	19	18	18	13	18	18	20
Portugal	18	17	17	15	15	15	16	12	10	14
Romania	19	19	16	16	19	20	21	20	19	18
Slovakia	21	22	20	20	20	19	20	22	23	19
Slovenia	10	11	11	10	11	11	11	14	13	11
Spain	15	14	14	14	14	14	12	17	15	15
Sweden	**1***	**1***	**1***	**1***	**1***	**1***	**1***	**1***	**2***	**1***

* Indicating top three countries, $^{\alpha}$ Projection based on estimated values

After reviewing the relevant literature to compare the outcomes of the Analysis 1, it's clear that the findings of the initial analysis are consistent with those of several previous studies, including the research by Szopik-Depczyńska et al. (2018), Hametner and Kostetckaia (2020), Stanujkic et al. (2020), Brodny and Tutak (2023), and Kuc-Czarnecka et al. (2023). In the second analysis, Türkiye was added to the country list, and the number of indicators was reduced to 5 due to data constraints. The criteria weighting values obtained by the Entropy method for Analysis 2 are given in Table 5.

Table 5. Weights of the selected SDG 9 criteria during 2013-2022

Criteria	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022α*
GDE	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.204
PA	0.168	0.169	0.170	0.170	0.170	0.170	0.170	0.171	0.172	0.173
RDP	0.207	0.206	0.206	0.206	0.206	0.207	0.207	0.207	0.206	0.206
SBT	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.207	0.207	0.207
TEA	0.209*	0.209*	0.208*	0.209*	0.208*	0.208*	0.208*	0.208*	0.208*	0.208*

* The highest value, α Projection based on estimated values

According to the results presented in Table 5, the analysis revealed that the majority of criteria in the set exhibit close values, with the exception of the Patent applications to the European Patent Office (PA) criterion. However, TEA stands out as the most noteworthy criterion among all other. In the subsequent stage, the evaluation and comparison of progress towards SDG 9 among both EU countries and Türkiye were conducted utilizing the VIKOR and MAIRCA methods. The results derived from the VIKOR method are presented in Table 6.

Table 6. Country rankings based on the VIKOR method between 2013-2022

Countries	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022α*
Austria	15	4	4	4	4	5	4	6	5	6
Belgium	6	6	5	5	5	6	6	4	4	5
Bulgaria	22	21	19	19	23	22	22	23	24	22
Croatia	21	22	22	20	20	19	20	20	21	20
Czechia	12	11	11	13	11	11	11	11	13	13
Denmark	**2***	**2***	**2***	**2***	**3***	**3***	5	5	6	4
Estonia	14	15	16	15	15	17	15	18	18	16
Finland	5	5	6	6	8	7	7	7	8	7
France	4	**3***	**3***	**3***	**2***	**2***	**2***	**2***	**1***	**3***
Germany	**3***	10	7	7	7	4	**3***	**3***	**3***	**2***
Greece	16	16	15	16	16	16	17	13	15	15
Hungary	13	14	14	14	17	14	16	15	14	14
Ireland	8	9	9	10	10	10	10	10	10	9
Italy	20	23	24	23	21	21	21	21	19	19
Latvia	19	20	21	24	25	23	24	24	23	23
Lithuania	23	18	20	22	24	25	25	25	25	25
Luxembourg	7	7	8	9	9	9	9	9	9	10
Netherlands	9	8	10	8	6	8	8	8	7	8
Poland	17	17	17	17	14	15	14	16	17	17
Portugal	24	25	25	25	22	24	23	22	16	24
Romania	26	26	26	26	26	26	26	26	26	26
Slovakia	18	19	18	18	18	18	18	19	20	18
Slovenia	10	12	13	11	12	13	13	14	11	12
Spain	11	13	12	12	13	12	12	12	12	11
Sweden	**1***	**1***	**1***	**1***	**1***	**1***	**1***	**1***	**2***	**1***
Türkiye	25	24	23	21	19	20	19	17	22	21

* Indicating top three countries, α Projection based on estimated values

It can be observed that Sweden and France are the best performing countries, and Denmark also exhibited a high performance. In line with the VIKOR outcomes from Analysis 1, Germany demonstrated an increase and attained a position among the top three countries in 2019. Romania, Portugal, Bulgaria and Latvia were the countries with the weakest performances. On the other hand, Türkiye, which exhibited poor performance in the first three years, showed improvement and climbed to the 17th position by the year 2020. However, in the last two years, a decline was observed.

Taking into account the accepatable advantage and stability conditions, except for the years 2017 and 2021, these were met throughout the analyzed period. In those years, both top two ranked countries (Sweden and France) were selected as the best performer, as the first condition was not fulfilled. Drawing insights from SA applied in Analysis 2, which encompasses Türkiye, the rankings of the countries exhibited similarity to the VIKOR results, with France, Germany, and Sweden consistently occupying leading positions; Türkiye in positions between 15th and 19th, and Romania and Bulgaria retainiing their positions as the countries with the lowest performance. The rankings obtained from the MAIRCA application are presented in Table 7.

Table 7. Country rankings based on the MAIRCA method between 2013-2022

Countries	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022$^{\alpha}$*
Austria	10	5	4	4	4	4	**3***	4	4	4
Belgium	6	8	7	7	5	5	5	**3***	**2***	5
Bulgaria	24	24	24	24	25	25	25	25	25	25
Croatia	25	25	25	25	24	24	24	23	24	24
Czechia	12	12	12	12	11	11	11	12	12	12
Denmark	**1***	**1***	**1***	**2***	**2***	**3***	4	5	5	**3***
Estonia	15	16	18	15	15	15	15	20	19	15
Finland	**3***	**3***	5	5	7	8	7	6	8	8
France	5	6	6	6	6	6	6	7	6	6
Germany	4	4	**3***	**3***	**3***	**2***	**2***	**2***	**3***	**2***
Greece	18	18	16	17	16	16	17	14	16	16
Hungary	13	13	13	13	13	13	13	13	13	13
Ireland	8	9	10	10	10	10	10	10	10	10
Italy	20	19	21	20	20	19	20	16	14	17
Latvia	19	20	22	22	23	23	23	24	23	23
Lithuania	17	14	17	18	21	21	21	21	21	21
Luxembourg	7	7	9	8	9	9	9	9	9	9
Netherlands	9	10	8	9	8	7	8	8	7	7
Poland	16	17	15	16	14	14	14	18	18	18
Portugal	23	23	23	23	22	22	22	19	17	22
Romania	26	26	26	26	26	26	26	26	26	26
Slovakia	22	22	19	21	18	20	19	22	22	20
Slovenia	11	11	11	11	12	12	12	11	11	11
Spain	14	15	14	14	17	17	16	17	15	14
Sweden	**2***	**2***	**2***	**1***	**1***	**1***	**1***	**1***	**1***	**1***
Türkiye	21	21	20	19	19	18	18	15	20	19

* Indicating top three countries, $^{\alpha}$ Projection based on estimated values

It is evident that Sweden consistently achieved the top position after 2016. Remarkably, Denmark secured top-three positions between 2013 and 2018, and Germany from 2015 to 2022. Austria ranked 3rd in 2019, and Belgium obtained the 3rd and 2nd positions in 2020 and 2021, respectively.

Conversely, Türkiye consistently ranked around the 20th position for the entire analyzed period, with the exception of 2020. According to the the SA, Germany, Sweden, and Denmark maintained top positions, while Türkiye appeared between 15th and 21st, Romania and Bulgaria occupied the lowest positions. It can also be stated that obtained results align with the findings of Ozkaya et al. (2021) and Aytekin et al. (2022), which identified Sweden, Germany, and the Netherlands as the leading countries and Türkiye as a weak performer.

The outlook of Türkiye, based on country rankings derived from the VIKOR analysis, in comparison to the top and bottom ranked countries, is presented below in Figure 2.

According to the given statistics and findings, it can be stated that between 2013 and 2020 Türkiye exhibited a significant improvement in performance based on gross domestic expenditure on R&D (GDE), PA, number of R&D personnel (RDP), share of buses and trains in inland passenger transport (SBT), and TEA compared to worst performing countries.

However, in between 2020 and 2021, there was a notable decline in performance, and its position regressed to the levels observed in 2016. The status of Türkiye, as determined by the country rankings obtained from the MAIRCA analysis, in relation to the top and bottom ranked countries, is depicted in Figure 3.

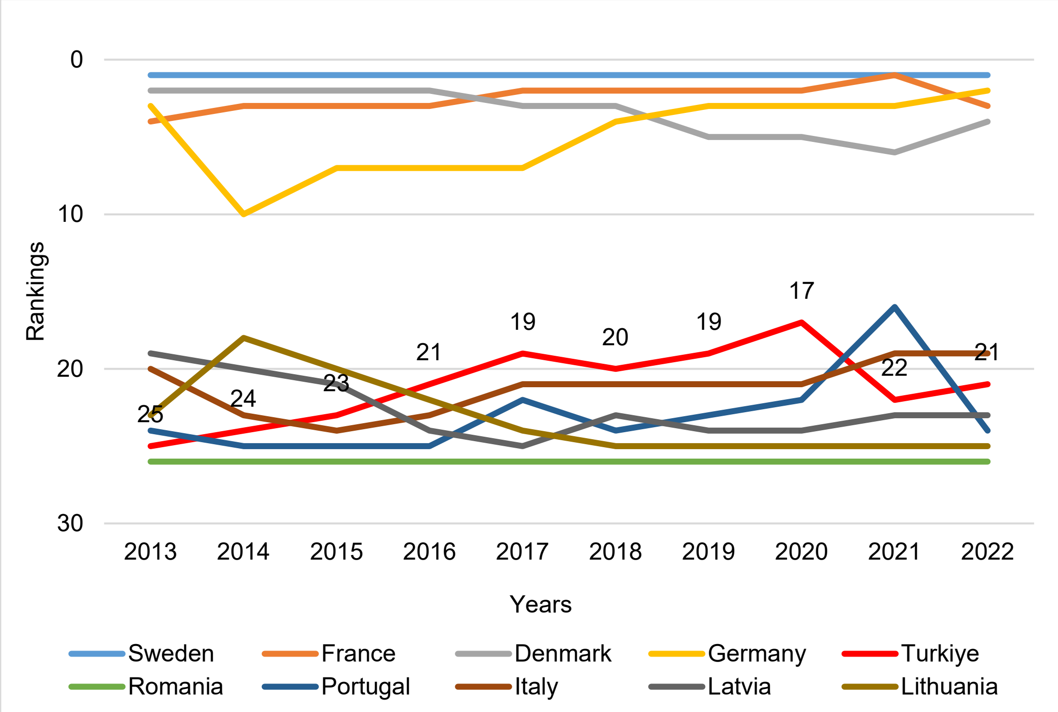

Figure 2. Performance comparisons based on VIKOR

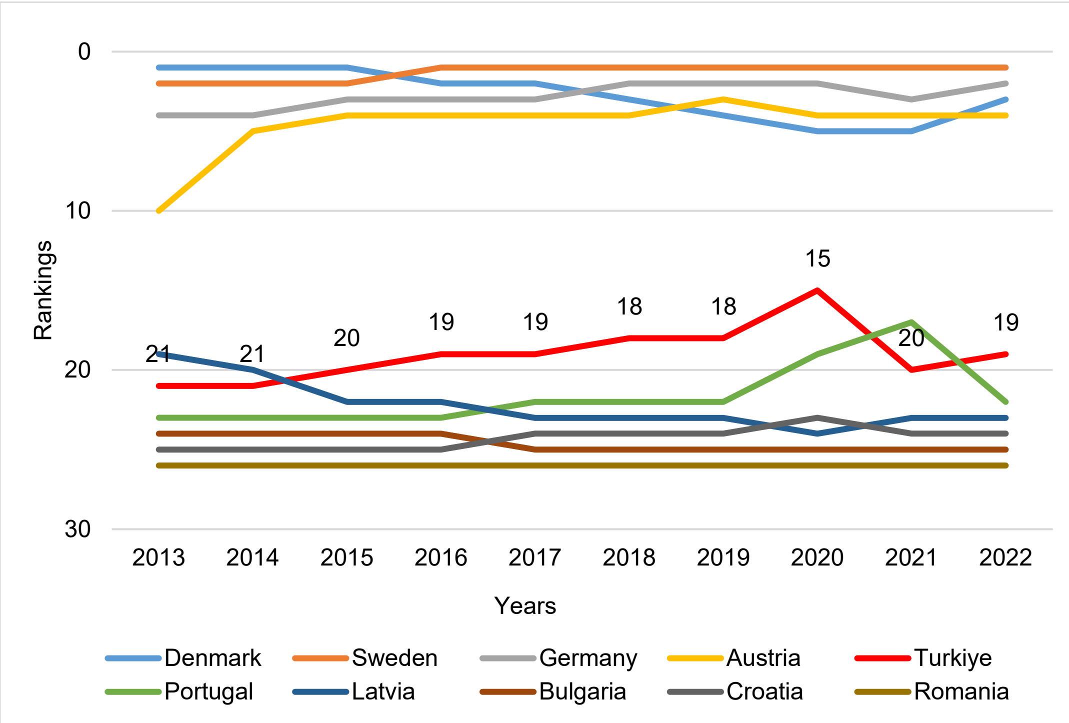

Figure 3. Performance comparisons based on MAIRCA

In line with the VIKOR results, it is evident that Türkiye demonstrated substantial performance improvement between 2013 and 2020 concerning the given criteria, as compared to lowest performers. However, during the period between 2020 and 2021, a significant decline in performance was observed, causing its position to regress to the levels observed in 2016.

5. DISCUSSION and CONCLUSION

Since the initial introduction of the concept of sustainable development (SD) in the Brundtland Report of 1987, it has gained widespread recognition as a crucial objective. In line with the United Nations (UN)'s 2030 Agenda and the establishment of 17 sustainable development goals (SDGs), the European Union

(EU) has also identified its SDG indicators.These primary indicators encompass a wide range of subjects, spanning from climate action to poverty, inequality, innovation, etc. Considering that SD is inherently intertwined with innovation, creativity, and productivity, it is evident that industrialization and infrastructure play a vital role in promoting development due to their ability to stimulate and attract investments. In this respect, among 17 indicators, SDG 9 (Industry, innovation and infrastructure) targets advancing the establishment of resilient and sustainable infrastructure, acknowledging the pivotal role of research and innovation, and encouraging inclusive and environmentally-aware industrial growth (EU, 2023a). In an EU context, the monitoring of SDG 9 encompasses various elements, including high-speed internet coverage, research and development (R&D) intensity and personnel, air emissions intensity of industry, patent applications, and modal splits in passenger and freight transport and as presented in the first chapter, it is stated that the EU has made significant advancements in SDG indicators over the years. By considering the SDG 9, the EU has also achieved noteworthy progress, such as the implementation of the Trans-European Transport Network (TEN-T) policy to establish an efficient EU-wide multimodal network of roads, railway lines, inland waterways, substantial climate action-related expenditures of approximately EUR 9.9 billion in 2021/22, and the development of IRIS2 (Infrastructure for Resilience, Interconnectivity, and Security by Satellite) to enhance communication capacities for governmental and business users (EU, 2023b). Concerning Türkiye's SDG 9 progress, it is evident that there has been an increase in gross domestic expenditure on R&D, the number of R&D personnel, and tertiary educational attainment. However, there are significant decreases in both the share of buses and trains in inland passenger transport compared to previous years and the number of patent applications to the European Patent Office in 2022 compared to 2021, as reported by the EU statistics office (Eurostat, 2023).

In this respect, the study utilized an objective criteria weighting and Multi-Criteria Decision Making (MCDM) approach to evaluate countries based on various SDG 9 criteria, by including two separate analyses aimed at assessing and comparing the progress towards SDG 9. One analysis focused solely on EU countries, while the other included both EU countries and Türkiye. The evaluation covered the period from 2013 to 2022 and it is important to note that the presence of missing values in the dataset necessitated considering the calculations for criteria weighting and country rankings for the year 2022 as projections as they are predominantly relying on estimated average values derived from the given time period. Based on the findings from the first analysis, the CRITIC method identified high-speed internet coverage (HSI) and the share of rail and inland waterways in inland freight transport (SRI) criteria as the most influential factors among others. According to the results of VIKOR and MAIRCA applications in the first analysis, Sweden demonstrated the most outstanding performance among the countries in relation to SDG 9. The Netherlands, Germany, Denmark, and Finland also attained notable rankings. Conversely, Greece and Croatia can be identified as the countries with the lowest performances. In light of the second analysis which includes Türkiye, the Entropy method indicated that most of the criteria in the set demonstrated similar values, except for the patent applications to the European Patent Office (PA) criterion. Nonetheless, tertiary educational attainment (TEA) consistently emerged as the most significant criterion, drawing notable attention among all other. Regarding the MCDM applications, Sweden remained the top performer in both applications, with Denmark and Germany also demonstrating a high level of performance. In contrast to the results of the first analysis, France exhibited effective performance during the handled period. Türkiye, after initially showing poor performance in the early years of the dataset, demonstrated improvement and managed to reach a mid-level position among 26 countries by the year 2020. However, a significant decline in performance was observed in the last two years. Taking into account the diverse sets of criteria in both Analysis 1 and 2, it can be concluded that, upon comparison, objective weighting mostly produced similar results. Additionally, the MCDM applications yielded close outcomes in both separate analyses, which can be seen as mutual validation. When comparing both analyses, it becomes evident that Sweden and Germany consistently held top rankings throughout the entire study period. Thereby, taking the approaches and applications of SDG-9 in these countries as exemplary models can be recommended, especially for nations that consistently ranked at the bottom in both analyses, such as Greece, Croatia, Bulgaria, and also Türkiye.

Upon examining the relevant literature to compare the outcomes of our initial analysis, it is evident that the findings of this paper align with those of several previous studies. Notably, Szopik-Depczyńska et al. (2018) and Stanujkic et al. (2020) also observed Sweden as the best performer. Similarly, the works of Hametner and Kostetckaia (2020), Brodny and Tutak (2023), and Kuc-Czarnecka et al. (2023) supported the notion that Sweden and Denmark, along with the Netherlands, Germany, and Finland, held the top positions in terms of performance. When related studies in the literature is revisited to compare obtained results in the second analysis, it becomes apparent that this study corroborates the work of Ozkaya et al. (2021). Similar to their findings, Northern European countries emerged as the leading performers in the rankings concerning SDG 9 criteria, with the Netherlands and Germany also maintaining top positions. In contrast, Türkiye demonstrated comparatively lower values. Furthermore, the results in this paper are also consistent with those of Aytekin et al. (2022), who found that the Netherlands, Germany, and Sweden were standouts as top-performing countries, while Türkiye exhibited weaker performance.

The study's contribution lies in its incorporation of the most recent data and adoption of an MCDM approach, thus enriching the existing literature on SDGs, particularly SDG 9, which has been explored by various previous studies utilizing similar methodologies. Furthermore, this study contributes to the academic literature by conducting two separate evaluations of EU countries and Türkiye using empirically validated indicators, two different objective criteria weighting approaches and well-known decision-making methods, while also providing significant insights into the comparison of Türkiye with EU countries in the context of SDG 9, contributing to the understanding of the re-generated Türkiye-EU relations of 2023’s. On the other hand, this study has certain notable limitations. Firstly, it focuses solely on one aspect of the SDGs, namely SDG 9, which are known to be interconnected according to the related literature. Additionally, the presence of missing values in the dataset necessitated data preprocessing, potentially influencing the final results. Moreover, the methodology employed in this study utilized only two MCDM methods, overlooking other methods available in the literature. Furthermore, the second analysis had to reduce the number of indicators to 5 due to data availability constraints, leading to an incomplete assessment of the EU-Türkiye comparison concerning SDG 9. Regarding the policy implications of this research, which validates the suitability of the adopted methodology for evaluating countries' performance with respect to SDGs, the proposed assessment model holds relevance for decision-makers, policymakers, academics, experts, and officials involved in related domains. On the other hand, the proposed model and methodology can prove valuable to policymakers and government officials aligning with the objectives of the 11th development plan aimed at achieving SDGs, especially those related to industry, innovation, and infrastructure. Particularly concerning the criteria included in the second analysis, new policies and incentives can be developed for the share of buses and trains in inland passenger transport and the number of patent applications, which experienced a decline in Türkiye during the period under study. Ultimately, the findings of this study may contribute to cross-country evaluations, especially in the context of the current reinvigorated Türkiye-EU relations. For the future researches, it is recommended to incorporate a comprehensive set of SDG indicators and/or other relevant variables pertaining to industry, innovation, and infrastructure, which have been validated by existing literature, thereby more extensive datasets for conducting similar performance analyses. Additionally, expanding the scope of this study can be achieved by exploring alternative and integrated approaches such as data mining, multi-criteria decision-making (MCDM), and even machine learning methodologies.

Conflict of Interest

No potential conflict of interest was declared by the author.

Funding

Any specific grant has not been received from funding agencies in the public, commercial, or not-forprofit sectors.

Compliance with Ethical Standards

It was declared by the author that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement

It was declared by the author that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

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