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EU INDUSTRIAL DEVELOPMENT AND INNOVATION PERFORMANCE ASSESSMENT UNDER SDG 9: A LOPCOW BASED COCOSO APPLICATION

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ABSTRACT

Sustainable development in today's world offers an opportunity to foster economic growth, technological advancement, and social progress without compromising the ability of future generations to meet their own needs. The 2030 Agenda for Sustainable Development outlines 17 goals and 169 tasks to guide this progress. The implementation of SDG 9 is critically significant in this context, and this paper aims to investigate it. This study assesses the performance of EU countries in developing robust infrastructure, promoting sustainable industry, and fostering innovation—key aspects of SDG 9. Multi-Criteria Decision-Making (MCDM) methods are employed in this assessment. The analysis is based on 11 indicators. The LOPCOW technique is used to determine the relative importance of these indicators, while the CoCoSo method is applied to rank the EU countries' performance on SDG9. According to the LOPCOW results, the most important criteria for assessing EU countries' SDG 9 performance are rural population access to all-season roads (%) and the income gap in internet access (percentage points). The CoCoSo method reveals Denmark has the best SDG 9 performance among EU countries. Sweden and Finland are ranked second and third, respectively. In contrast, Hungary, the Slovak Republic, and Lithuania exhibit the lowest SDG 9 performance scores.

Keywords: Innovation performance assessment, sustainable development, SDG 9, LOPCOW, CoCoSo.

SDG 9 KAPSAMINDA AB ENDÜSTRİYEL KALKINMA VE YENİLİKÇİLİK PERFORMANSI DEĞERLENDİRMESİ: LOPCOW TABANLI COCOSO UYGULAMASI

ÖZ

Günümüz modern dünyasında sürdürülebilir kalkınma, gelecek nesillerin yeteneklerini sınırlamadan ekonomide büyümeyi, teknolojik ilerlemeyi ve sosyal gelişmeyi sürdürme fırsatıdır. Sürdürülebilir Kalkınma için 2030 Gündemi, bu ilerlemeyi yönlendirecek 169 görev ile 17 temel hedefe sahiptir. Gündem 2030'un 9. hedefinin ülkelerde uygulanma düzeyi bu bağlamda kritik öneme sahiptir ve bu makalede sunulan çalışma bunu araştırmayı amaçlamaktadır. Bu araştırma, AB ülkelerinin sağlam altyapı geliştirme, sürdürülebilir endüstriyi destekleme ve inovasyonu teşvik etme konusundaki performansını değerlendirmeyi içerir; bunların hepsi SDG9'un temel yönleridir. Bu değerlendirmede ÇKKV yöntemleri kullanılmıştır. Analiz 11 göstergeye dayanmaktadır. Bu göstergelerin göreceli önem düzeylerini belirlemek için LOPCOW tekniği kullanmış ve AB ülkelerinin SDG 9 performans sıralaması CoCoSo yöntemi kullanılarak elde edilmiştir. LOPCOW sonuçlarına göre, AB ülkelerinin SDG 9 performansını değerlendirmede en önemli kriterler kırsal nüfusun tüm mevsimlerde yollara erişilebilirliği (%) ve internet erişimindeki gelir farkıdır (yüzde puan). CoCoSo bulgularına göre Danimarka AB ülkeleri arasında en iyi SDG 9 performansına sahip ülke olarak tespit edilmiştir. İsveç ve Finlandiya sırasıyla ikinci ve üçüncü sırada yer almaktadır. Macaristan, Slovak Cumhuriyeti ve Litvanya en düşük SDG 9 performans puanlarına sahip ülkeler olarak belirlenmiştir.

Anahtar Kelimeler: İnovasyon performansı değerlendirmesi, sürdürülebilir kalkınma, SDG 9, LOPCOW, CoCoSo.

Introduction

Rapid population growth and increasing environmental stresses are two fundamental challenges to global development. Economic progress is closely linked to energy consumption, leading to a significant rise in CO2 emissions. However, mitigating CO2 emissions is quite costly (Fernández-Amador et al., 2017). In this context, energy sustainability strategies, which focus on slowing global energy consumption growth by reducing energy demands in industrial production, are gaining attention. Economic growth should be accompanied by technological advancements and the efficient use of natural resources (Chen et al., 2020).

The "Transforming our world: The 2030 Agenda for Sustainable Development" was adopted by the United Nations General Assembly on November 25, 2015. This agenda emphasizes achieving sustainable development (SD) for everybody by fostering collaborative relationships at every level. The new goals and targets, collectively known as the Sustainable Development Goals (SDGs), took effect on January 1, 2016. They will serve as the primary reference point for development strategies integrating sustainability in all its dimensions—economic, social, and environmental—by 2030. The 2030 Agenda provides a comprehensive framework for development, resulting in potential synergies or trade-offs among the 17 Goals (Kynčlová et al., 2020).

The SDG-9 index offers a comprehensive yet straightforward approach to analyzing countries' progress in industrialization while promoting social inclusion and reducing natural resource use and environmental impact. The subheading defines SDG 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation". The indicators were selected based on the United Nations General Assembly's global indicator framework for the 2030 Agenda's goals and ambitions (Kynčlová et al., 2020). This goal highlights the need for sustainable industrial innovation, long-term infrastructure investment, and the adoption of new technologies to ensure sustainable economic growth, social and grassroots development, and effective climate action (Küfeoğlu, 2022).

SD is a complex process that may be assessed using a set of indicators representing various dimensions. Evaluating countries' progress against multiple targets across different dimensions can be challenging. Therefore, policymakers and analysts need to assess a country's relative position on each key target. In this regard, evaluating countries based on different SDGs is crucial for identifying weaknesses and highlighting successful policy approaches.

MCDM methods evaluate a set of alternatives based on multiple, usually competing, preference criteria, enabling decision-makers to make decisions that integrate all criteria and objectives simultaneously (Zavadskas & Turskis, 2011).

This study valuates EU countries' progress toward the 2030 Agenda's industry-related targets. The main idea is to provide an MCDM-based approach for assessing countries' performance related to SDG 9. The primary objective is to provide insights into the current state of the EU manufacturing industry in terms of innovation and environmental sustainability. The performance of EU countries in promoting sustainable industry, scientific research, and innovation is assessed using the 2024 sustainability reports. This evaluation comprises several conflicting criteria and is defined as an MCDM problem and is analyzed using the LOPCOW-supported CoCoSo method.

Using an integrated MCDM technique and the most recent data, this study compares EU countries based on SDG 9 and presents the key findings. The main objective of this study is to perform an assessment using an objective criteria-weighting approach and MCDM methodologies, which will help rank countries in the context of SDG 9. Studies evaluating countries' SD performances often take an integrated approach, addressing all SDG indicators. In contrast, this study solely evaluates countries' SDG 9 performance, using the 2024 SDG reports. It is crucial for providing comprehensive assessments of weaknesses and strengths, as well as areas for improvement, and is expected to contribute to the literature on SDG 9. A unique aspect of this research is that it is one of the few to employ the LOPCOW-supported CoCoSo approach for SDG performance analysis.

A combination of LOPCOW and CoCoSo techniques is developed in this study to analyze EU countries' SDG 9 performances. The LOPCOW method is an objective weight calculation procedure that does not require prior knowledge of the criteria and can effectively capture experts' hesitations during the preference-sharing process. Additionally, it has the advantage of significantly reducing the impact of extreme values by using a logarithmic operator (Ecer et al., 2023). The CoCoSo approach provides a simple computation procedure and a compromise solution for ranking alternatives in the presence of conflicting evaluation criteria. (Bağcı & Türkoğlu, 2023). Due to these advantages, these methods are preferred in this research.

The study is structured into five sections. The first section introduces the concept of SD and discusses its goals, focusing on the scope of SDG 9. The second section provides a review of the literature. The third section explains the study's methodology in detail. The fourth section presents the analytical procedure and the results. The final section offers the conclusion and suggestions for future research.

1. SD and SDGs

SD is defined as growth that meets the needs of the present without compromising the ability of future generations to meet their own needs. This concept requires collaborative efforts to build a fair, inclusive, and resilient world for both people and the planet. To achieve SD, three main components must be harmonious: economic growth, social inclusion, and environmental protection. These components are interconnected, and each plays a vital role in ensuring the well-being of individuals and societies.

The Millennium Development Goals (MDGs) were established during the 2000 United Nations Millennium Summit to highlight the importance of SD (Sena et al., 2024). The 2030 Agenda for Sustainable Development, adopted in 2015 by all United Nations Member States, outlines a shared framework for achieving peace and prosperity for both people and the planet, both now and in the future. The agenda encompasses 17 SDGs for both developed and developing countries. These goals aim to eliminate poverty and other deprivations, enhance health and education, reduce inequalities, promote economic growth, protect the environment, and combat climate change. The 17 SDGs address multiple concerns such as food, water, health, energy, climate, ecosystems, poverty, and innovation (Mantlana & Maoela, 2020).

The "End Poverty" goal is the first of the 17 goals, identified as SDG 1. Poverty is one of the world's most serious issues, caused by a shortage of resources needed to meet basic human survival needs. Poverty is no longer just a problem of limited income or resources; it has evolved into a human rights concern. As a result, the first SDG goal is linked to long-term poverty reduction efforts (Cabanillas-Carbonell et al., 2023).

The "Zero Hunger" goal is placed as the second of the 17 goals, identified as SDG 2. SDG 2 is a target within the broader agenda that aims to eliminate hunger and malnutrition, boost agricultural output, and improve food system sustainability (Fanzo, 2019).

SDG 3 aims to ensure good health and promote well-being for all people at all ages. This goal intends to ensure that everyone has access to safe and effective medications and vaccines (Sundewall & Forsberg, 2020).

SDG 4 focuses on providing high-quality education that is equitable and encourages lifelong learning opportunities for all. It seeks to enhance opportunities at all stages of education, including pre-primary, primary, secondary, vocational, further, and adult education (Unterhalter, 2019).

SDG 5 aims to promote gender equity and empower all girls and women. This goal also addresses women's unpaid labor, rights related to sexuality and reproduction, and gender-based violence (Hirsu et al., 2019).

SDG 6, "Clean Water and Sanitation", aspires to achieve universal access to water and wastewater services, along with sustainable water management. This includes investing in infrastructure, constructing sanitation facilities, and promoting cleanliness at all levels to ensure safe and accessible clean water for all by 2030 (Rajapakse et al., 2023).

SDG 7, which focuses on clean energy, calls for universal access to sustainable, reliable, and modern energy. It emphasizes using renewable energy resources, improving energy efficiency and developing sustainable energy infrastructures. This goal aims to ensure global energy availability, with a particular emphasis on generating a significant portion of energy from renewable sources (Estevão & Lopes, 2024).

SDG 8 aims to promote inclusive, equitable, and sustainable economic growth, full and productive employment, and decent work for all. Decent work entails job opportunities in which everyone is productive, earns fair wages, enjoys workplace safety, receives social protection for families, and has the potential for personal growth and social inclusion (Bieszk-Stolorz & Dmytrów, 2023).

SDG 9 seeks to support innovation, infrastructure development, and sustainable industrialization (Mavuri et al., 2019).

SDG 10 proposes strengthening the financial market regulations to reduce inequalities within and between nations. It also emphasizes the importance of directing development aid and foreign direct investment toward the most vulnerable areas. This goal highlights that equitable income distribution and inclusive growth can be achieved by eliminating discriminatory laws (Uche et al., 2024).

SDG 11 states that human settlements and cities should become more resilient, safe, and sustainable. In this context, the emphasis is on upgrading informal settlements, investing in transportation systems, and developing public green spaces (Berisha et al., 2022).

SDG 12 aims to reduce the ecological footprint by promoting sustainable production and consumption patterns. It calls for a reduction in per capita global food waste in the retail and consumer sectors by 2030 (Okayama et al., 2021).

SDG 13 calls for immediate action to prevent climate change and its impacts. This goal focuses on integrating climate change initiatives into national plans and strategies (Sena et al, 2024).

SDG 14 focuses on the protection and sustainable use of seas, oceans, and marine resources. It outlines several necessary improvements to the ocean economy (Armstrong, 2020).

SDG 15 outlines targets for safeguarding terrestrial ecosystems, promoting sustainable use, ensuring responsible forest management, combating desertification, and preventing biodiversity loss. It also aims to reverse the decline of life on Earth (Sayer et al., 2019).

SDG 16 focuses on promoting justice, peace, and strong institutions. This goal emphasizes justice, democracy, human rights, and equality (Razafindrakoto & Roubaud, 2018).

SDG 17, the final Global Goal, is centered on establishing partnerships to support the achievement of other SDGs. It includes targets related to international trade, technology transfer, debt sustainability, capacity building, and development aid (Cooper & French, 2018).

To achieve long-term economic growth, societal and cultural advancement, and address climate change, developing and low-income countries require sustained investments in infrastructure, sustainable industrial development, and innovative strategies. SDG 9 is built on three interrelated pillars: innovation, infrastructure, and industry (Mead, 2017). The development of industrialization through new technological advancements and innovative skills is proposed as the key to achieving sustainable economic growth while improving societal well-being (Küfeoğlu, 2022).

SDG 9 – "Build resilient structures, promote equitable and sustainable industrialization, and foster innovation" – consists of eight targets with twelve indicators. These core objectives include: developing sustainable, resilient, and inclusive infrastructure (9.1); promoting sustainable and equitable industrialization (9.2); expanding access to financial markets and services for small-scale industrial enterprises (9.3); upgrading environmentally friendly technologies and processes in industry (9.4); enhancing research and fostering innovative advancements (9.5); facilitating the sustainable construction of infrastructure in developing nations (9.6); supporting domestic technological and innovation advancements in developing countries (9.7); and providing universal access to information and communication technologies in least developed countries (9.8).

The percentage of rural residents who reside within 2 kilometers of an all-season road and the volume of passengers and freight transported by mode are among the indicators of the first target. The indicators of the second target are the value of manufacturing added as a percentage of GDP and per capita, and the employment in manufacturing as a percentage of total employment. The percentage of small-scale companies in the total industry value added and the percentage of small-scale enterprises with a loan or line of credit indicate the third target. The fourth target indicator is the CO2 emissions per unit value added. Development and research expenditure as a percentage of GDP and researchers per million inhabitants are indicators of the fifth target. The official international support for infrastructure is the sixth target indicator. The seventh target indicator is represented by the percentage of medium- and high-technology industries in the total value added, and the eighth target indicator is measured by the percentage of the population served by a mobile network (Sustainable Development Goals, 2025).

2. Literature Review

The SDGs aim to eradicate hunger and poverty globally by 2030, eliminate inequalities, address climate change, ensure access to quality education, and promote peace and justice. Achieving these goals, which will enhance the quality of life for all, requires a focus on fostering stable and sustainable economic growth, boosting productivity, and driving technological innovation (Hák et al., 2016). In this context, SDG 9, identified as one of the key goals, emphasizes the development of resilient infrastructures, creating inclusive and sustainable industries, and promoting innovation. The impact of these three factors on SD has garnered attention and has been a topic of study in recent years (Stoenoiu, 2022). The application of MCDM approaches in evaluating countries' progress toward achieving the SDG goals has become a popular area of research. Some studies conducted in recent years are presented below.

Dwivedi and Sharma (2025) employed Entropy and a novel sum-weighted information (SWI) approach to assess the success of SDGs across Indian states. The findings revealed that Kerala was the state making the most substantial progress in meeting the objectives outlined in "Agenda 2030".

Burhan (2024) proposed conducting assessments comprising Türkiye and the European Union (EU) countries, with an emphasis on SDG 9. The evaluation utilized the VIKOR and MAIRCA-based MCDM approaches. According to the findings, Sweden exhibited the highest performance, while Greece and Croatia displayed the lowest performance. Türkiye initially performed poorly but eventually showed improvement.

Yavuz and Esen (2024) evaluated the SD performance of countries from 2002 to 2021 using the Entropy-based ARAS technique. The findings emphasized that the countries with the best SD performance were Sweden, Finland, and Denmark.

Brodny and Tutak (2023) conducted research to assess EU countries' performance in building robust infrastructure, stimulating sustainable industry, and fostering innovation—key areas of Goal 9 of the 2030 Agenda. The Critic, Entropy, and standard deviation approaches were employed to weigh the criteria in the analysis process. EDAS, WASPAS, and TOPSIS techniques were then used to rank the countries. The findings showed that the countries with the highest SDG 9 performance were Denmark, Germany, Luxembourg, the Netherlands, Finland, and Sweden. In contrast, Bulgaria, Portugal, Greece, and Lithuania were found to have poor SDG 9 performance.

To evaluate the performance of Latin American countries, Goker et al. (2022) suggested a fuzzy MCDM approach that combines DEA with QFD. According to the results, Peru ranked first, followed by Chile and Costa Rica.

Aytekin et al. (2022) conducted a study comparing the global innovation efficiency of EU member and candidate countries, which is closely related to SDG 9. Based on 2020 data, this study employed DEA and the EATWIOS techniques. The results showed that the Netherlands, Germany, and Sweden had the best global innovation efficiency.

Ricciolini et al. (2022) employed and compared two different versions of the Multi Reference Point technique to assess the sustainability of EU states within the context of the 2030 Agenda. The results revealed that Nordic countries outperformed others. Sweden ranked first, followed by Denmark and Finland. In contrast, Romania, Bulgaria, and Greece exhibited the lowest performance.

Resce and Schiltz (2021) developed a novel method for assessing European nations' performance on the SDGs, called Hierarchical

Stochastic Multicriteria Acceptability Analysis (HSMAA). Regardless of the weights assigned to certain indicators and objectives, the results revealed that Denmark ranked first, while Bulgaria and Romania exhibited lower performance levels.

Based on the 2018 Logistics Performance Index rankings, Alkan and Merdivenci (2021) evaluated the SD performance of the top five countries (Japan, Germany, Sweden, Belgium, and Austria). The study was based on 20 economic, social, and environmental indicators grouped under the three basic dimensions of SD. The entropy-supported EDAS method was employed in the analysis process. Sweden ranked first in terms of SD, according to the research findings.

Torkayesh and Torkayesh (2021) employed an integrated MCDM approach to assess the performance of G7 countries in information and communication technology (ICT) development. The analysis utilized the LBWA and MARCOS techniques, evaluating six main criteria: ICT employment, ICT goods exports, ICT investment, ICT added value, and internet access. Access to computers and the internet, regarded as two fundamental elements of today's world, was identified as a key factor among the social sustainable development goals. The results suggested that the United States and Japan were the best countries in terms of ICT development, whereas countries such as Italy and Canada had the weakest performances.

Ozkaya et al. (2021) evaluated 40 countries based on 115 science, technology, and innovation indicators closely related to SDG 9. The study used Entropy, TOPSIS, VIKOR, PROMETHEE I-II, ARAS, COPRAS, MULTI-MOORA, ELECTRE, SAW, and MAUT techniques. Singapore, Sweden, Finland, and the United States were identified as the top five countries.

Allen et al. (2020) evaluated Australia's progress toward the SDGs. The assessment covered Australia's progress on 86 SDG targets and 144 associated indicators, selected through an expert-led, consultative approach. The findings revealed that Australia had mixed performance on the SDGs, achieving great success in education and health, but showing poor progress in climate action and inequality reduction.

Stanujkic et al. (2020) assessed the SD performance of EU countries using the Entropy-supported CoCoSo technique. The results highlighted Sweden as the country making the most substantial progress toward meeting the goals of Agenda 2030. Sweden, Denmark, Germany, France, and Finland achieved the most significant improvements in SDG performance between 2015 and 2018.

When reviewing the studies available in the literature, it becomes evident that they mostly analyze the SDG performances of countries using a set of complex indicators that address all aspects of SD. This study, which is conducted using the current 2024 SDG reports, focuses solely on evaluating countries' SDG 9 performances and is significant in terms of providing comprehensive assessments of weaknesses and strengths, as well as areas for improvement under this heading. It is expected to contribute to the literature in this context.

3. Methodology

This section provides an explanation of the MCDM approaches employed in the study, along with a detailed overview of the analytical procedures for each methodology.

3.1. LOPCOW Method

The LOPCOW (LOgarithmic Percentage Change-driven Objective Weighting) method is a contemporary objective criterion weighting technique developed by Ecer and Pamucar in 2022. Many researchers favor this method for several reasons, including its ability to handle negative and zero values in the initial decision matrix, accommodate a large number of evaluation criteria and selection alternatives, and address the highly skewed distribution of criteria weights that affect the true ranking positions (Biswas et al., 2024). The LOPCOW method involves the following steps (Ecer & Pamucar, 2022).

Step 1: Creation of the initial decision matrix.

Equation (1) defines the initial decision matrix for the problem, which includes *m* decision alternatives and *n* assessment criteria.

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}; i=1,2,...,m; j=1,2,...,n. \tag{1}$$

Step 2: Normalization of the initial decision matrix.

The linear normalization approach is utilized to normalize the initial decision matrix. Equation (2) is used for the benefit criteria, and Equation (3) is used for the cost criteria.

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}; \textit{for benefit criteria} \tag{2}$$

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}; \textit{for cost criteria} \tag{3}$$

Step 3. Calculation of criteria percentage values (PV).

In this stage, the mean square value of each criterion is calculated as a percentage of its standard deviation to eliminate the gap caused by the data size.

$$PV_{ij} = \left| \ln\left(\frac{\sqrt{\frac{\Sigma_{i=1}^{m} r_{ij}^2}{m}}}{\sigma} \right) * 100 \right| \tag{4}$$

Step 4: Determining the criteria weights (w_j).

The weight values of the criteria are calculated using Equation (5). The sum of the criteria weight coefficients must equal 1.

$$w_j = \frac{PV_{ij}}{\Sigma_{i=1}^{n} PV_{ij}} \tag{5}$$

3.2. CoCoSo Method

Yazdani et al. (2019) proposed the CoCoSo (COmbined COmpromise SOlution) technique, which bases the compromise decision-making algorithm on the integrated SAW (Simple Additive Weighting) and EWP (Exponentially Weighted Product) models (Qiyas et al, 2022). This approach combines mathematical and geometric weighting to solve MCDM problems. The basic principle is to use three different measurements to estimate the relative value of each alternative and then rank them accordingly. Combining these three aggregation methods makes the final evaluation outcomes more superior and reasonable. This method effectively incorporates multiple aggregation techniques to achieve internal balance, reduce variability in decision results, and solve the problem of biased results generated by a single-choice procedure (Zhu et al., 2023). Additionally, this approach allows operations on a decision matrix with negative-valued inputs without requiring special transformation. The following are the steps in the CoCoSo solution procedure (Yazdani et al, 2019):

Step 1. Establishing the initial decision matrix. This matrix is as shown in Equation (1).

Step 2. Normalization of the benefit and cost criteria. Equations (2) and (3) are used for this normalization depending on the type of criteria.

Step 3. The total weighted comparability sequence (S_i) of each alternative is determined by applying Equation (6). The power-weighted comparability sequence sum (P_i) for each alternative is obtained using Equation (7).

The (S_i) value is generated through a gray relational generating approach.

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \tag{6}$$

The (P_i) value is calculated using the Weighted Product Model (WPM), which is also utilized in the Weighted Aggregated Sum Product Assessment (WASPAS) method.

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \tag{7}$$

Step 4. The relative weights of the alternatives are determined using the following aggregation algorithms. At this stage, three scoring methods are applied to calculate the relative weights of the alternatives, as shown in Equations (8)-(10).

$$k_{ia} = \frac{P_i + S_i}{\Sigma_{i=1}^{m} (P + S_i)} \tag{8}$$

$$k_{ib} = \frac{S_i}{\min\limits_i S_i} + \frac{P_i}{\min\limits_i P_i} \tag{9}$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{(\lambda \max\limits_i S_i + (1-\lambda) \max\limits_i P_i}; \qquad 0 \leq \lambda \leq 1. \tag{10}$$

Equation (8) represents the arithmetic mean of the sums of Weighted Sum Model (WSM) and Weighted Product Model (WPM) scores. Equation (9) calculates the total of the relative WSM and WPM scores compared to the ideal solution. Equation (10) provides a balanced compromise between the WSM and WPM results. In this equation, λ is selected by decision-makers, typically set at $\lambda = 0.5$.

Step 5. In this step, the integrated scores of the alternatives are calculated. Equation (11) incorporates the relative assessments derived from Equations (8-10).

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}). \tag{11}$$

Equation (11) generates the k_i values, which are then sorted in decreasing order to determine the overall ranking of the alternatives and finalize the solution to the problem.

4. Application

In the application section of this study, the SDG 9 performances of EU countries are evaluated. The analysis data is sourced from the 2024 SDG reports. The EU countries, identified by their codes, are presented in Table 1, and the evaluation criteria are shown in Table 2. Most of the evaluation criteria in Table 2 are benefit-oriented and aimed at being maximized. Criterion C10, which represents the gap in internet access by income, is cost-oriented and intended to be minimized. The LOPCOW and CoCoSo approaches, the current MCDM algorithms, are preferred for the application process. The importance levels of the criteria are objectively established using the LOPCOW approach, and then the countries' SDG 9 performance rankings are determined using the CoCoSo method.

TABLO 1 | EU Countries with Codes

Country Code	Country	Country Code	Country	Country Code	Country
DEU	Germany	SWE	Sweden	FRA	France
AUT	Austria	ITA	Italy	NLD	Netherlands
BEL	Belgium	LVA	L atvia	IRL	Ireland
CZE	Czechia	LTU	Lithuania	ESP	Spain
DNK	Denmark	LUX	Luxembourg	PRT	Portugal
EST	Estonia	HUN	Hungary	SVK	Slovak Republic
FIN	Finland	POL	Poland	SVN	Slovenia
GRC	Greece				

TABLO 2 | Evaluation Criteria Used in the Analysis

Criteria Code	Criteria	Criteria Type
C1	Rural population with access to all-season roads (%)	Max
C2	Population using the internet (%)	Max
C3	Mobile broadband subscriptions (per 100 population)	Max
C4	Logistics Performance Index: Quality of trade and transport-related infrastructure	Max
C5	The Times Higher Education Universities Ranking: Average score of the top 3 universities	Max
C6	Articles published in academic journals (per 1,000 population)	Max
C7	Expenditure on research and development (% of GDP)	Max
C8	Researchers (per 1,000 employed population)	Max
C9	Triadic patent families filed (per million population)	Max
C10	Gap in internet access by income (percentage points)	Min
C11	Female share of graduates from STEM fields at the tertiary level (%)	Max

4.1. Calculating Criteria Weights with the LOPCOW Method

This study initially assessed the significance levels of the countries' SDG 9 performance components using the LOPCOW method. The first stage of this method is to generate the initial decision matrix, as shown in Table 3.

TABLO 3 | Initial Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
DEU	99,99	92,48	95,54	4,30	79,40	2,19	3,14	10,63	52,61	12,35	27,56
AUT	100	93,61	121,29	3,90	59,90	3,28	3,26	12,82	49,08	14,19	25,90
BEL	100	94,01	94,89	4,10	68,00	3,14	3,43	15,88	34,76	18,25	25,83
CZE	100	84,54	105,03	3,00	40,47	2,36	2,00	9,09	4,29	36,08	35,57
DNK	99,81	98,78	142,69	4,10	65,60	5,43	2,81	16,20	54,79	9,76	34,25
EST	100	91,02	209,55	3,50	40,63	3,08	1,75	9,36	3,20	28,57	38,38
FIN	99,83	92,99	160,45	4,20	58,93	4,25	2,99	16,22	53,31	9,24	27,40
FRA	99,51	85,33	106,95	3,80	74,73	1,74	2,22	11,50	29,16	20,70	31,81
NLD	99,94	92,52	123,33	4,20	74,30	3,76	2,31	11,31	49,12	6,06	29,29
IRL	99,93	95,59	118,60	3,50	58,30	3,67	1,13	10,94	25,28	18,07	29,00
ESP	99,54	94,49	110,81	3,80	58,80	2,32	1,43	7,91	6,80	13,97	29,56
SWE	99,56	95,7	132,37	4,20	69,63	4,32	3,42	17,35	83,75	15,09	35,48
ITA	99,79	85,06	95,91	3,80	60,87	2,30	1,45	6,27	15,26	47,45	39,52
LVA	100	92,19	120,09	3,30	25,70	1,53	0,74	4,83	2,60	22,31	31,13
LTU	99,96	87,72	133,26	3,50	31,70	1,88	1,11	7,76	2,27	42,57	29,60
LUX	100	99,35	115,65	3,60	57,25	4,30	1,04	6,28	51,95	10,54	27,58
HUN	100	89,14	81,59	3,10	42,88	1,46	1,64	9,56	4,24	38,34	31,68
POL	100	86,94	202,74	3,50	39,40	1,43	1,44	8,08	1,95	24,17	43,36
PRT	99,78	84,50	95,74	3,60	47,20	3,20	1,73	11,75	4,87	35,32	37,76
SVK	99,90	87,21	86,74	3,30	28,80	1,62	0,92	7,58	1,81	10,48	35,22
SVN	99,99	88,91	96,01	3,60	25,50	3,51	2,13	10,54	7,11	25,71	33,32
GRC	99,63	83,17	100,10	3,70	42,20	2,29	1,46	10,40	2,76	41,72	40,09

Equations (2) and (3) are employed to normalize the initial decision matrix in the method's second step. The normalized decision matrix is presented in Table 4.

TABLO 4 | Normalized Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
DEU	0,979	0,575	0,109	1,000	1,000	0,191	0,893	0,463	0,620	0,848	0,098
AUT	1,000	0,646	0,310	0,692	0,638	0,464	0,935	0,638	0,577	0,803	0,004
BEL	1,000	0,670	0,104	0,846	0,788	0,427	1,000	0,882	0,402	0,705	0,000
CZE	1,000	0,085	0,183	0,000	0,278	0,231	0,467	0,340	0,030	0,275	0,555
DNK	0,611	0,965	0,477	0,846	0,744	1,000	0,771	0,908	0,647	0,910	0,480
EST	1,000	0,485	1,000	0,385	0,281	0,413	0,376	0,362	0,017	0,456	0,716
FIN	0,654	0,607	0,616	0,923	0,620	0,705	0,836	0,910	0,628	0,923	0,089
FRA	0,000	0,134	0,198	0,615	0,913	0,077	0,550	0,532	0,334	0,646	0,341
NLD	0,872	0,578	0,326	0,923	0,905	0,582	0,583	0,518	0,577	1,000	0,197
IRL	0,864	0,768	0,289	0,385	0,609	0,560	0,145	0,488	0,286	0,710	0,181
ESP	0,045	0,699	0,228	0,615	0,618	0,223	0,256	0,245	0,061	0,809	0,212
SWE	0,086	0,775	0,397	0,923	0,819	0,724	0,995	1,000	1,000	0,782	0,550
ITA	0,574	0,117	0,112	0,615	0,656	0,218	0,265	0,115	0,164	0,000	0,781
LVA	1,000	0,557	0,301	0,231	0,004	0,024	0,000	0,000	0,010	0,607	0,302
LTU	0,926	0,281	0,404	0,385	0,115	0,112	0,138	0,234	0,006	0,118	0,215
LUX	1,000	1,000	0,266	0,462	0,589	0,719	0,112	0,116	0,612	0,892	0,099
HUN	1,000	0,369	0,000	0,077	0,323	0,008	0,335	0,378	0,030	0,220	0,334
POL	1,000	0,233	0,947	0,385	0,258	0,000	0,258	0,260	0,002	0,563	1,000
PRT	0,543	0,082	0,111	0,462	0,403	0,443	0,367	0,552	0,037	0,293	0,680
SVK	0,802	0,250	0,040	0,231	0,061	0,048	0,065	0,219	0,000	0,893	0,536
SVN	0,986	0,355	0,113	0,462	0,000	0,520	0,517	0,456	0,065	0,525	0,427
GRC	0,228	0,000	0,145	0,538	0,310	0,215	0,266	0,444	0,012	0,138	0,813
Σ	0,348	0,293	0,263	0,284	0,308	0,280	0,319	0,276	0,303	0,302	0,284

The next step involves the calculation of the criterion percentage values (*PV*) using Equation (4). In the method's final step the criterion weight coefficients are determined using Equation (5). The calculated percentage values (*PV*) and criterion weights (w_j) are presented in Table 5.

TABLO 5 | Percentage values *(PV)* and criterion weights (w_j)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
PV	84,55	62,3	41,32	76,83	63,46	47,9	55,55	65,46	29,25	79	52,41
w_j	0,128	0,095	0,063	0,117	0,096	0,073	0,084	0,099	0,044	0,12	0,08
Rank	1	6	10	3	5	9	7	4	11	2	8

According to the results of the LOPCOW approach, the most important criterion in evaluating the SDG 9 performance among EU countries is identified as the rural population with access to all-season roads (%) (C1). The second most important criterion is the gap in internet access by income (percentage points) (C10). Triadic patent families filed (per million population) (C9) is the least important criteria. These weight coefficients will be employed in the solution process using the CoCoSo method.

4.2. Determining SDG 9 Performance Ranking of EU Countries using the CoCoSo Method

In the initial step of the CoCoSo solution process, the initial decision matrix in Table 3 is normalized using Equation (2) and Equation (3). This normalizing step is similar to the LOPCOW approach. The resulting normalized decision matrix is shown in Table 4.

In the next step, the total weighted comparability sequence (S_i) for each alternative is calculated using Equation (6), and the power-weighted comparability sequence sum (P_i) is determined using Equation (7). Table 6 shows the (S_i) values of the alternatives, while Table 7 displays the (P_i) values.

TABLO 6 | (S_i) Values of the Alternatives

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	S_i
DEU	0,126	0,054	0,007	0,117	0,096	0,014	0,075	0,046	0,028	0,102	0,008	0,673
AUT	0,128	0,061	0,019	0,081	0,062	0,034	0,079	0,063	0,026	0,096	0,000	0,650
BEL	0,128	0,063	0,007	0,099	0,076	0,031	0,084	0,088	0,018	0,085	0,000	0,679
CZE	0,128	0,008	0,012	0,000	0,027	0,017	0,039	0,034	0,001	0,033	0,044	0,343
DNK	0,079	0,091	0,030	0,099	0,072	0,073	0,065	0,090	0,029	0,109	0,038	0,775
EST	0,128	0,046	0,063	0,045	0,027	0,030	0,032	0,036	0,001	0,055	0,057	0,520
FIN	0,084	0,057	0,039	0,108	0,060	0,051	0,071	0,091	0,028	0,111	0,007	0,706
FRA	0,000	0,013	0,012	0,072	0,088	0,006	0,046	0,053	0,015	0,078	0,027	0,410
NLD	0,112	0,055	0,020	0,108	0,087	0,042	0,049	0,051	0,026	0,120	0,016	0,687
IRL	0,111	0,073	0,018	0,045	0,059	0,041	0,012	0,049	0,013	0,085	0,014	0,519
ESP	0,006	0,066	0,014	0,072	0,060	0,016	0,022	0,024	0,003	0,097	0,017	0,397
SWE	0,011	0,073	0,025	0,108	0,079	0,053	0,084	0,099	0,044	0,094	0,044	0,714
ITA	0,074	0,011	0,007	0,072	0,063	0,016	0,022	0,011	0,007	0,000	0,062	0,346
LVA	0,128	0,053	0,019	0,027	0,000	0,002	0,000	0,000	0,000	0,073	0,024	0,327
LTU	0,119	0,027	0,025	0,045	0,011	0,008	0,012	0,023	0,000	0,014	0,017	0,302
LUX	0,128	0,095	0,017	0,054	0,057	0,052	0,009	0,012	0,027	0,107	0,008	0,566
HUN	0,128	0,035	0,000	0,009	0,031	0,001	0,028	0,038	0,001	0,026	0,027	0,324
POL	0,128	0,022	0,059	0,045	0,025	0,000	0,022	0,026	0,000	0,068	0,080	0,475
PRT	0,070	0,008	0,007	0,054	0,039	0,032	0,031	0,055	0,002	0,035	0,054	0,386
SVK	0,103	0,024	0,003	0,027	0,006	0,003	0,005	0,022	0,000	0,107	0,043	0,343
SVN	0,127	0,034	0,007	0,054	0,000	0,038	0,044	0,045	0,003	0,063	0,034	0,448
GRC	0,029	0,000	0,009	0,063	0,030	0,016	0,022	0,044	0,001	0,017	0,065	0,295
Min												0,295
Max												0,775

TABLO 7 | *(P_i)* Values of the Alternatives

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	
DEU	0,997	0,949	0,870	1,000	1,000	0,886	0,990	0,926	0,979	0,980	0,831	10,410
AUT	1,000	0,959	0,929	0,958	0,958	0,946	0,994	0,956	0,976	0,974	0,645	10,295
BEL	1,000	0,963	0,867	0,981	0,977	0,940	1,000	0,988	0,960	0,959	0,000	9,635
CZE	1,000	0,792	0,899	0,000	0,884	0,899	0,938	0,898	0,856	0,856	0,954	8,976
DNK	0,939	0,997	0,955	0,981	0,972	1,000	0,978	0,990	0,981	0,989	0,943	10,724
EST	1,000	0,934	1,000	0,894	0,885	0,938	0,921	0,904	0,834	0,910	0,974	10,193
FIN	0,947	0,954	0,970	0,991	0,955	0,975	0,985	0,991	0,980	0,990	0,825	10,562
FRA	0,000	0,827	0,903	0,945	0,991	0,829	0,951	0,939	0,952	0,949	0,918	9,205
NLD	0,983	0,949	0,932	0,991	0,990	0,961	0,955	0,937	0,976	1,000	0,879	10,553
IRL	0,981	0,975	0,925	0,894	0,953	0,959	0,850	0,931	0,946	0,960	0,873	10,247
ESP	0,672	0,967	0,911	0,945	0,955	0,896	0,891	0,870	0,883	0,975	0,884	9,849
SWE	0,730	0,976	0,944	0,991	0,981	0,977	1,000	1,000	1,000	0,971	0,954	10,522
ITA	0,931	0,816	0,872	0,945	0,960	0,895	0,894	0,806	0,923	0,000	0,981	9,023
LVA	1,000	0,946	0,927	0,843	0,583	0,761	0,000	0,000	0,814	0,942	0,909	7,725
LTU	0,990	0,887	0,945	0,894	0,812	0,853	0,846	0,865	0,794	0,774	0,885	9,544
LUX	1,000	1,000	0,920	0,914	0,950	0,976	0,831	0,807	0,978	0,986	0,832	10,195
HUN	1,000	0,910	0,000	0,741	0,897	0,702	0,912	0,908	0,855	0,834	0,916	8,675
POL	1,000	0,871	0,997	0,894	0,877	0,000	0,892	0,874	0,753	0,933	1,000	9,092
PRT	0,925	0,789	0,871	0,914	0,916	0,942	0,919	0,943	0,864	0,863	0,970	9,915
SVK	0,972	0,877	0,817	0,843	0,764	0,802	0,794	0,860	0,000	0,987	0,951	8,666
SVN	0,998	0,907	0,872	0,914	0,000	0,953	0,946	0,925	0,885	0,926	0,935	9,260
GRC	0,827	0,000	0,886	0,930	0,893	0,894	0,894	0,923	0,820	0,789	0,984	8,840
Min												7,725
Max												10,724

After determining the total weighted comparability sequence (S_i) and the power-weighted comparability sequence sum (P_i) of each option, the next step involves calculating the relative evaluation scores *(k_{ia},k_{ib},k_{ic})* using Equations (8-10). The integrated scores of the alternatives (k_i) are then generated using Equation (11). The integrated score values are sorted in descending order to rank the countries based on SDG 9 performance. Table 8 presents the relative evaluation scores, integrated score values, and the final ranking results.

TABLO 8 | Relative Evaluation Scores (k_{ia}, k_{ib}, k_{ic}), Integrated Score Values (k_i), and Ranking Results

	k_{ia}	k_{ib}	k_{ic}	k_i	Rank		k_{ia}	k_{ib}	k_{ic}	k_i	Rank
DEU	0,050	3,626	0,964	1,604	5	**SWE**	0,050	3,781	0,977	1,665	2
AUT	0,049	3,533	0,952	1,566	6	**ITA**	0,042	2,340	0,815	1,092	16
BEL	0,046	3,546	0,897	1,546	7	**LVA**	0,036	2,106	0,700	0,965	22
CZE	0,042	2,324	0,810	1,085	17	**LTU**	0,044	2,256	0,856	1,081	18
DNK	0,052	4,011	1,000	1,757	1	**LUX**	0,048	3,236	0,936	1,455	8
EST	0,048	3,078	0,932	1,399	10	**HUN**	0,040	2,221	0,783	1,038	20
FIN	0,051	3,758	0,980	1,658	3	**POL**	0,043	2,784	0,832	1,253	11
FRA	0,043	2,578	0,836	1,183	15	**PRT**	0,046	2,592	0,896	1,214	14
NLD	0,050	3,692	0,978	1,634	4	**SVK**	0,040	2,282	0,783	1,059	19
IRL	0,048	3,085	0,936	1,403	9	**SVN**	0,044	2,715	0,844	1,234	12
ESP	0,046	2,618	0,891	1,221	13	**GRC**	0,041	2,144	0,794	1,017	21

Denmark has the highest SDG 9 performance among EU countries in 2024, according to CoCoSo integrated score values. Sweden and Finland are ranked second and third, respectively. The findings show that Latvia had the lowest SDG 9 performance in the relevant year.

5. Results and Conclusion

SD encompasses several dimensions, including socioeconomic, ecological, and ethical aspects. These topics often involve significant disagreements. To address these concerns, the United Nations General Assembly established the SDGs. The 2030 Agenda for Sustainable Development includes 17 SDGs to improve global conditions. These goals provide a framework for global efforts to create a more equitable and sustainable world by 2030 (Yavuz & Esen, 2024).

Tracking and assessing a country's progress toward the SDGs is both a challenge and an opportunity for everyone involved in achieving the 2030 Agenda. Evaluating countries' performance in meeting the SDGs can be complex, requiring advanced analytical techniques. MCDM techniques offer a structured approach to assessing and comparing the performance of different countries using various criteria. Performance and advancement composite indicators are two potential tools for measuring the multiple dimensions of sustainable development achievements (Saieed et al., 2021).

Digital development presents a significant challenge for policymakers in the modern global economy. To ensure that development efforts are sustainable, comprehensive SD is required. In this digital age, the inclusive development framework that must be prepared is the ICT infrastructure. Achieving ICT-related goals is one of the sub-targets of SDG 9, which includes innovation, infrastructure, and sustainable industrialization. SDG 9 aims to strengthen infrastructure, promote inclusive and sustainable industrialization, and encourage innovation.

In this study, the SDG 9 performance of EU countries is assessed using 11 indicators. After calculating the weight coefficients of the criteria using the LOPCOW procedure, the countries are evaluated using the CoCoSo method. According to the results from the LOPCOW procedure, the most important criteria for evaluating the SDG 9 performance of EU nations are the rural population with access to all-season roads (%) and the income gap in internet access (percentage points). According to CoCoSo's rating statistics, Denmark has the best SDG 9 performance among EU countries. Sweden and Finland are ranked second and third, respectively. Latvia, Greece, and Hungary have the lowest SDG 9 performance scores. These countries need to focus on their weaknesses and take action quickly.

Countries that fall behind in the SDG 9 performance ranking have similar values when compared to other alternatives based on the criterion of rural population with access to all-season roads. The gap in internet access percentages, particularly across different socioeconomic levels, contributes to these countries' poor performance. Similarly, these countries have lower logistics performance indexes than others. Computers and the internet play an increasingly vital role in all sectors, and the Covid-19 pandemic has highlighted their importance in e-commerce and other industries (Torkayesh & Torkayesh, 2021). In this context, it can be recommended that lower-ranked countries, such as Latvia, Greece, and Hungary, make fundamental investments in ICT. Additionally, addressing transportation infrastructure issues is critical for improving trade quality. With these enhancements, it will be possible to improve the sustainability performance of these countries.

The analysis results align with the findings of Burhan (2024) and Torkayesh & Torkayesh (2021). Both studies found that internet access was a highly important criterion in the weighting process. According to Burhan's analysis, Denmark, Sweden, and Finland were the top three countries based on rankings using the MAIRCA approach between 2013 and 2022. Similarly, Latvia was classified as one of the countries with the lowest SDG 9 performance. The findings are also similar to those reported by Brodny and Tutak (2023). In their research, Denmark, Sweden, and Finland were identified as having the best SDG 9 performance, while Latvia and Greece were classified as having the lowest SDG 9 performance. When related studies in the literature are reviewed to compare the results, it becomes apparent that this study also supports the findings of Ozkaya et al. (2021). Similar to their findings, Sweden and Finland emerged as the leading performers in the rankings based on SDG 9 criteria. The strong sustainability performance results of Sweden, Denmark, and Finland are further supported by the findings of Ricciolini et al. (2022).

The insights obtained from this study can be used to design new strategies that promote sustainable and solidarity-based development across the EU. Furthermore, the findings may be useful to decision-makers since they highlight key indicators related to industrialization, innovation, and infrastructure that should be addressed when developing countries' sustainable development strategies. The applied framework enables policymakers and stakeholders to identify the strengths and weaknesses of countries and prioritize areas for improvement. The research approach presented in this paper adds value because it can be applied to assessments of various SD targets for countries.

The limitations of the study include the use of 2024 data for the assessment, the inclusion of only EU countries in the analysis, the evaluation based on the indicators presented in the 2024 SDG reports, and the use of two MCDM methods in the analysis process. In future research, it may be valuable to compare the SDG 9 performance ranking results obtained using alternative MCDM approaches with the current study's findings. The analyses can be conducted using various indicators applicable to different SDG performance evaluations of countries. Additionally, new longitudinal studies can be implemented to track countries' progress toward SDG 9 targets.

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