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A Hybrid MCDM Approach for SDGs Assessment of EU Countries

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ABSTRACT

This study assesses the progress of EU countries in achieving the Sustainable Development Goals (SDGs) using Multi-Criteria Decision-Making (MCDM) methods. The evaluation covers 27 countries and is based on 15 indicators for the 2019–2021 period. The MPSI-RAPS model was employed to determine indicator weights and rank the alternatives. To ensure robustness, a comprehensive sensitivity analysis was conducted across 16 scenarios. The final rankings from the MPSI-RAPS model identified Sweden, the Netherlands, and Germany as the top-performing countries in sustainable development progress. Notably, rankings varied significantly across scenarios, underscoring the impact of methodological choices on outcomes.

1. Introduction

The concept of sustainability, whose origins trace back to the 18th century, gained significant global attention in 1987 when the United Nations (UN) "World Commission on Environment and Development" (WCED) introduced an ethical framework emphasizing the need to meet the requirements of both present and future generations [1]. Efforts to define sustainability in economic terms have frequently resulted in conflation with the concepts of sustainable development and growth [2].

Over the past three decades, significant strides have been made in discussions on sustainable development. While many developing countries have increasingly recognized the importance of sustainability, industrialized nations have made even greater progress in this regard [3]. The first official definition of this notion was introduced in the Brundtland Report published by the WCED. It defines sustainable development as “meeting the needs of the present generation without compromising the ability of future generations to meet their own” [4]. The UN has played an important role in resolving both current and future sustainability challenges by facilitating international cooperation. Through global conferences, the UN has fostered agreements and policies to advance sustainable development at various levels [3]. A milestone in these efforts came in 2015

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when all 193 UN member states endorsed the 2030 Agenda for sustainable development. This comprehensive framework calls upon all nations and stakeholders to work collaboratively to eradicate poverty and hunger, safeguard the needs of present and future generations, and protect the planet [5].

The 2030 Agenda embodies an ambitious vision through the Sustainable Development Goals (SDGs), emphasizing the protection of human rights and the environment while maintaining a balance among the economic, social, and environmental aspects of sustainable development. Confronting global issues such as poverty, healthcare, climate change, injustice, and inequality, the SDGs are recognized as a comprehensive and indivisible framework [6]. As a formal declaration adopted by UN member states, the SDGs serve as a global action plan to promote sustainability across all nations and form the foundation of the 2030 Agenda. This agenda comprises 169 targets and a range of indicators structured around 17 SDGs (Table 1), each integrating economic, environmental, and social dimensions [7]. In response, studies across various disciplines have increasingly focused on these goals, recognizing them as critical focal points for understanding and advancing sustainable human and environmental development by 2030 [8].

Table 1
The 17 SDGs and their descriptions

1	“No poverty”	“It calls for an end to all forms of poverty, including extreme poverty, within the next 15 years.”
2	“Zero hunger”	“Ending hunger, ensuring food security and good nutrition, and promoting sustainable agriculture.”
3	“Good health and well-being”	“Ensuring healthy lives for all and promoting well-being at all ages. It focuses on healthy living, determinants of health, causes of death, and access to healthcare.”
4	“Quality education”	“Ensuring inclusive, equitable, quality education and promoting lifelong learning opportunities for all.”
5	“Gender equality”	“Achieving gender equality and empowering women and girls.”
6	“Clean water and sanitation”	“Ensuring the availability and sustainable management of water and sanitation for all.”
7	“Affordable and clean energy”	“Ensuring everyone has access to affordable, reliable, sustainable, and modern energy.”
8	“Decent work and economic growth”	“Promoting sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.”
9	“Industry, Innovation, and Infrastructure”	“Creating resilient infrastructure, promoting inclusive and sustainable industrialization and innovation.”
10	“Reduced inequalities”	“Reducing inequality within and between countries.”
11	“Sustainable cities and communities”	“Making cities and human settlements inclusive, safe, resilient, and sustainable.”
12	“Responsible consumption and production”	“Ensuring sustainable consumption and production models.”
13	“Climate action”	“Take urgent action to combat climate change and its effects. It focuses on climate mitigation, climate impacts, adaptation and initiatives that support climate action.”
14	“Life below water”	“Conservation and sustainable use of oceans, seas, and marine resources for sustainable development.”
15	“Life on land”	“Protecting, restoring, and promoting the sustainable use of terrestrial ecosystems, sustainably managing forests, combating desertification, halting land degradation and halting biodiversity loss.”

Table 1
Continued

16	"Peace, justice, and strong institutions"	"Promoting peaceful and inclusive societies for sustainable development, ensuring access to justice for all, and building effective, accountable, and inclusive institutions at all levels."
17	"Partnerships for the goals"	"Strengthening the means of implementation and revitalizing the global partnership for sustainable development."

Source: [9]

The SDGs present a valuable opportunity to advance sustainability research, emphasizing the need for interdisciplinary and localized approaches to better understand the broader impacts of local decisions [10]. While the SDGs provide a global framework, their execution occurs at the local level. Moreover, each country's level of development and commitment to sustainability directly influences its national priorities and actions [3]. This study aims to assess the progress of European Union (EU) countries in achieving the SDGs using "Multi-Criteria Decision-Making" (MCDM) methods. The evaluation covers 27 countries, analyzed based on 15 indicators for the 2019–2021 period. The "Modified Preference Selection Index" (MPSI)- "Ranking Alternatives by Perimeter Similarity" (RAPS) model was utilized to identify indicator weights and rank the alternatives, providing a structured approach to measuring sustainability performance.

The key distinctions and contributions of this study can be summarized as follows: i) It evaluates the progress of EU countries in achieving the SDGs, offering insights into how various nations are advancing in sustainability. ii) The robustness of the proposed model is validated through an extensive sensitivity analysis involving 16 different scenarios. iii) By employing three distinct objective weighting techniques, the study examines the influence of criterion weights on MCDM rankings, thereby eliminating subjective biases in decision-making. iv) Given the significance of the topic, the proposed framework can be adapted and extended to assess SDG performance in other countries and regional groups.

The rest of the study is organized as follows: Section 2 presents related studies. Sections 3 and 4 include the methodology and application sections. Section 5 is dedicated to the sensitivity analysis. Sections 6 and 7 are dedicated to the discussion and conclusion, respectively.

2. Related Work

With the passing of a few years since the adoption of the SDGs, various studies have emerged examining the adequacy of indicators [11], the transformation of how to implement the SDGs [12], the integration of various indicators to enhance global and national connections for the SDGs [13], case studies focusing on how companies perceive SDGs [14], investigations and measurements of inconsistencies within the SDGs [15], assessments of the impact of the SDGs on sustainable development [16], implementing the SDGs at the university level [17], connecting climate action with other SDGs [18], the role of the mining sector in the implementation of SDGs [19], gender and the SDGs [20] and many other diverse topics. However, there is a limited number of publications on how effectively countries are achieving the SDGs, and this forms the starting point of this study. Table 2 presents a summary of studies in literature that apply MCDM methods to assess the SDGs at the country level.

Table 2
Related works

Author(s)	Scope	Method(s)
[21]	Assessing EU countries in terms of the main areas of Agenda 2030 Goal 9 for the period 2015-2020 (creating stable infrastructure, promoting sustainable industrialization and promoting innovation)	Entropy, CRITIC, SD, TOPSIS, WASPAS, EDAS
[22]	To examine targets 7 and 13 to evaluate the sustainable energy and climate development of EU countries for the period 2010, 2015 and 2020	CODAS, EDAS, TOPSIS, VIKOR, WASPAS
[23]	To analyze the Sustainable Development Goals positions of EU countries for the period 2015-2018	CoCoSo, Entropy
[24]	Prioritization of indicators of Sustainable Development Goal 7	FSWARA
[25]	Assessing the security performance of EU countries in the context of sustainable development, considering Goal 16	SMART, ARAS
[26]	To analyze the sustainable development of 16 regions of Poland in the period 2015-2021 based on Goal 9	CODAS, CoCoSo, Entropy, CRITIC
[27]	Analyze the challenges and opportunities that sustainable agriculture faces in China's economy, particularly in advancing the Sustainable Development Goals	AHP, SAW
[28]	Analyzing the sustainability developments of EU countries and Norway and Iceland	AHP
[29]	Analyzing the sustainability developments of EU countries in the 2002-2021 period, considering Goal 8 and the COVID-19 pandemic	COPRAS, Dynamic Time Warping and the hierarchical clustering methods
[30]	Comparing EU countries in terms of the degree and dynamics of SDG7 implementation based on the period 2005-2020	COPRAS, Dynamic Time Warping, the hierarchical clustering
[31]	Assessing the implementation of SDG 8 in EU countries for the periods 2002–2021.	TOPSIS
[32]	Examining the Union Territories of India using 15 indicators for 2020-21	Entropy, COCOSO
[33]	Examining the sustainable development progress of EU countries in 2016	TOPSIS, VIKOR
[34]	Evaluation of the implementation of SDG Goal 1 in EU countries for the period 2016.	TOPSIS, VMCM

As shown in Table 2, two studies have analyzed the SDGs in their entirety. The first, presented by [33], examined the SDG development of EU countries for the year 2016 based on 14 goals. The second study, conducted by [23], focused on the SDG progress of EU countries from 2015 to 2018, considering all 17 goals. In most studies on the SDGs within literature, only one or a few goals have been included in the analysis. Additionally, the study populations typically consist of EU countries, with the Entropy method being a commonly used weighting technique, while TOPSIS and CoCoSo are frequently employed for ranking.

3. Preliminaries

3.1. Z-Score (Standard Score) Standardization Method

To address challenges in normalization caused by negative and zero-valued data in the decision matrix, [35] introduced the Z-score standardization method, which transforms the matrix into a positive form. The steps of the method are as follows [35]:

Step 1: Decision matrix is created.

Step 2: The decision matrix is normalized using Eq. (1).

$$x_{ij} = \frac{X_{ij} - \bar{X}_i}{S_i} \tag{1}$$

x_{ij} is the data obtained after normalization. X_{ij}, S_i and $\bar{X}i$ represent the original data, standard deviation values and arithmetic mean, respectively.

Step 3: The decision matrix is converted to positive with Eq. (2).

$$x'_{ij} = x_{ij} + A, A > \left|minx_{ij}\right| \quad (2)$$

A represents the minimum value within the decision matrix. The notation x'_{ij} represents the standardized value following the conversion. $x'_{ij}>0$.

3.2. MPSI Method

MPSI is a relatively new method introduced by [36] for the objective determination of weight coefficients in MCDM problems. The steps of the method are as follows [36].

Step 1. The normalized decision matrix R is created as follows:

Eq. (3) and 4 are used for benefit and cost criteria, respectively:

$$r_{ij} = \frac{x_{ij}}{max_i(x_{ij})} \quad (3)$$

$$r_{ij} = \frac{min_i(x_{ij})}{x_{ij}} \quad (4)$$

r_{ij} is the normalized value of the criteria, $0 < r_{ij} < 1$.

Step 2. Calculate the mean value v_j of the normalized criterion j using Eq. (5).

$$v_j = \frac{1}{m}\sum_{i=1}^{m} r_{ij} \quad (5)$$

Step 3. Calculate the preference variation value p_j using Eq. (6).

$$p_j = \sum_{i=1}^{m}\left(r_{ij} - v_j\right)^2 \quad (6)$$

Step 4 Criterion weights (w_j) are calculated with Eq. (7).

$$w_j = \frac{p_j}{\sum_{j=1}^{n} p_j} \quad (7)$$

3.3. RAPS Method

The method introduced by [37] is quite new. In this method, alternatives are ranked based on perimeter similarity, which represents the perimeter of each alternative's surroundings to the optimal alternative [38]. The steps of the method are as follows [37].

Step 1: Data is normalized depending on the direction of the criteria. The utility and cost criteria are normalized by Eq. (8) and 9, respectively.

$$r_{ij} = \frac{x_{ij}}{max_i(x_{ij})}, \ \forall_i \in [1,2,\dots,m] \Lambda j \in S_{max} \quad (8)$$

$$r_{ij} = \frac{min_i(x_{ij})}{x_{ij}} \quad (9)$$

Step 2: The weighted normalized decision matrix is created with Eq. (10).

$$u_{ij} = w_j * r_{ij} \quad (10)$$

Step 3: The optimum alternative is determined by Eq. (11)

$$q_i = \left(\max(u_{ij})\middle|1 \le j \le n\right), \forall_i \in [1,2,\dots,m] \quad (11)$$

The best alternative is expressed by the following set.

$Q = \{q_{1,}q_2, \dots, q_j\}$, j=1,2,…,n

Step 4: The optimal alternative is decomposed into two subsets or two components.

$$Q = Q^{max} \cup Q^{min} \quad (12)$$

If k represents the total number of beneficial criteria, h=n-k represents the total number of cost criteria, and the optimal alternative is defined as:

$Q = \{q_1, q_2, \dots, q_k\} \cup \{q_1, q_2, \dots, q_h\}$;

$k + h = j$

Step 5: Alternatives are separated by Eq. (13).

$$U_i = U_i^{max} \cup U_i^{min}, \qquad \forall_i \in [1,2,\dots,m] \tag{13}$$
$$U_i = \{u_{i1}, u_{i2}, \dots, u_{ik}\} \cup \{u_{i1}, u_{i2}, \dots, u_{ih}\}, \qquad \forall_i \in [1,2,\dots,m]$$

Step 6: The magnitude of each component of the optimum alternative is calculated with Eq. (14) and 15.

$$Q_k = \sqrt{q_1^2 + q_2^3 + .. + q_k^2} \tag{14}$$
$$Q_h = \sqrt{q_1^2 + q_2^3 + .. + q_h^2} \tag{15}$$

The same approach is applied for each alternative.

$$U_{ik} = \sqrt{u_{i1}^2 + u_{i2}^3 + .. + u_{ik}^2} \tag{16}$$
$$U_{ih} = \sqrt{u_{i1}^2 + u_{i2}^3 + .. + u_{ih}^2} \tag{17}$$

Two methods are used to rank alternatives: The trace of a matrix and the similarity between the perimeter of the optimal alternative and the alternative.

Step 7: Sorting alternatives according to perimeter similarity

Firstly, the Q_k and Q_h components of the base and perpendicular sides of the triangle, which is represented as a right-angled triangle perimeter, are shown with Eq. (18). For each alternative, the perimeter is calculated using Eq. (19). The ratio between the perimeter of each alternative and the optimal alternative is expressed by Eq. (20). Alternatives are arranged and ranked in decreasing order of PS_i values of each alternative.

$$P = Q_k + Q_h + \sqrt{Q_k^2 + Q_h^2} \tag{18}$$
$$P_i = U_{ik} + U_{ih} + \sqrt{U_{ik}^2 + U_{ih}^2} \tag{19}$$
$$PS_i = \frac{P_i}{P}, \qquad \forall_i \in [1,2,\dots,m] \tag{20}$$

4. A Numerical Example

The objective of this study is to assess the level of sustainable development in EU countries using MCDM methods (Figure 1), based on the 17 SDGs. The analysis was conducted using data from the Eurostat database for the years 2019 to 2021. The year 2022 was excluded from the analysis due to missing data for several countries.

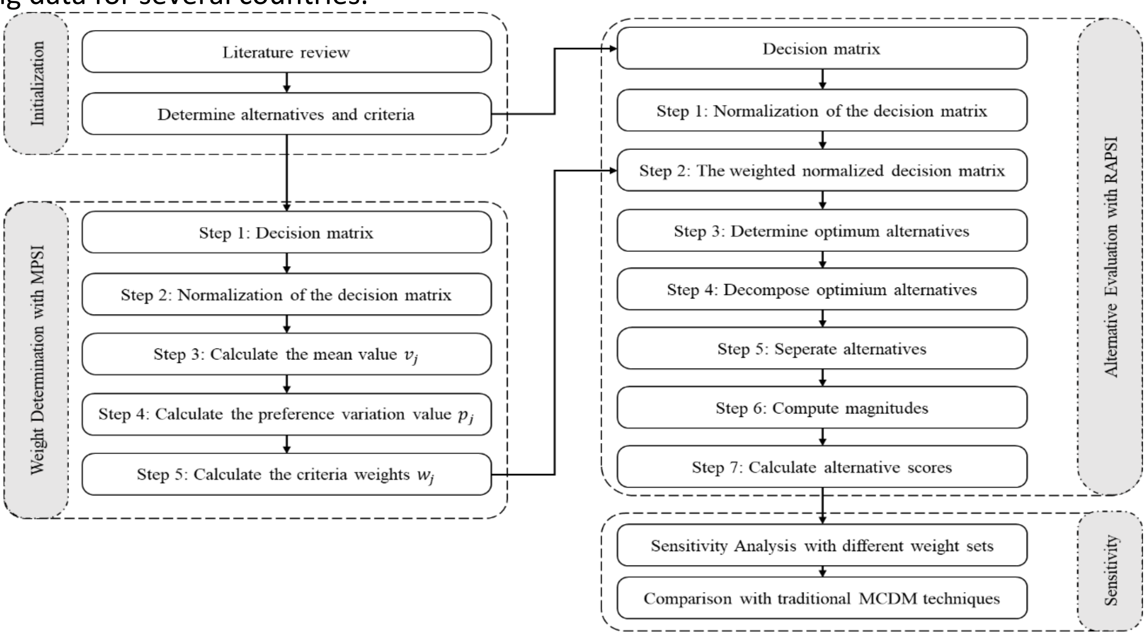

Fig. 1. Outline of the study

In this study, an analysis was conducted using 15 indicators selected from the 17 SDGs. Due to data limitations for the 27 EU countries, the SDG 6 (clean water and sanitation) and SDG 15 (life on land) indicators were excluded from the evaluation. The 27 EU countries were assessed based on the following criteria:

c_1: "Persons at risk of monetary poverty after social transfers"
c_2: "Government support to agricultural research and development"
c_3: "Self-reported unmet need for medical examination and care by sex"
c_4: "Tertiary educational attainment by sex"
c_5: "Positions held by women in senior management positions"
c_6: "Share of renewable energy in gross final energy consumption by sector"
c_7: "Real GDP per capita"
c_8: "Gross domestic expenditure on R&D by sector"
c_9: "Purchasing power adjusted GDP per capita"
c_{10}: "Recycling rate of municipal waste"
c_{11}: "Average CO_2 emissions per km from new passenger cars"
c_{12}: "net Greenhouse gas emissions"
c_{13}: "Bathing sites with excellent water quality by locality"
c_{14}: "Corruption Perceptions Index"
c_{15}: "Official development assistance as share of gross national income"

Due to the presence of zero values in the decision matrix, it was transformed into positive values using the Z-score standardization method, as shown in Table 3. The MPSI method was then applied to determine the weights for each criterion, thereby reducing subjectivity in the decision-making process. The resulting criterion weights are presented in Table 4 and visually depicted in Figure 2.

Table 3
Positive decision matrix

2021	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Opt.	-	+	-	+	+	+	+	+	+	+	-	-	+	-	+
Belgium	1.287	1.988	1.915	2.820	3.299	1.239	2.584	3.847	2.526	3.093	1.893	2.337	1.711	2.824	2.572
Bulgaria	3.614	1.775	1.567	1.067	1.715	1.567	1.037	1.088	1.155	1.610	3.261	1.416	1.759	0.668	1.353
Czechia	0.296	1.919	1.219	1.199	1.842	1.620	1.626	2.473	1.901	2.430	3.027	1.864	1.672	1.503	1.392
Denmark	1.188	2.246	1.716	2.699	3.006	3.014	3.368	3.386	2.795	3.207	0.429	1.600	2.532	3.866	3.672
Germany	2.104	6.449	1.120	1.402	3.113	1.743	2.564	3.746	2.526	3.761	1.689	1.634	2.016	3.310	3.869
Estonia	3.243	1.695	5.095	2.040	0.483	3.283	1.537	2.192	1.841	1.724	3.429	0.973	1.700	2.893	1.510
Ireland	1.336	2.063	2.064	3.915	2.546	1.201	4.506	1.414	4.664	0.079	1.629	3.612	1.804	2.893	2.060
Greece	2.995	1.870	4.250	2.142	1.510	1.968	1.607	1.854	1.296	0.079	2.055	2.059	3.264	1.155	1.510
Spain	3.515	3.789	1.617	2.598	2.781	1.870	1.915	1.831	1.720	2.072	2.481	3.044	3.552	1.989	1.903
France	1.683	3.169	2.461	2.760	4.023	1.757	2.396	2.710	2.177	2.458	1.389	2.247	3.625	2.685	2.886
Croatia	2.896	1.676	1.915	1.280	1.881	2.737	1.386	1.617	1.424	1.784	2.613	2.149	2.519	1.016	1.392
Italy	3.119	2.941	1.965	0.530	3.387	1.732	2.092	1.887	1.982	2.898	2.349	2.217	6.268	1.642	2.021
Cyprus	1.559	1.684	1.120	3.570	0.425	1.681	2.023	1.200	1.881	0.910	3.621	4.849	1.786	1.433	1.156
Latvia	3.936	1.698	3.058	2.273	1.764	3.618	1.358	0.997	1.471	2.474	3.423	2.988	1.702	1.850	1.353
Lithuania	3.094	1.690	2.263	3.489	1.774	2.483	1.456	1.471	1.854	2.485	3.015	0.623	1.687	1.989	1.432
Luxembourg	2.624	1.654	1.567	4.006	1.784	1.135	5.275	1.369	5.754	3.082	2.301	2.424	1.672	3.380	4.773
Hungary	1.262	1.831	1.617	0.997	0.513	1.329	1.397	2.079	1.545	1.974	2.853	1.713	1.672	0.738	1.982
Malta	2.327	1.655	1.120	1.969	0.649	1.169	1.906	0.941	2.130	0.818	1.083	2.552	1.754	1.503	2.218
Netherlands	1.708	2.590	1.170	3.297	3.319	1.239	2.923	2.755	2.728	3.218	0.579	2.258	1.757	3.449	2.925
Austria	1.782	1.870	1.219	1.959	2.977	3.155	2.634	3.814	2.580	3.473	1.845	3.165	1.672	2.893	2.100
Poland	1.807	1.670	2.412	1.777	2.009	1.453	1.400	1.842	1.592	2.268	3.045	2.586	1.840	1.642	1.471
Portugal	2.698	1.734	2.213	2.476	2.625	2.953	1.628	2.113	1.545	1.730	1.299	2.266	2.148	2.059	1.589
Romania	3.713	1.746	3.256	0.024	1.305	2.104	1.178	0.750	1.518	0.693	2.463	0.461	1.718	0.877	1.471

Table 3
Continued

2021	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Opt.	-	+	-	+	+	+	+	+	+	+	-	-	+	-	+
Slovenia	1.039	1.709	3.455	2.517	1.490	2.219	1.803	2.631	1.868	3.381	2.907	2.758	1.692	1.711	1.628
Slovakia	1.188	1.803	2.511	1.665	2.302	1.599	1.530	1.268	1.444	2.735	3.225	1.333	1.672	1.364	1.432
Finland	0.816	1.950	3.256	1.726	3.035	3.698	2.652	3.588	2.345	2.197	0.771	3.349	1.746	3.866	2.729
Sweden	2.029	1.992	1.716	2.658	3.299	5.291	3.077	3.994	2.594	2.224	0.171	0.378	1.915	3.658	4.458

Table 4
Weight values for the period 2019-2021

2019	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	0.066	0.041	0.058	0.084	0.085	0.062	0.054	0.088	0.047	0.090	0.067	0.066	0.041	0.088	0.063
2020	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	0.054	0.039	0.069	0.090	0.091	0.055	0.054	0.089	0.047	0.088	0.060	0.069	0.040	0.094	0.062
2021	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}
	0.047	0.036	0.084	0.092	0.092	0.053	0.053	0.093	0.045	0.105	0.054	0.071	0.038	0.073	0.065

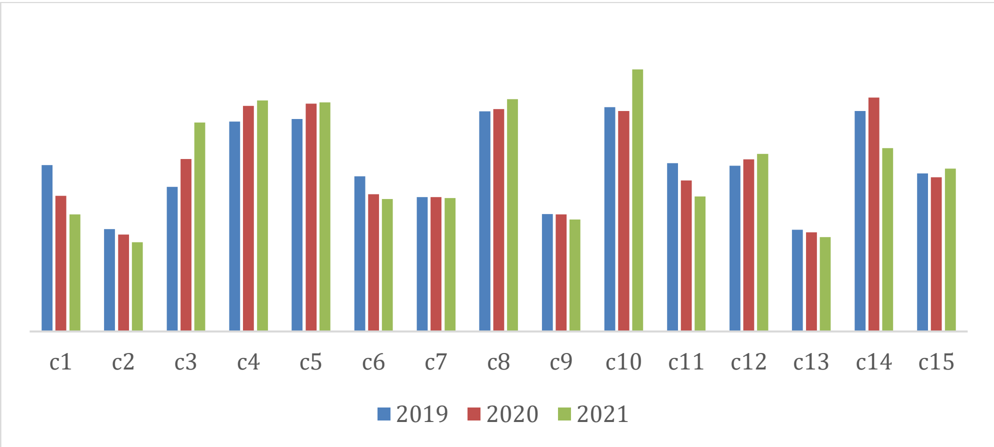

Fig. 2. Criteria weights for 2019-2021

After applying the MPSI method to determine the weights for each criterion, the steps of the RAPS method were sequentially implemented to rank the alternatives. In the first step, the criteria were normalized using Eqs. (8) and (9), as shown in Table 5. Next, a weighted decision matrix was created using the weights obtained from the MPSI method, as outlined in Eq. (10) and presented in Table 6. In the third step, the optimal alternative was identified, with the results displayed in Table 7. The decomposition of the optimal alternative and other alternatives was determined using Eqs. (11) and (12), with the results shown in Tables 7 and 8. The magnitude of each component for the optimal alternative was calculated using Eqs. (14-17), as presented in Table 9. Finally, the alternatives were ranked using Eqs. (18-20), and the rankings are shown in Table 10.

Table 5
Normalized decision matrix

Alt.	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}
Belgium	0.230	0.308	0.585	0.704	0.820	0.234	0.490	0.963	0.439	0.822	0.091	0.162	0.273	0.237	0.539
Bulgaria	0.082	0.275	0.715	0.266	0.426	0.296	0.197	0.272	0.201	0.428	0.053	0.267	0.281	1.000	0.283
Czechia	1.000	0.298	0.918	0.299	0.458	0.306	0.308	0.619	0.330	0.646	0.057	0.203	0.267	0.445	0.292
Denmark	0.249	0.348	0.653	0.674	0.747	0.570	0.638	0.848	0.486	0.853	0.399	0.236	0.404	0.173	0.769
Germany	0.141	1.000	1.000	0.350	0.774	0.329	0.486	0.938	0.439	1.000	0.101	0.232	0.322	0.202	0.811
Estonia	0.091	0.263	0.220	0.509	0.120	0.620	0.291	0.549	0.320	0.459	0.050	0.389	0.271	0.231	0.316
Ireland	0.222	0.320	0.543	0.977	0.633	0.227	0.854	0.354	0.811	0.021	0.105	0.105	0.288	0.231	0.432
Greece	0.099	0.290	0.264	0.535	0.375	0.372	0.305	0.464	0.225	0.021	0.083	0.184	0.521	0.579	0.316
Spain	0.084	0.587	0.693	0.648	0.691	0.353	0.363	0.458	0.299	0.551	0.069	0.124	0.567	0.336	0.399
France	0.176	0.491	0.455	0.689	1.000	0.332	0.454	0.678	0.378	0.653	0.123	0.168	0.578	0.249	0.605
Croatia	0.102	0.260	0.585	0.320	0.468	0.517	0.263	0.405	0.247	0.474	0.066	0.176	0.402	0.658	0.292
Italy	0.095	0.456	0.570	0.132	0.842	0.327	0.397	0.473	0.344	0.770	0.073	0.171	1.000	0.407	0.423
Cyprus	0.190	0.261	1.000	0.891	0.106	0.318	0.384	0.301	0.327	0.242	0.047	0.078	0.285	0.466	0.242
Latvia	0.075	0.263	0.366	0.567	0.439	0.684	0.257	0.250	0.256	0.658	0.050	0.127	0.272	0.361	0.283
Lithuania	0.096	0.262	0.495	0.871	0.441	0.469	0.276	0.368	0.322	0.661	0.057	0.608	0.269	0.336	0.300
Luxembourg	0.113	0.256	0.715	1.000	0.443	0.215	1.000	0.343	1.000	0.820	0.074	0.156	0.267	0.198	1.000
Hungary	0.235	0.284	0.693	0.249	0.127	0.251	0.265	0.521	0.269	0.525	0.060	0.221	0.267	0.906	0.415
Malta	0.127	0.257	1.000	0.492	0.161	0.221	0.361	0.236	0.370	0.217	0.158	0.148	0.280	0.445	0.465
Netherlands	0.173	0.402	0.958	0.823	0.825	0.234	0.554	0.690	0.474	0.856	0.296	0.168	0.280	0.194	0.613
Austria	0.166	0.290	0.918	0.489	0.740	0.596	0.499	0.955	0.448	0.923	0.093	0.120	0.267	0.231	0.440
Poland	0.164	0.259	0.464	0.444	0.499	0.275	0.265	0.461	0.277	0.603	0.056	0.146	0.293	0.407	0.308
Portugal	0.110	0.269	0.506	0.618	0.652	0.558	0.309	0.529	0.269	0.460	0.132	0.167	0.343	0.325	0.333
Romania	0.080	0.271	0.344	0.006	0.324	0.398	0.223	0.188	0.264	0.184	0.070	0.821	0.274	0.762	0.308
Slovenia	0.285	0.265	0.324	0.628	0.370	0.419	0.342	0.659	0.325	0.899	0.059	0.137	0.270	0.391	0.341
Slovakia	0.249	0.280	0.446	0.416	0.572	0.302	0.290	0.317	0.251	0.727	0.053	0.284	0.267	0.490	0.300
Finland	0.363	0.302	0.344	0.431	0.755	0.699	0.503	0.898	0.408	0.584	0.222	0.113	0.279	0.173	0.572
Sweden	0.146	0.309	0.653	0.664	0.820	1.000	0.583	1.000	0.451	0.591	1.000	1.000	0.306	0.183	0.934

Table 6
Weighted decision matrix

Alt.	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}
Belgium	0.011	0.011	0.049	0.065	0.075	0.012	0.026	0.090	0.020	0.086	0.005	0.011	0.010	0.017	0.035
Bulgaria	0.004	0.010	0.060	0.025	0.039	0.016	0.010	0.025	0.009	0.045	0.003	0.019	0.011	0.073	0.018
Czechia	0.047	0.011	0.077	0.028	0.042	0.016	0.016	0.058	0.015	0.068	0.003	0.014	0.010	0.033	0.019
Denmark	0.012	0.012	0.055	0.062	0.068	0.030	0.034	0.079	0.022	0.089	0.022	0.017	0.015	0.013	0.050
Germany	0.007	0.036	0.084	0.032	0.071	0.017	0.026	0.087	0.020	0.105	0.005	0.016	0.012	0.015	0.053
Estonia	0.004	0.009	0.018	0.047	0.011	0.033	0.016	0.051	0.014	0.048	0.003	0.028	0.010	0.017	0.021
Ireland	0.010	0.011	0.045	0.090	0.058	0.012	0.046	0.033	0.036	0.002	0.006	0.007	0.011	0.017	0.028
Greece	0.005	0.010	0.022	0.049	0.034	0.020	0.016	0.043	0.010	0.002	0.005	0.013	0.020	0.042	0.021
Spain	0.004	0.021	0.058	0.060	0.063	0.019	0.019	0.043	0.013	0.058	0.004	0.009	0.021	0.025	0.026
France	0.008	0.018	0.038	0.064	0.092	0.018	0.024	0.063	0.017	0.069	0.007	0.012	0.022	0.018	0.039
Croatia	0.005	0.009	0.049	0.030	0.043	0.027	0.014	0.038	0.011	0.050	0.004	0.012	0.015	0.048	0.019
Italy	0.004	0.016	0.048	0.012	0.077	0.017	0.021	0.044	0.015	0.081	0.004	0.012	0.038	0.030	0.028
Cyprus	0.009	0.009	0.084	0.082	0.010	0.017	0.020	0.028	0.015	0.025	0.003	0.006	0.011	0.034	0.016
Latvia	0.004	0.009	0.031	0.052	0.040	0.036	0.014	0.023	0.011	0.069	0.003	0.009	0.010	0.026	0.018
Lithuania	0.004	0.009	0.041	0.080	0.040	0.025	0.015	0.034	0.014	0.069	0.003	0.043	0.010	0.025	0.020
Luxembourg	0.005	0.009	0.060	0.092	0.041	0.011	0.053	0.032	0.045	0.086	0.004	0.011	0.010	0.014	0.065
Hungary	0.011	0.010	0.058	0.023	0.012	0.013	0.014	0.048	0.012	0.055	0.003	0.016	0.010	0.066	0.027
Malta	0.006	0.009	0.084	0.045	0.015	0.012	0.019	0.022	0.017	0.023	0.009	0.011	0.011	0.033	0.030
Netherlands	0.008	0.014	0.080	0.076	0.076	0.012	0.030	0.064	0.021	0.090	0.016	0.012	0.011	0.014	0.040
Austria	0.008	0.010	0.077	0.045	0.068	0.032	0.027	0.089	0.020	0.097	0.005	0.008	0.010	0.017	0.029
Poland	0.008	0.009	0.039	0.041	0.046	0.015	0.014	0.043	0.012	0.063	0.003	0.010	0.011	0.030	0.020

Table 6
Continued

Alt.	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}
Portugal	0.005	0.010	0.042	0.057	0.060	0.030	0.016	0.049	0.012	0.048	0.007	0.012	0.013	0.024	0.022
Romania	0.004	0.010	0.029	0.001	0.030	0.021	0.012	0.017	0.012	0.019	0.004	0.058	0.010	0.056	0.020
Slovenia	0.013	0.009	0.027	0.058	0.034	0.022	0.018	0.061	0.015	0.094	0.003	0.010	0.010	0.029	0.022
Slovakia	0.012	0.010	0.037	0.038	0.052	0.016	0.015	0.030	0.011	0.076	0.003	0.020	0.010	0.036	0.020
Finland	0.017	0.011	0.029	0.040	0.069	0.037	0.027	0.084	0.018	0.061	0.012	0.008	0.011	0.013	0.037
Sweden	0.007	0.011	0.055	0.061	0.075	0.053	0.031	0.093	0.020	0.062	0.054	0.071	0.012	0.013	0.061

Table 7
Optimal alternative

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}
	min	max	min	max	max	max	max	max	max	max	min	min	max	min	max
	q1	q2	q3	q4	q5	q6	q7	q8	q9	q10	q11	q12	q13	q14	q15
Q	0.047	0.036	0.084	0.092	0.092	0.053	0.053	0.093	0.045	0.105	0.054	0.071	0.038	0.073	0.065

Table 8
Decomposition of the optimal alternative

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}
	min	max	min	max	max	max	max	max	max	max	min	min	max	min	max
	q1	q2	q3	q4	q5	q6	q7	q8	q9	q10	q11	q12	q13	q14	q15
Q^{max}	-	0.036	-	0.092	0.092	0.053	0.053	0.093	0.045	0.105	-	-	0.038	-	0.065
Q^{min}	0.047	-	0.084	-	-	-	-	-	-	-	0.054	0.071	-	0.073	-

Table 9
Decomposition of alternatives

	u_1	u_2	u_3	u_4	u_5	u_6	u_7	u_8	u_9	u_{10}	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}
A1 U^{max}	-	0.011	-	0.065	0.075	0.012	0.026	0.090	0.020	0.086	-	-	0.010	-	0.035
A1 U^{min}	0.011	-	0.049	-	-	-	-	-	-	-	0.005	0.011	-	0.017	-
A2 U^{max}	-	0.010	-	0.025	0.039	0.016	0.010	0.025	0.009	0.045	-	-	0.011	-	0.018
A2 U^{min}	0.004	-	0.060	-	-	-	-	-	-	-	0.003	0.019	-	0.073	-
A3 U^{max}	-	0.011	-	0.028	0.042	0.016	0.016	0.058	0.015	0.068	-	-	0.010	-	0.019
A3 U^{min}	0.047	-	0.077	-	-	-	-	-	-	-	0.003	0.014	-	0.033	-
A4 U^{max}	-	0.012	-	0.062	0.068	0.030	0.034	0.079	0.022	0.089	-	-	0.015	-	0.050
A4 U^{min}	0.012	-	0.055	-	-	-	-	-	-	-	0.022	0.017	-	0.013	-
A5 U^{max}	-	0.036	-	0.032	0.071	0.017	0.026	0.087	0.020	0.105	-	-	0.012	-	0.053
A5 U^{min}	0.007	-	0.084	-	-	-	-	-	-	-	0.005	0.016	-	0.015	-
A6 U^{max}	-	0.009	-	0.047	0.011	0.033	0.016	0.051	0.014	0.048	-	-	0.010	-	0.021
A6 U^{min}	0.004	-	0.018	-	-	-	-	-	-	-	0.003	0.028	-	0.017	-
A7 U^{max}	-	0.011	-	0.090	0.058	0.012	0.046	0.033	0.036	0.002	-	-	0.011	-	0.028
A7 U^{min}	0.010	-	0.045	-	-	-	-	-	-	-	0.006	0.007	-	0.017	-
A8 U^{max}	-	0.010	-	0.049	0.034	0.020	0.016	0.043	0.010	0.002	-	-	0.020	-	0.021
A8 U^{min}	0.005	-	0.022	-	-	-	-	-	-	-	0.005	0.013	-	0.042	-
A9 U^{max}	-	0.021	-	0.060	0.063	0.019	0.019	0.043	0.013	0.058	-	-	0.021	-	0.026
A9 U^{min}	0.004	-	0.058	-	-	-	-	-	-	-	0.004	0.009	-	0.025	-
A10 U^{max}	-	0.018	-	0.064	0.092	0.018	0.024	0.063	0.017	0.069	-	-	0.022	-	0.039
A10 U^{min}	0.008	-	0.038	-	-	-	-	-	-	-	0.007	0.012	-	0.018	-
A11 U^{max}	-	0.009	-	0.030	0.043	0.027	0.014	0.038	0.011	0.050	-	-	0.015	-	0.019
A11 U^{min}	0.005	-	0.049	-	-	-	-	-	-	-	0.004	0.012	-	0.048	-
A12 U^{max}	-	0.016	-	0.012	0.077	0.017	0.021	0.044	0.015	0.081	-	-	0.038	-	0.028
A12 U^{min}	0.004	-	0.048	-	-	-	-	-	-	-	0.004	0.012	-	0.030	-
A13U^{max}	-	0.009	-	0.082	0.010	0.017	0.020	0.028	0.015	0.025	-	-	0.011	-	0.016
A13U^{min}	0.009	-	0.084	-	-	-	-	-	-	-	0.003	0.006	-	0.034	-
A14U^{max}	-	0.009	-	0.052	0.040	0.036	0.014	0.023	0.011	0.069	-	-	0.010	-	0.018
A14U^{min}	0.004	-	0.031	-	-	-	-	-	-	-	0.003	0.009	-	0.026	-
A15U^{max}	-	0.009	-	0.080	0.040	0.025	0.015	0.034	0.014	0.069	-	-	0.010	-	0.020
A15U^{min}	0.004	-	0.041	-	-	-	-	-	-	-	0.003	0.043	-	0.025	-
A16U^{max}	-	0.009	-	0.092	0.041	0.011	0.053	0.032	0.045	0.086	-	-	0.010	-	0.065
A16U^{min}	0.005	-	0.060	-	-	-	-	-	-	-	0.004	0.011	-	0.014	-

Table 9
Continued

	u_1	u_2	u_3	u_4	u_5	u_6	u_7	u_8	u_9	u_{10}	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}
A17U^{max}	-	0.010	-	0.023	0.012	0.013	0.014	0.048	0.012	0.055	-	-	0.010	-	0.027
A17U^{min}	0.011	-	0.058	-	-	-	-	-	-	-	0.003	0.016	-	0.066	-
A18U^{max}	-	0.009	-	0.045	0.015	0.012	0.019	0.022	0.017	0.023	-	-	0.011	-	0.030
A18U^{min}	0.006	-	0.084	-	-	-	-	-	-	-	0.009	0.011	-	0.033	-
A19U^{max}	-	0.014	-	0.076	0.076	0.012	0.030	0.064	0.021	0.090	-	-	0.011	-	0.040
A19U^{min}	0.008	-	0.080	-	-	-	-	-	-	-	0.016	0.012	-	0.014	-
A20U^{max}	-	0.010	-	0.045	0.068	0.032	0.027	0.089	0.020	0.097	-	-	0.010	-	0.029
A20 U^{min}	0.008	-	0.077	-	-	-	-	-	-	-	0.005	0.008	-	0.017	-
A21 U^{max}	-	0.009	-	0.041	0.046	0.015	0.014	0.043	0.012	0.063	-	-	0.011	-	0.020
A21 U^{min}	0.008	-	0.039	-	-	-	-	-	-	-	0.003	0.010	-	0.030	-
A22 U^{max}	-	0.010	-	0.057	0.060	0.030	0.016	0.049	0.012	0.048	-	-	0.013	-	0.022
A22U^{min}	0.005	-	0.042	-	-	-	-	-	-	-	0.007	0.012	-	0.024	-
A23 U^{max}	-	0.010	-	0.001	0.030	0.021	0.012	0.017	0.012	0.019	-	-	0.010	-	0.020
A23U^{min}	0.004	-	0.029	-	-	-	-	-	-	-	0.004	0.058	-	0.056	-
A24U^{max}	-	0.009	-	0.058	0.034	0.022	0.018	0.061	0.015	0.094	-	-	0.010	-	0.022
A24U^{min}	0.013	-	0.027	-	-	-	-	-	-	-	0.003	0.010	-	0.029	-
A25U^{max}	-	0.010	-	0.038	0.052	0.016	0.015	0.030	0.011	0.076	-	-	0.010	-	0.020
A25U^{min}	0.012	-	0.037	-	-	-	-	-	-	-	0.003	0.020	-	0.036	-
A26U^{max}	-	0.011	-	0.040	0.069	0.037	0.027	0.084	0.018	0.061	-	-	0.011	-	0.037
A26U^{min}	0.017	-	0.029	-	-	-	-	-	-	-	0.012	0.008	-	0.013	-
A27 U^{max}	-	0.011	-	0.061	0.075	0.053	0.031	0.093	0.020	0.062	-	-	0.012	-	0.061
A27U^{min}	0.007	-	0.055	-	-	-	-	-	-	-	0.054	0.071	-	0.013	-

Table 10
Perimeter similarity of each alternative

	max	min	Perimeter	Perimeter Similarity
Q	Q_k	Q_h	$P = Q_k + Q_h + \sqrt{Q_k^2 + Q_h^2}$	$PS_i = \frac{P_i}{P}$
	0.226	0.150	0.648	
	U_{ik}	U_{ih}	$P_i = U_{ik} + U_{ih} + \sqrt{U_{ik}^2 + U_{ih}^2}$	
Belgium	0.167	0.054	0.398	0.6143
Bulgaria	0.076	0.097	0.295	0.4561
Czechia	0.108	0.097	0.351	0.5413
Denmark	0.168	0.063	0.411	0.6344
Germany	0.174	0.087	0.455	0.7028
Estonia	0.097	0.038	0.238	0.3682
Ireland	0.131	0.050	0.322	0.4971
Greece	0.085	0.050	0.233	0.3595
Spain	0.123	0.064	0.326	0.5035
France	0.157	0.045	0.365	0.5642
Croatia	0.091	0.070	0.276	0.4270
Italy	0.134	0.058	0.338	0.5219
Cyprus	0.098	0.091	0.323	0.4990
Latvia	0.109	0.042	0.267	0.4121
Lithuania	0.125	0.065	0.331	0.5115
Luxembourg	0.167	0.063	0.409	0.6312
Hungary	0.087	0.090	0.302	0.4659
Malta	0.072	0.091	0.279	0.4305
Netherlands	0.164	0.084	0.433	0.6690
Austria	0.164	0.080	0.427	0.6589
Poland	0.104	0.051	0.270	0.4171
Portugal	0.117	0.051	0.294	0.4548
Romania	0.054	0.086	0.241	0.3719
Slovenia	0.137	0.043	0.324	0.5006
Slovakia	0.110	0.057	0.291	0.4489
Finland	0.145	0.039	0.334	0.5161
Sweden	0.173	0.106	0.482	0.7441

Table 11
Ranking alternatives by RAPS method

Alternatives	2019		2020		2021		Final rank	
	PSi	Rank	PSi	Rank	PSi	Rank	Value	Rank
Belgium	0.7156	6	0.6141	6	0.6143	7	0.6480	7
Bulgaria	0.6427	17	0.5081	19	0.4561	18	0.5356	19
Czechia	0.6578	14	0.5362	16	0.5413	9	0.5784	11
Denmark	0.7311	4	0.5972	7	0.6344	5	0.6542	6
Germany	0.7494	3	0.6553	3	0.7028	2	0.7025	3
Estonia	0.5689	27	0.3896	27	0.3682	26	0.4422	27
Ireland	0.6653	13	0.5596	10	0.4971	16	0.5740	14
Greece	0.5915	25	0.4397	26	0.3595	27	0.4636	26
Spain	0.6431	18	0.5384	13	0.5035	13	0.5617	15
France	0.7147	7	0.5916	9	0.5642	8	0.6235	8
Croatia	0.6378	19	0.5168	18	0.4270	22	0.5272	20
Italy	0.6770	12	0.5941	8	0.5219	10	0.5977	9
Cyprus	0.6196	21	0.5041	20	0.4990	15	0.5409	18
Latvia	0.6330	20	0.4634	24	0.4121	24	0.5028	22
Lithuania	0.6768	11	0.5374	14	0.5115	12	0.5752	13
Luxembourg	0.7082	8	0.6310	4	0.6312	6	0.6568	5
Hungary	0.6557	15	0.5299	17	0.4659	17	0.5505	16
Malta	0.5731	26	0.4499	25	0.4305	21	0.4845	24
Netherlands	0.7649	1	0.6751	2	0.6690	3	0.7030	2
Austria	0.7246	5	0.6238	5	0.6589	4	0.6691	4
Poland	0.6019	23	0.4804	21	0.4171	23	0.4998	23
Portugal	0.5993	24	0.4793	22	0.4548	19	0.5111	21
Romania	0.6111	22	0.4661	23	0.3719	25	0.4830	25
Slovenia	0.6842	10	0.5410	12	0.5006	14	0.5753	12
Slovakia	0.6535	16	0.5368	16	0.4489	20	0.5464	17
Finland	0.6953	9	0.5481	11	0.5161	11	0.5865	10
Sweden	0.7606	2	0.7118	1	0.7441	1	0.7388	1

As shown in Table 11, Sweden has been identified as the top performer, with the highest relative proximity value. The countries are ranked in terms of their progress toward achieving the sustainable development goals as follows: Sweden > Netherlands > Germany > Austria > Luxembourg > Denmark > Belgium > France > Italy > Finland > Czechia > Slovenia > Lithuania > Ireland > Spain > Hungary > Slovakia > Portugal > Cyprus > Bulgaria > Croatia > Latvia > Poland > Malta > Estonia. In contrast, Estonia is identified as the lowest-ranked country in this analysis.

In addition to the tabular representation of scores and rankings, we visualized the sustainability performance of European Union countries on a map (Figure 3). This geographical representation offers a clearer, more intuitive understanding of the spatial distribution of SDG achievements across the region. By color-coding the countries based on their final scores, we can easily observe regional trends. For instance, countries in Northern and Western Europe, such as Sweden, the Netherlands, and Germany, display consistently higher scores, reflecting their strong performance in achieving the SDGs. These regions appear in darker shades, indicating their leadership in sustainability efforts. Conversely, countries in Southern and Eastern Europe, such as Romania, Greece, and Estonia, are depicted in lighter colors, corresponding to lower scores. This visualization underscores the disparities in SDG performance across different parts of Europe, revealing areas where additional focus and improvement are necessary.

The map serves as a complementary tool to the numerical data, making it easier to communicate the overall findings of the study. By visually highlighting the relative positions of each country, stakeholders can quickly identify patterns, areas of concern, and best-performing nations. This geographical perspective is particularly useful for policymakers and organizations aiming to address regional sustainability gaps and strengthen their efforts toward achieving the OECD's SDG targets.

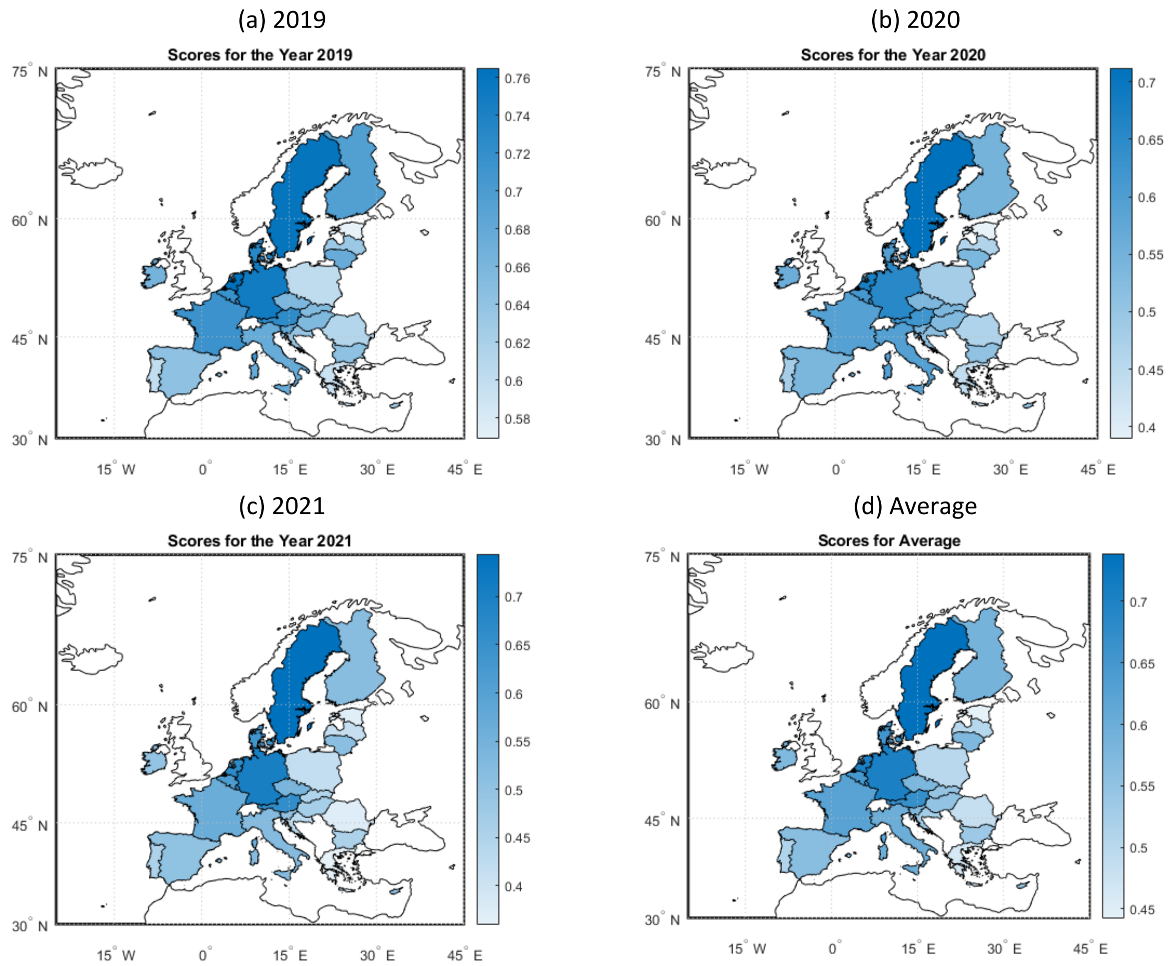

Fig. 3. Cartographic representation of the MPSI-RAPS scores over the years

5. Sensitivity Analysis

5.1. Weight Sensitivity Analysis

In this section, a sensitivity analysis is conducted to examine the impact of criterion weights on the ranking of alternatives. Following a similar approach to that of [39], the first scenario assumes equal weights for all criteria (w = 0.067). In the subsequent scenarios, one criterion is given greater importance than the others, with the more important criterion assigned a weight of 0.40, while the remaining criteria are assigned a weight of 0.043. The analysis explores the effects of varying criterion weights across 16 scenarios, as presented in Table 12, with the results illustrated in Figures 4-6.

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Table 12
Scenarios considered for sensitivity analysis

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}
Scen. 1	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Scen. 2	0.400	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 3	0.043	0.400	0.043	0.043	0.043	0.043	0.043	0.043	0,043	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 4	0.043	0.043	0.400	0.043	0.043	0.043	0.043	0.043	0,043	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 5	0.043	0.043	0.043	0.400	0.043	0.043	0.043	0.043	0,043	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 6	0.043	0.043	0.043	0.043	0.400	0.043	0.043	0.043	0,043	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 7	0.043	0.043	0.043	0.043	0.043	0.400	0.043	0.043	0,043	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 8	0.043	0.043	0.043	0.043	0.043	0.043	0.400	0.043	0,043	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 9	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.400	0,043	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 10	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0,400	0.043	0.043	0.043	0.043	0.043	0.043
Scen. 11	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0,400	0.043	0.043	0.043	0.043	0.043
Scen. 12	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0,400	0.043	0.043	0.043	0.043
Scen. 13	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0,400	0.043	0.043	0.043
Scen. 14	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0,400	0.043	0.043
Scen. 15	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0,400	0,043
Scen. 16	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0,400

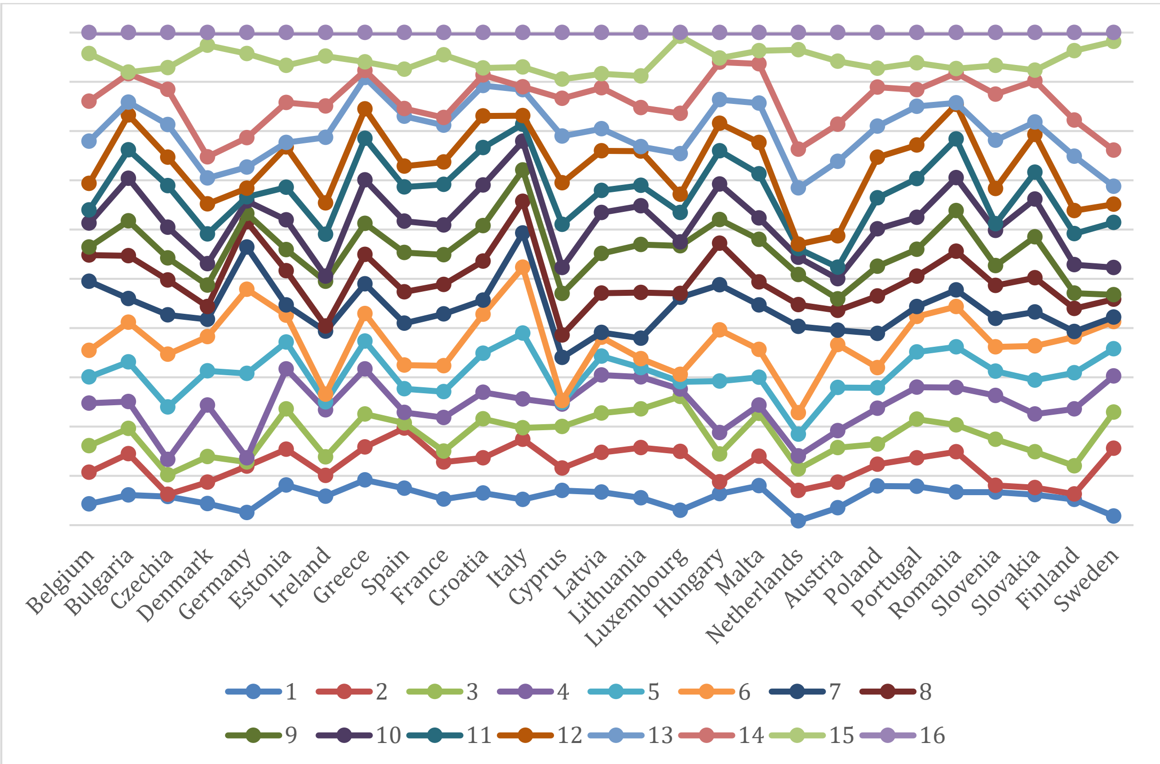

Fig. 4. Ranking of countries in various scenarios (2019)

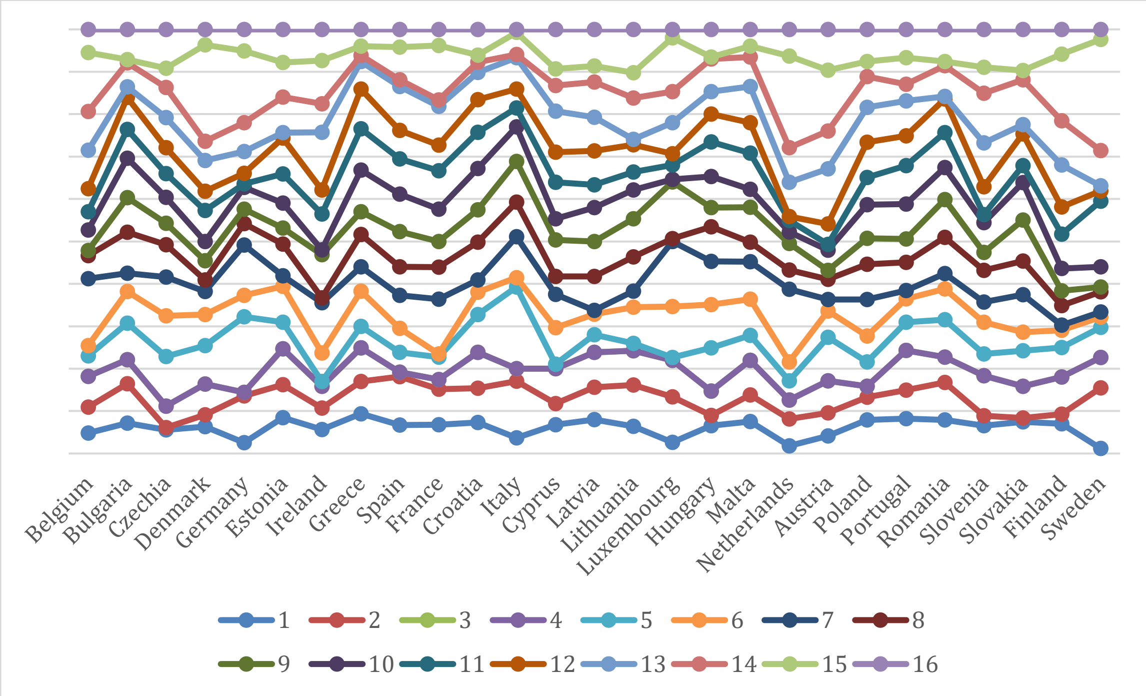

Fig. 5. Ranking of countries in various scenarios (2020)

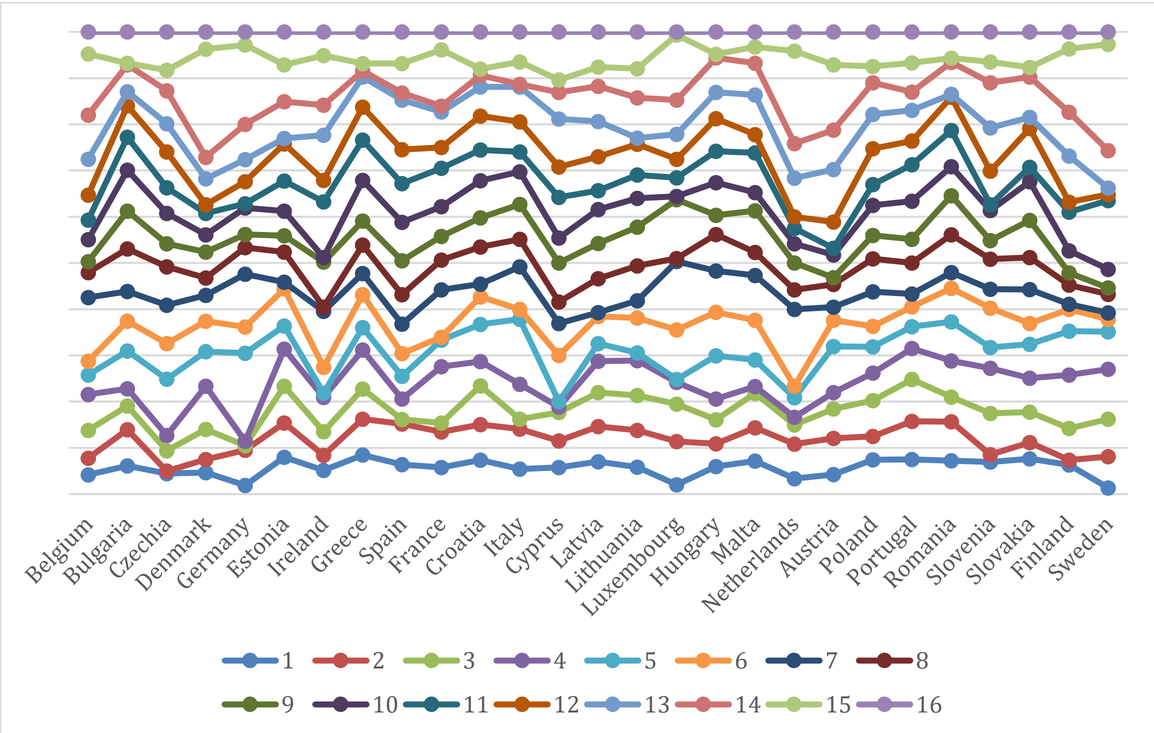

Fig. 6. Ranking of countries in various scenarios (2021)

The findings indicate that the ranking of alternatives based on the RAPS technique is highly sensitive to the assigned criterion weights. In the first scenario, where the weights are equal, Sweden consistently ranked highly for the years 2019, 2020, and 2021, with a strong positive correlation observed between the MPSI-RAPS rankings and those from scenario 1 (0.970 for 2019, 0.983 for 2020, and 0.978 for 2021). Overall, the rankings derived from different scenarios showed considerable variation, with no alternative to maintaining the same position across all rankings. The rankings based on changes in criterion weights were notably distinct from one another, suggesting that the rankings from scenario 1 are closer to those obtained using the MPSI-RAPS model.

Table 13
Correlation relationship between scenarios

2019	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
MPSI-RAPS	.970	.520	.711	.568	.386	.386	.192	.729	.796	.758	.888	.836	.217	.466	-.56	.774
2020	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
MPSI-RAPS	.983	.522	.759	.58	.429	.778	.054	.835	.672	.844	.849	.975	.305	.484	.55	.725
2021	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
MPSI-RAPS	.978	.738	.823	.662	.412	.753	.101	.819	.719	.819	.758	.88	.357	.505	-.49	.810

Table 13 presents a comparison of the rankings obtained using the MPSI-RAPS model across 16 scenarios. The results show that the ranking closest to the MPSI-RAPS ranking for the year 2019 was obtained with scenario 1 (0.970). In contrast, a negative correlation was observed between Scenario 15 and the MPSI-RAPS ranking. This trend was consistent for the years 2020 and 2021 as well. In Scenario 15, the criterion with the highest weight is c_{14} (Corruption Perceptions Index). Interestingly, this scenario led to ranking results that deviated from the expected outcomes in all three years.

5.2. Comparison with Other MCDM Techniques

This section presents a comparative analysis of the performance of the proposed system against traditional MCDM techniques documented in the literature. There are studies indicating that different MCDM techniques, which employ various normalization methods, result in different rankings [40-42]. Therefore, to test the robustness of the system proposed in this study, a comparison was made with MCDM techniques that utilize different normalization methods. The rationale behind selecting each method is provided below:

The CoCoSo model, based on an integrated SAW and exponentially weighted product model, was proposed by [43] and utilizes Max-Min normalization. The TOPSIS method, based on the principle that alternatives have the shortest distance to the positive ideal solution and the longest distance to the negative ideal solution, was developed by [44] and employs vector normalization. The WASPAS method, developed by [45], employs additive normalization. The MARCOS method, developed by [46], is based on defining the relationship between alternatives and reference values and implements linear normalization.

This comparison aims to assess the stability and reliability of the proposed system across varying normalization techniques. The rankings of European Union countries based on various MCDM techniques, RAPSI, CoCoSo, MARCOS, TOPSIS, and WASPAS, are presented in Figure 7, providing valuable insights into the relative performance of these countries under different evaluation methods. Below are some key observations:

i. Consistent Top Performers: Sweden and Germany consistently rank at the top across all methods, with Sweden taking first place in RAPSI and CoCoSo, while Germany ranks first in MARCOS, TOPSIS, and WASPAS. This suggests a strong alignment in these countries' sustainability and development performance, indicating robust policies and achievements that hold up well under various evaluation techniques.
ii. Variability in Rankings: While some countries maintain stable rankings across different methods, others show significant variability. For example, Austria ranks fourth under RAPSI but drops to 20th under WASPAS, and Luxembourg falls from 6th in RAPSI to 21st

in WASPAS. This variability may reflect the sensitivity of certain techniques to specific criteria or weighting schemes, highlighting the importance of the choice of MCDM techniques when evaluating country's performance.

iii. Mid-Tier Countries: Countries like the Netherlands, Denmark, and Belgium consistently appear in the top tier across the methods, though their precise rankings fluctuate slightly. These nations seem to perform well overall, regardless of the specific MCDM method used, indicating that they are generally well-rounded in their sustainability efforts.

iv. Outliers and Inconsistencies: Some countries, such as Austria and Luxembourg, experience sharp discrepancies in their rankings. For instance, Austria is ranked fourth under RAPSI but significantly lower in WASPAS (20th). Similarly, Luxembourg ranks sixth in RAPSI but 21st in WASPAS. These differences could be attributed to the criteria weights and the computational characteristics of the respective MCDM techniques, indicating that country performance may be more context-dependent than initially anticipated.

v. Bottom Performers: Greece, Romania, and Estonia consistently appear at the lower end of the rankings, regardless of the MCDM technique used. This implies that these countries may face systemic challenges in achieving sustainability targets, which are evident across multiple evaluations.

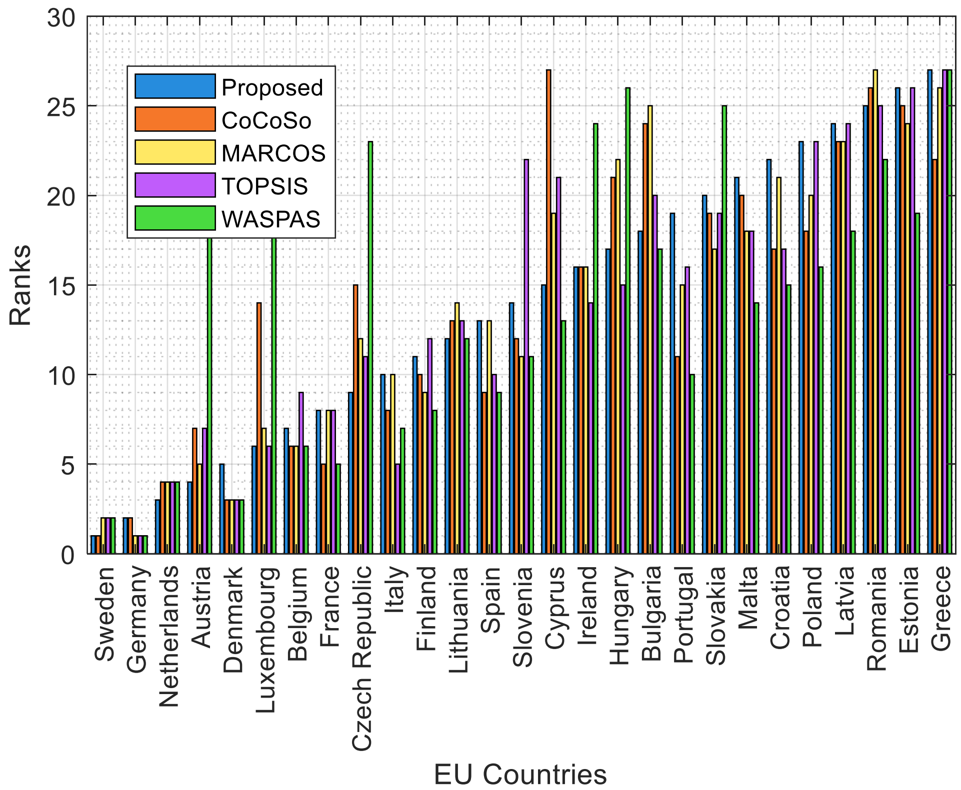

Fig. 7. Rank Comparison with traditional MCDM techniques (sorted by the RAPS method)

Table 14 presents the correlation coefficients between the different MCDM techniques (RAPSI, CoCoSo, MARCOS, TOPSIS, and WASPAS). These coefficients measure the degree of linear relationship between the rankings produced by each technique. Below are some observations:

i. The strongest correlations are observed between RAPSI and MARCOS (0.945) and RAPSI and TOPSIS (0.934). This suggests that these techniques produce very similar rankings of countries, indicating that they share a common approach or emphasize similar aspects of the criteria used for evaluation. As such, policymakers could use these techniques interchangeably without expecting major discrepancies in results.

ii. Similarly, the correlation between MARCOS and TOPSIS (0.908) reinforces the consistency between these methods, suggesting that they align closely in their treatment of the data.
iii. CoCoSo shows strong correlations with MARCOS (0.932) and RAPSI (0.850), indicating that while it generally aligns with these methods, there is still some divergence. The lower correlation with TOPSIS (0.882) suggests slight methodological differences that might cause it to rank certain countries differently, potentially reflecting different weighting schemes or evaluation priorities.
iv. CoCoSo also has a moderate correlation with WASPAS (0.753), implying that while some consistency exists, CoCoSo's ranking approach diverges more significantly from WASPAS than from other techniques.
v. WASPAS shows the lowest correlations with the other techniques, especially with RAPSI (0.623) and TOPSIS (0.625). This implies that WASPAS ranks countries differently compared to these methods, suggesting a distinct approach that might prioritize or de-emphasize different criteria. The moderate correlation with CoCoSo (0.753) and MARCOS (0.697) indicates some overlap, but overall, WASPAS appears to be an outlier in this analysis.

RAPSI, MARCOS, and TOPSIS form a tightly correlated group, indicating that these methods produce highly similar rankings. Policymakers could expect consistency in results when choosing between these techniques, though they may want to explore the nuanced differences that lead to slight variations

Table 14
Correlation coefficients with traditional MCDM techniques

	RAPSI	CoCoSo	MARCOS	TOPSIS	WASPAS
RAPSI	1.000000	0.850427	0.945055	0.934066	0.623321
CoCoSo	0.850427	1.000000	0.931624	0.881563	0.753358
MARCOS	0.945055	0.931624	1.000000	0.907814	0.696581
TOPSIS	0.934066	0.881563	0.907814	1.000000	0.625153
WASPAS	0.623321	0.753358	0.696581	0.625153	1.000000

6. Discussion

In the European Union, sustainable development involves complex processes aimed at fostering a knowledge-based economy, modernization, and the creation of a high-quality society with an improved standard of living [47]. The concept of sustainable development is a central and overarching goal enshrined in Article 2 of the Lisbon Treaty. This mandates all EU-27 countries to adopt and implement this strategy, working together in solidarity to achieve the established objectives [21].

This study incorporates a temporal dimension by analyzing three distinct years (2019, 2020, and 2021) to assess the extent to which 27 EU countries have achieved the SDGs. The analysis was carried out using the MPSI-RAPS model, based on 14 indicators sourced from the Eurostat database. The results reveal that the countries making the most significant progress toward achieving the SDGs during the 2019-2021 period are Sweden, the Netherlands, Germany, Austria, and Luxembourg. Notably, Sweden emerged as the top performer, while Estonia ranked last in terms of SDG progress.

Sweden has made progress in most of the considered goals. It holds a significant advantage over other EU countries, especially in terms of per capita real GDP, the share of renewable energy in energy consumption, average CO2 emissions, and net greenhouse gas emissions. The top three countries in all years (2019-2021) were Sweden, Netherlands, and Germany. The first of the two important common features of these three countries is that they have a high GDP. According to Eurostat data, Sweden's average GDP per capita for the period 2019-2021 is 44.123 euros. In the same period, this amount is 41.500 Euros and 35.377 Euros for the Netherlands and Germany, respectively. Another common feature among these countries is that they joined the EU many years ago. The Netherlands and Germany joined the EU in 1951, while Sweden became an EU member in 1975. Being under the protection of the EU for an extended period means putting in more effort in adopting sustainable development practices [23]. On the other hand, Estonia, Greece, Malta, and Romania have consistently ranked at the bottom every three years. Except for Malta, these countries are in Eastern Europe, with their respective dates of accession to the EU being 2004, 1981, 2004, and 2007. Estonia, ranked last, faces several challenges, including a low per capita GDP of 15.687 Euros, a high poverty risk, insufficient access to medical care, gender inequality in corporate leadership, and high CO2 emissions from newly registered passenger cars. Greece and Malta also encounter similar issues, such as medical care accessibility, high CO2 emissions, low GDP per capita, and low municipal waste recycling rates. Romania faces challenges including inadequate government support for agricultural research, poor medical care accessibility, low GDP, and high CO2 emissions. To improve their rankings and achieve the SDGs, these countries must address these issues, resolve key challenges, and work toward sustainable development, enabling them to compete with higher-ranking countries.

Several studies have examined the progress of EU countries in achieving the SDGs. For example, Brodny and Tutak [21] assessed the development of EU countries in terms of Goal 9 of the 2030 Agenda (building resilient infrastructure, promoting sustainable industrialization, and fostering innovation) from 2015 to 2020, using MCDM methods. The study employed TOPSIS, WASPAS, and EDAS methods for ranking, while weights were determined using Entropy, CRITIC, and standard deviation methods. The results showed that Luxembourg, the Netherlands, Denmark, Sweden, and Germany ranked in the top five, while Bulgaria, Greece, Romania, Cyprus, and Lithuania ranked at the bottom. In another study, Stanujkic *et al.,* [23] used the CoCoSo methodology and the Shannon Entropy method to evaluate the sustainable development progress of EU countries, identifying Sweden, Denmark, Germany, Finland, and France as the top five, while Romania, Bulgaria, Cyprus, Malta, and Estonia ranked at the bottom. Ayyildiz [24] focused on energy and climate sustainability in the EU, evaluating data from 2010, 2015, and 2020. In 2010, the top five countries were Sweden, Denmark, Austria, Portugal, and Croatia, with Cyprus, Bulgaria, Luxembourg, Poland, and Estonia in the bottom five. In 2015, Sweden, Denmark, Romania, Finland, and Austria ranked highest, while Cyprus, Bulgaria, Poland, Luxembourg, and Belgium ranked lowest. In 2020, Sweden, Denmark, Austria, Finland, and Romania topped the rankings, with Cyprus, Bulgaria, Poland, Luxembourg, and the Czech Republic at the bottom. In [33], the TOPSIS and VIKOR methods were applied to evaluate sustainable development in 2016. The rankings varied between methods: according to TOPSIS, the top five were Austria, Denmark, Germany, Finland, and Luxembourg, while Romania, Bulgaria, Poland, Lithuania, and Cyprus were at the bottom. Using VIKOR, the top five were Austria, France, Germany, Belgium, and Denmark, while Romania, Estonia, Cyprus, Croatia, and Spain ranked at the bottom. Piwowarski *et al.,* [34] used the TOPSIS method and the Vector Measurement Construction (VMCM) method to assess poverty reduction. Luxembourg, Finland, Austria, Malta, and Spain were the top performers, with Romania and Bulgaria at the bottom. Lastly, Martín and Carnero [28] applied the Analytic Hierarchy Process (AHP) to evaluate EU countries' progress toward the SDGs. The results highlighted Norway, Sweden, Denmark, the United Kingdom, and the Netherlands as the top achievers, while Romania and Bulgaria ranked lowest. Overall, these studies consistently highlight that Sweden, Denmark, and other Western European countries perform well in terms of sustainable development, while Romania, Bulgaria, and other Eastern European nations face significant challenges.

In this study, Sweden consistently ranks at the top, while Estonia is placed at the bottom. Based on the average rankings across the 2019-2021 period, the top five countries are Sweden, the Netherlands, Germany, Austria, and Luxembourg, while the bottom five include Estonia, Greece, Romania, Malta, and Poland. These findings align with conclusions drawn by other researchers, further validating the results of this study.

7. Conclusion

This study aims to assess the progress of EU countries in achieving the SDGs using MCDM methods. The evaluation is based on the SDGs of 27 countries, determined using 15 indicators for the 2019-2021 period. The MPSI-RAPS model was employed to determine the weights of the indicators and rank the alternatives accordingly. To ensure the robustness of the model, a sensitivity analysis was conducted, incorporating 16 different scenarios.

The final ranking results obtained using the MPSI-RAPS model reveal that the top five countries are Sweden, the Netherlands, Germany, Austria, and Luxembourg, while the bottom five are Estonia, Greece, Romania, Malta, and Poland. Notably, countries such as Czechia, Spain, Cyprus, Malta, and Portugal showed progress from 2019 to 2021. In contrast, Ireland, Croatia, Latvia, Slovenia, and Slovakia experienced a decline in their rankings relative to other countries. The sensitivity analysis, which involved 16 different scenarios, led to varying rankings based on changes in criterion weights. Correlation analysis indicates that, for 2019, the ranking closest to the MPSI-RAPS ranking was achieved in scenario 1 (equal weights), with a correlation coefficient of 0.970. Conversely, a negative correlation was observed between scenario 15 (S15) and the MPSI-RAPS ranking, a pattern that persisted for both 2020 and 2021.

At the conclusion of the study, the following key findings were observed: i) The results highlight the critical importance of the weight determination phase in solving decision problems. ii) Generally, countries that joined the EU earlier and have higher GDPs tend to rank higher in terms of sustainable development progress. iii) Most of the top-ranking countries in the context of sustainable development progress are in Western Europe, while most of the lower-ranking countries are in Eastern Europe. iv) The results are consistent with similar studies in literature, reinforcing the suitability of the model used for evaluating sustainable development progress.

The results of this study offer valuable insights into the sustainable development progress of EU countries. By identifying key challenges faced by countries and highlighting the necessary measures for advancing sustainability, the study provides useful information for policymakers. Moreover, given the lack of recent research on the sustainable development progress of EU countries, this study fills a critical gap in the literature. However, the study has some limitations, such as the use of only 15 indicators and the application of the MPSI-RAPS model. Future research could build on this by conducting a comparative analysis using alternative MCDM methods and incorporating the most recent data based on the 17 SDGs.

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Conflicts of Interest
The authors declare no conflicts of interest.

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