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EVALUATION OF HORIZON 2020 PROJECT PERFORMANCES OF ASSOCIATED COUNTRIES BY TRF-FUCOM AND M-OPARA METHODS

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Abstract

This study aimed to examine the success rankings of Associated Countries that participated in the Horizon 2020 programme, which was implemented from 2014 to 2020. Referring to the data of the European Commission limited with Associated Countries, the research is handled as a multiple criteria decision-making (MCDM) problem fort the first time in this respect. Eight evaluation criteria were weighted via the Trapezoidal Fuzzy Full Consistency Method (TrF-FUCOM). On the other hand, sixteen Associated Countries were ranked by Modified Objective Pairwise Adjusted Ratio Analysis Method (M-OPARA). To validate the consistency of the employed ranking method, two sensitivity analyses were conducted. The ranking of the highest performing Associated Countries in the Horizon 2020 programme was determined as follows: Switzerland, Israel, Norway, Türkiye, Iceland, Serbia, Bosnia and Herzegovina, the Faroe Islands, Moldova, Montenegro, North Macedonia, Tunisia, Georgia, Armenia, and Albania.

Keywords: *Horizon 2020, Associated Countries, Linear Programming, FUCOM, OPARA*
JEL Classification: *C44, D81, O32*

ORTAK ÜLKELERİN UFUK 2020 PROJE PERFORMANSLARININ TRF-FUCOM VE M-OPARA YÖNTEMLERİYLE DEĞERLENDİRİLMESİ

Öz

Bu çalışmada 2014-2020 yılları arasında uygulanan Ufuk 2020 programına katılan Ortak Ülkelerin başarı sıralamalarının incelenmesi amaçlanmıştır. Avrupa Komisyonu'nun üye ülkelerle kısıtlı verilerini temel alan araştırma, bu açıdan ilk defa çok kriterli karar verme (ÇKKV) problemi olarak ele alınmıştır. Sekiz değerlendirme kriteri Trapezoidal Fuzzy Full Consistency Method (TrF-FUCOM) ile ağırlıklandırılmıştır. Öte yandan, on altı Ortak Ülke Modified Objective Pairwise Adjusted Ratio Analysis Method (M-OPARA) ile sıralanmıştır. Kullanılan sıralama yönteminin tutarlılığını doğrulamak için iki farklı duyarlılık analizi yapılmıştır. Ufuk 2020 programında en yüksek performans gösteren Ortak Ülkelerin sıralaması ise İsviçre, İsrail, Norveç, Türkiye, İzlanda, Sırbistan, Bosna Hersek, Faroe Adaları, Moldova, Karadağ, Kuzey Makedonya, Tunus, Gürcistan, Ermenistan ve Arnavutluk şeklinde belirlenmiştir.

Anahtar Kelimeler: *Ufuk 2020, Ortak Ülkeler, Doğrusal Programlama, FUCOM, OPARA*
JEL Sınıflandırması: *C44, D81, O32*

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1. Introduction

The concept of "project", which represents one of the most significant alternative sources of financing for organizations in contemporary societies, is defined as a sequence of activities designed to achieve specific objectives within a predetermined timeframe and budget. For an initiative to be acknowledged as a project, it must possess clearly defined target groups and final beneficiaries, along with established coordination, management, financial oversight, and a comprehensive monitoring and evaluation system (European Commission: Directorate-General for Development and Relations with African, 2004: 1-8).

On the other hand, a "grant" refers to an unconditional financial contribution extended by a contracting authority to beneficiaries, contingent upon the fulfilment of specified criteria. Grants issued by the European Union (EU) are typically financed through the EU's general budget or the European Development Fund (EDF). Within the framework of these practices, two distinct types of financial support can be identified. The former is the "Action Grant", which is allocated to actions that facilitate the achievement of one or more of the EU's policy priorities. The latter, "Operation Grant," serves nonproject-based current expenditures necessary for organizations that assist in advancing one or more of the EU's policy priorities (European Commission Directorate-General for International Partnerships, 2021: 28; Gündüç, 2022: 9).

Since 1984, the European Union has placed significant emphasis on research and innovation activities (R&I) to attain competitive advantage, enhance resilience, and foster technological independence. In this context, Horizon 2020, which spanned the years 2014-2020 and allocated a budget of 75.6 billion Euros, was executed as part of the eighth framework program. The Horizon 2020, designed to foster excellence in scientific research, enhance industrial leadership, and address societal challenges through a focus on R&I activities, has garnered over one million individual applications from 177 distinct countries since its inception and funded approximately 35,000 projects (European Commission, 2024a: 1).

By challenging international R&I projects, the Horizon 2020 program has made substantial contributions to scientific breakthroughs and advancements in emerging fields of science and technology, particularly in composite materials, chemical engineering, quantum mechanics, and medical science. This program has also been instrumental in promoting scientific excellence on a global scale, with 33 Nobel Laureates having received support from the program either prior to or following their award (European Commission, 2024b: 1).

While the Horizon 2020 program was designed primarily for EU Member States, Associated Countries are also afforded the opportunity to participate under the same conditions, as stipulated in Article 7 of the Horizon 2020 Regulation. As of January 1, 2027, the countries eligible to apply for the Horizon 2020 program, designated as Associated Countries, include Albania, Armenia, Bosnia and Herzegovina, the Faroe Islands, Georgia, Iceland, Israel, Moldova, Montenegro, North Macedonia, Norway, Serbia, Switzerland, Tunisia, Türkiye, and Ukraine (European Commission, 2025b).

The program topics addressed under Horizon 2020 for both European Union Member States and Associated Countries encompassed the following areas: "Agriculture and Forestry, Biobased Industries, Biotechnology, Energy, Environment and Climate Action, Food and Healthy Diet, Funding Researchers, Health, Information and Communication Technology (ICT) Research and Innovation, Innovation, International Cooperation, Key Enabling Technologies, Oceans and Seas, Partnerships with Industry and Member States, Plastics, Raw Materials, Research Infrastructures, Security, Small and Medium-sized Enterprises (SMEs), Social Sciences and Humanities, Society, Space, the European Research Area (ERA), and Transport" (European Commission, 2025a).

As one of the countries eligible to apply for the Horizon 2020 program as an Associated Country, Türkiye submitted a total of 10,261 project applications between 2014 and 2020, with an acceptance rate of 10.25% for these applications. A total of 1,189 institutions participated in this program, yielding a net European Union contribution of €275.2 million to Türkiye.

In accordance with the explanations regarding the Horizon 2020 program presented thus far, the primary objective of this research is to evaluate and rank the performance of the Associated Countries participating in this initiative. The data concerning the Associated Countries has been sourced from the official website of the European Commission. Therefore, this study was structured as a MCDM problem to evaluate these countries' performance using the indicators presented by the European Commission. The Tr-F FUCOM method was employed to ascertain the significance and weighting of eight evaluation criteria, whereas the M-OPARA method was utilized to conduct the performance ranking of sixteen Associated Countries. To validate the consistency of the employed ranking method, a sensitivity analysis was conducted, and the resulting rankings were compared with the outcomes derived from nine distinct traditional MCDM methods.

The initial part of the study comprises the Introduction section, which delineates the content and scope of the Horizon 2020 programme and incorporates a literature review on relevant issues. This is followed by the Materials and Methods section, which articulates the data and methodologies employed in the research. The Findings section subsequently presents the calculation results. While the outcomes obtained through the application of the employed methodologies are presented and evaluated in the Results and Discussion section, the final assessment of the research is articulated in the Conclusion section.

2. Literature Review

Examples of previous studies, that encompass the Horizon 2020 programme, and the methodologies employed in the research, are presented below.

Veugelers et al. (2015) conducted a study to examine the effectiveness of the Horizon 2020 program, which was implemented to mitigate stagnation in research, development and innovation activities within the European Union. This research examined the extent to which geographical conditions were considered during the implementation of the program, the policies proposed, the utilization of instruments beyond the provided funds, and the efforts made by the countries in this context. In his study, Enger (2018) examined the determinants of participation in the Horizon 2020 programme and the impact of network position on the likelihood of applying for and acceptance of cooperation projects. The primary findings of the study indicate that possessing a robust and influential network significantly enhances the probability of project acceptance. Kim and Yoo (2019) conducted a study to analyse and evaluate the alterations in the European Union's science and technology policies resulting from the implementation of Horizon 2020 applications. Additionally, the study aimed to design and facilitate potential research on international cooperation with the EU. The principal themes highlighted included the establishment of ecosystems through mutual complementarity among industries, addressing social challenges through science and technology, enhancing the participation of SMEs, and bolstering knowledge sharing and collaboration with non-EU countries. Wanzenböck et al. (2020) conducted a regression analysis to examine the success determinants of collaborative projects, focusing on the parameters of "network visibility," "level of experience and familiarity," and "research capabilities and excellence or reputation of consortium members." The findings of the study indicated that the likelihood of success for Horizon 2020 projects is increased when partnerships involve Western European countries characterized by high levels of experience and reputation. In their study aimed at elucidating the innovation scorecards of SMEs operating in continental Europe through the analysis of projects conducted under the Horizon 2020 framework, Ferrer-Serrano et al. (2021) assessed the relationships among European countries that support innovation and their respective positions within this network. Furthermore, they identified the key actors active in this network, including major science centres, and examined their relationships with both industry and public institutions. In their study examining the impact of the Horizon 2020 program on the growth and innovation capabilities of firms, Mulier and Samarin (2021) revealed that recipient firms were able to increase their investments in both tangible and intangible assets, attain greater turnover and employment growth, and submit a greater number of patent applications. Tabarés et al. (2022) investigated the efficacy of strategies formulated under the Horizon 2020 programme aimed at enhancing the principles of responsible research and innovation (RRI). The findings of their study revealed that the implementation of the RRI concept is constrained by prevailing values, scientific cultures, economic objectives, limited resources, and ambiguities regarding the definition of RRI. In their study, Kalampokis et al. (2023) investigated the extent to which Horizon 2020 projects and pilot applications facilitated the development of new technologies within the public sector and assessed the impact of these technologies on e-government practices. Kosztyán et al. (2024) introduced a novel link prediction model aimed at analysing and forecasting the future dynamics of Horizon 2020 collaboration networks. The research evaluated the geographical distribution of participants exhibiting robust connections. Furthermore, the principal factors influencing these collaborations were identified. Ultimately, the findings indicated that the collaborations formed within the projects were predominantly concentrated in the Western European region. Tenhunen-Lunkka and Honkanen (2024) sought to identify the key success factors influencing the management of research, development, and innovation projects funded by the European Union, including Horizon 2020, through a survey methodology. The principal findings of the study indicated that the three most significant success factors are interorganizational communication, trust, and collaboration.

Previous studies on the FUCOM and OPARA methods, including their fuzzy versions, utilized in this study are summarized in Table 1.

Table 1: **Literature Review of FUCOM and OPARA Methods**

Author	Subject
FUCOM	
(Fazlollahtabar et al., 2019)	"Forklift selection"
(Stević & Brković, 2020)	"Evaluation of human resources"
(Durmić et al., 2020)	"Sustainable supplier selection"
(Abdullah et al., 2022)	"Evaluation of healthcare institutions"
(Badi et al., 2022)	"Measuring sustainability performance indicators"
(Saha et al., 2022)	"Selection of healthcare waste treatment method"
(Khosravi et al., 2022)	"Selecting of organizational structure for hospitals"
(Popović et al., 2022)	"Optimization of logistics process"
(Pajić et al., 2025)	"Selection of efficient suppliers"
(Andrejić et al., 2023)	"Selection of distribution channel"
(Tešić et al., 2023)	"Human resource management"
(Chakraborty et al., 2023)	"Performance evaluation of the Indian National Parks"
(Dey et al., 2023)	"Determination of optimal bacterial concentrations"
(N. Jomhari et al., 2024)	"Modernizing legacy software"
(Sridharam & Ghose, 2024)	"Assessment of groundwater potential"
(Milinković et al., 2025)	"Evaluation of potentials for urban planning"
(Rohit et al., 2025)	"Rainfall analysis"
(Paul et al., 2025)	"Evaluation of seismic hazard"
OPARA	
(Keshavarz-Ghorabaee et al., 2024)	"Personnel evaluation and selection"
(Vo, 2024)	"Assessment of a faculty's scientific research capacity"
(Milinković et al., 2025)	"Evaluation of potentials for urban planning"

A review of prior studies on the Horizon 2020 programme reveals a range of critical issues, including the geographical distribution of the programme, its impact on the science and technology policies of the European Union, its contributions to the innovation scorecards of SMEs, its influence on corporate assets, its role in advancing the concept of responsible research and innovation, and the determinants of participation in the programme and the success factors associated with collaborative projects. However, no comprehensive performance evaluation has been conducted regarding the utilization rates of the Horizon 2020 programme thus far. Therefore, the primary contribution of this study to the existing literature lies in its novel approach to framing the issue as a MCDM problem for the first time. Additionally, the integration of the TrF-FUCOM and M-OPARA methods is presented as a secondary contribution to the literature.

3. Materials and Methods

The data needed for this research, which aims to determine the performance rankings of the Associated Countries benefiting from the Horizon 2020 programme implemented between 2014 and 2020, were obtained from the statistical data available on the official website of the European Commission.

The TrF-FUCOM method was employed to ascertain the relative importance of these eight criteria and to establish their weights in comparison to other criteria. The M-OPARA method was subsequently employed to rank the alternatives based on their success among the sixteen Associated Countries. A sensitivity analysis was conducted to assess the stability of the ranking method employed. Furthermore, the results of this ranking were compared with those derived from nine traditional MCDM methods.

The implementation steps followed throughout the research are presented in Table 2.

Table 2: **Implementation Steps of the Research**

Determination Of Criterion Weights	Ordering The Alternatives	Sensitivity Analysis
1. definition of criteria	1. construction of initial decision matrix	1. implementation of global robust sensitivity
2. determination of significance level of criteria	2. obtaining the range-based pairwise adjusted ratio	2. comparison with nine MCDM methods
3. fuzzy comparison of the most important criterion with other criteria	3. obtaining the linearity-based pairwise adjusted ratio	
4. determination of optimal fuzzy weights of each criterion	4. obtaining theaggregated pairwise adjusted ratio	
	5. calculation of final scores for each alternative	

3.1. TrF-FUCOM Method

Introduced to the academic literature by Pamucar et al. in 2018, the FUCOM method enables subjective weighting of criteria while offering several distinct advantages owing to its straightforward solution steps and its capacity for involving multiple decision-makers (Pamučar et al., 2018). Compared with other analogous methods, such as the Analytic Hierarchy Process (AHP) (Saaty, 2004) and Best-Worst Method (BWM) (Rezaei, 2015), which necessitate $n(n-1)/2$ and $(2n-3)$ pairwise comparisons, respectively, the FUCOM method requires only $(n-1)$ comparisons to ascertain criteria weights. Moreover, while the AHP and BWM methods exhibit certain deviations, total transitivity is occasionally overlooked, resulting in diminished consistency within the model and impacting the reliability of the outcomes. In contrast, the FUCOM method prioritizes the maximization of result consistency and serves as a significant approximation for establishing the reliability of criteria weights. Given that the parameters of some decisions cannot be precisely predicted in real-life applications, fuzzy approaches have been developed for the FUCOM method and are also employed in various criterion weighting methods. The literature review indicates that fuzzy applications of FUCOM can be represented in both triangular (Pamucar & Ecer, 2020) and trapezoidal (Majumder, 2023) forms. Consequently, these advantages of the method contributed to its selection during the criteria weighting phase of our study.

The procedure of the TrF-FUCOM method, employed for weighting the evaluation criteria, is delineated as follows (Garg et al., 2022).

“Step1. Definition of criteria

Determination of the n number of evaluation criteria to be utilized in the study by decision-makers.

Step 2. Determination of the significance level of the criteria

The ordering of criteria to be employed in the study is arranged in descending order of importance as $\gamma_{j(1)} > \gamma_{j(2)} > \gamma_{j(3)} > \cdots > \gamma_{j(k)}$, where the most significant criterion is denoted by $\gamma_{j(1)}$ and where k indicates the order of the relevant criteria. In instances where criteria are deemed equally important, the notation of equality $(=)$ is substituted by the symbol $>$.

Step 3. Fuzzy comparison of the most important criterion with other criteria

The most important criterion is evaluated in relation to the other criteria through the application of trapezoidal fuzzy numbers, utilizing the linguistic measures delineated in Table 3.

Table 3: **Trapezoidal Linguistic Scale for Pairwise Comparisons**

Linguistic terms	Trapezoidal Fuzzy Measures $(\boldsymbol{l}, \boldsymbol{m}, \boldsymbol{n}, \boldsymbol{s})$	Score Index (SI)
Absolutely More Important	$(8, \frac{17}{2}, 9, 9)$	9
Intermediate Scales	$(\sigma - 1, \sigma - \frac{1}{2}, \sigma + \frac{1}{2}, \sigma + 1)$	$\sigma = 1, 2, 3, 4, 5, 6, 7, 8$
Equally Important	$(1, 1, 1, 1)$	1

Since the comparison is conducted in this manner, the total number of pairwise comparisons among the criteria is $n - 1$. As a result of these comparisons, the fuzzy importance level for each criterion $(\widetilde{\omega}_{\gamma_{j(k)}})$ is established.

Upon this process, the determination of comparative fuzzy importance among the criteria $\left(\tilde{\vartheta}_{\frac{k}{(k+1)}}\right)$ is performed via Equation (1).

$$\tilde{\vartheta}_{\frac{k}{(k+1)}} = \frac{\widetilde{\omega}_{\gamma_{j(k+1)}}}{\widetilde{\omega}_{\gamma_{j(k)}}} = \frac{\left(\widetilde{\omega}^{l}_{\gamma_{j(k+1)}}, \widetilde{\omega}^{m}_{\gamma_{j(k+1)}}, \widetilde{\omega}^{n}_{\gamma_{j(k+1)}}, \widetilde{\omega}^{s}_{\gamma_{j(k+1)}}\right)}{\left(\widetilde{\omega}^{l}_{\gamma_{j(k)}}, \widetilde{\omega}^{m}_{\gamma_{j(k)}}, \widetilde{\omega}^{n}_{\gamma_{j(k)}}, \widetilde{\omega}^{s}_{\gamma_{j(k)}}\right)} \tag{1}$$

A trapezoidal fuzzy vector of criteria can be derived from this operation via Equation (2).

$$\vartheta = (\tilde{\vartheta}_{1/2}, \tilde{\vartheta}_{2/3}, \tilde{\vartheta}_{3/4}, \dots, \tilde{\vartheta}_{k/(k+1)}) \tag{2}$$

where $\tilde{\vartheta}_{\frac{k}{(k+1)}}$ indicates the relative importance of the k^{th} criterion over the $(k+1)^{th}$ criterion.

Step 4. Determination of the optimal fuzzy weights of each criterion

In the last step of this implementation, trapezoidal fuzzy weight coefficients for each criterion $(\tilde{p}_1, \tilde{p}_2, \tilde{p}_3, \dots, \tilde{p}_n)^T$ are calculated. To perform this operation, the final values of these weight coefficients should satisfy the following two conditions:

Condition 1: The ratio of weight coefficients for each consecutive criterion is equivalent to the relative importance of the corresponding criterion, as expressed in Equation (3).

$$\frac{\tilde{p}_k}{\tilde{p}_{(k+1)}} = \tilde{\vartheta}_{k/(k+1)} \tag{3}$$

Condition 2: In alignment with the property of transitivity, pairwise comparisons of non-consecutive criteria are conducted via Equation (4).

$$\frac{\tilde{p}_k}{\tilde{p}_{(k+2)}} = \tilde{\vartheta}_{k/(k+1)} \otimes \tilde{\vartheta}_{(k+1)/(k+2)} \tag{4}$$

The minimum value of deviations from the maximum consistency (DMC) (λ) can be satisfied if this transitivity condition is fulfilled. Therefore, by obtaining the minimum λ value, the conditions of $\left|\frac{\tilde{p}_k}{\tilde{p}_{(k+1)}} - \tilde{\vartheta}_{k/(k+1)}\right| \le \lambda$ and $\left|\frac{\tilde{p}_k}{\tilde{p}_{(k+2)}} - \tilde{\vartheta}_{k/(k+1)} \otimes \tilde{\vartheta}_{(k+1)/(k+2)}\right| \le \lambda$ are also ensured. To obtain the optimal trapezoidal fuzzy weight coefficients $(\tilde{p}_1, \tilde{p}_2, \tilde{p}_3, \dots, \tilde{p}_n)^T$ of each criterion, the nonlinear optimization Equation (5) should be constructed as

$$\min \lambda$$
$$s.t. \begin{cases} \left|\frac{\tilde{p}_k}{\tilde{p}_{(k+1)}} - \tilde{\vartheta}_{k/(k+1)}\right| \le \lambda \\ \left|\frac{\tilde{p}_k}{\tilde{p}_{(k+2)}} - \tilde{\vartheta}_{k/(k+1)} \otimes \tilde{\vartheta}_{(k+1)/(k+2)}\right| \le \lambda \\ \sum_{j=1}^{n} \tilde{p}_j = 1 \\ 0 \le p_j^l \le p_j^m \le p_j^n \le p_j^s \\ j = 1,2,3, \dots\dots, n \end{cases} \tag{5}$$

Since it is essential to satisfy $\frac{\tilde{p}_k}{\tilde{p}_{(k+1)}} - \tilde{\vartheta}_{k/(k+1)} = 0$ and $\frac{\tilde{p}_k}{\tilde{p}_{(k+2)}} - \tilde{\vartheta}_{k/(k+1)} \otimes \tilde{\vartheta}_{(k+1)/(k+2)} = 0$ for maximum consistency, the nonlinear model in Equation (5) can be reorganized as in Equation (6)

$$\min \lambda$$
$$s.t. \begin{cases} \left|\tilde{p}_k - \tilde{p}_{(k+1)} \otimes \tilde{\vartheta}_{k/(k+1)}\right| \le \lambda \\ \left|\tilde{p}_k - \tilde{p}_{(k+2)} \otimes \tilde{\vartheta}_{k/(k+1)} \otimes \tilde{\vartheta}_{(k+1)/(k+2)}\right| \le \lambda \\ \sum_{j=1}^{n} \tilde{p}_j = 1 \\ 0 \le p_j^l \le p_j^m \le p_j^n \le p_j^s \\ j = 1,2,3, \dots\dots, n \end{cases} \tag{6}$$

where $\tilde{p}_j = (p_j^l, p_j^m, p_j^n, p_j^s)$ and where $\tilde{\vartheta}_{k/(k+1)} = (\tilde{\vartheta}_{k/(k+1)}^l, \tilde{\vartheta}_{k/(k+1)}^m, \tilde{\vartheta}_{k/(k+1)}^n, \tilde{\vartheta}_{k/(k+1)}^s)$.

Finally, the fuzzy values of each criterion are transformed into crisp values via Equation (7)".

$$R(\tilde{p}_j^*) = \frac{p_j^{l^*} + p_j^{m^*} + p_j^{n^*} + p_j^{s^*}}{6} \tag{7}$$

In addition, let $\tilde{A}_1 = (l_1, m_1, n_1, s_1)$ and $\tilde{A}_2 = (l_2, m_2, n_2, s_2)$ be two trapezoidal fuzzy numbers. In that case, the fundamental arithmetic operations involving trapezoidal fuzzy numbers are performed according to the general principles indicated in Table 4.

Table 4: **Arithmetic Operations with Trapezoidal Fuzzy Numbers**

Arithmetic Operation	Method
Addition	$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, n_1 + n_2, s_1 + s_2)$
Subtraction	$\tilde{A}_1 \ominus \tilde{A}_2 = (l_1 - s_2, m_1 - n_2, n_1 - m_2, s_1 - l_2)$
Multiplication	$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1.l_2, m_1.m_2, n_1.n_2, s_1.s_2)$
Division	$\tilde{A}_1 \oslash \tilde{A}_2 = (l_1/s_2, m_1/n_2, n_1/m_2, s_1/l_2)$
Multiplication by a fixed number	$k \otimes \tilde{A} = (k.l, k.m, k.n, k.s)$
Reverse operation	$\tilde{A}^{-1} = (l, m, n, s)^{-1} = (1/s, 1/n, 1/m, 1/l)$

3.2. M-OPARA Method

Introduced in 2024 by Keshavarz-Ghorabaee et al. (2024), the OPARA method represents one of the most recent advancements in MCDM approaches. Unlike traditional MCDM methodologies, the OPARA method aims to mitigate information loss by avoiding normalization techniques. This approach employs pairwise adjusted ratios that seek to maintain the inherent characteristics of the original data, thereby facilitating a comprehensive assessment of each alternative. This method also involves two adjustment parameters. The former parameter modifies the pairwise adjusted ratios in accordance with the range of each criterion, thereby mitigating the influence of criteria with high ranges. The latter parameter, which is appreciated by the decision maker, seeks to diminish the adverse effects of nonlinear data by considering the linearity of the criterion.

The methodology employed in this study encompasses the following steps (Keshavarz-Ghorabaee et al., 2024).

“Step 1. Construction of the initial decision matrix

The initial decision matrix is constructed via Equation (8), where m represents the number of alternatives and where n represents the number of criteria.

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{8}$$

In instances where nonpositive values are present in the X_{ij} matrix, the transformation in Equation (9) is implemented, as subsequent operations may yield undefined results (Trung et al., 2025).

$$X'_{ij} = X_{ij} + \frac{max\ (X_{ij})}{max(X_{ij}) - min\ (X_{ij})} \tag{9}$$

Step 2. Obtaining the Range-based Pairwise Adjusted Ratio (RPAR)

The RPAR value of the k^{th} alternative over the l^{th} alternative is calculated via Equation (10), where BC represents the benefit-oriented criteria and where CC represents the cost-oriented criteria.

$$RPAR = \sum_{j_{BC}} \omega_j \left(\frac{x_{kj}}{x_{lj}}\right)^{\rho_j} + \sum_{j_{CC}} \omega_j \left(\frac{x_{lj}}{x_{kj}}\right)^{\rho_j} \qquad k, l \in \{1,2,3, \dots, m\} \tag{10}$$

The notation ρ_j in this expression denotes the adjustment parameter within the RPAR equation, which is computed via Equation (11) based on the performance range criteria established in accordance with the maximum and minimum values associated with each criterion.

$$\rho_j = \begin{cases} \dfrac{(\alpha - 1)\max\limits_i x_{ij} + \min\limits_i x_{ij}}{\alpha \max\limits_i x_{ij}}; & if\ \dfrac{\max\limits_i x_{ij} - \min\limits_i x_{ij}}{\max\limits_i x_{ij} + \min\limits_i x_{ij}} > \beta \\ 1; & otherwise \end{cases} \tag{11}$$

This function mitigates the amplification of the relative impact of a criterion in the evaluation process when there exists a significant disparity between the minimum and maximum performance levels of that criterion. The expressions α and β in this equation represent parameters that are appreciated by the decision maker, considering the information pertaining to the criterion. When the minimum performance is equal to the maximum performance, the value of ρ_j is equal to 1. Therefore, it is anticipated that the value of the ρ_j value will consistently lie within the range of $\left(\frac{\alpha-1}{\alpha}, 1\right]$.

Step 3. Obtaining the Linearity-based Pairwise Adjusted Ratio (LPAR)

The LPAR value of the k^{th} alternative over the l^{th} alternative is calculated via Equation (12), where BC represents the benefit-oriented criteria and where CC represents the cost-oriented criteria. Unlike the RPAR values, the adjustment of the LPAR value is based on the linearity of the criteria's performance.

$$LPAR = \sum_{j_{BC}} \omega_j \left(\frac{x_{kj}}{x_{lj}}\right)^{\tau_j} + \sum_{j_{CC}} \omega_j \left(\frac{x_{lj}}{x_{kj}}\right)^{\tau_j} \qquad k, l \in \{1,2,3,\dots,m\} \tag{12}$$

The parameter τ_j in this equation is discretionary by the decision maker and is taken as 1 if the criterion has a linear structure. To intensify LPAR, a value of τ_j greater than 1 may be considered, whereas for the purpose of abating LPAR, values less than 1 are taken into account. These ratios can aid decision-makers in adjusting the nonlinear effects of criteria for evaluations. In the cases where $k = l$, the values of $RPAR_{kl}$ and $LPAR_{kl}$ are equal to 1.

Step 4. Obtaining the Aggregated Pairwise Adjusted Ratios (APAR)

The Aggregated Pairwise Adjusted Ratios (APAR) are calculated via Equation (13), where w represents the aggregation parameter lying within the bounds of [0,1].

$$APAR = w.RPAR_{kl} + (1-w).LPAR_{kl} \tag{13}$$

Step 5. Calculation of final scores for each alternative

The final scores for each alternative are calculated separately via Equation (14), and the alternatives are ordered in descending order according to their corresponding scores."

$$S_i = \frac{1}{m}\left[\sum_{l=1}^{m}\left(\frac{APAR_{il}}{\sum_{k=1}^{m} APAR_{kl}}\right)\right] \tag{14}$$

3.3. Sensitivity Analysis

In this research, Global Robust Sensitivity Analysis was utilised to confirm whether the ranking method yields stable results. This method determines how the ranking of alternatives changes after the weight of the most important criterion is gradually decreased and the values of other criteria are increased proportionally. The calculation step of the approach is as follows (Kahraman, 2002; Liu et al., 2023).

"Step1. Specifying the weights of the criteria

The weight of each criterion is arrayed according to the criterion number.

Step 2. Calculation of elasticity coefficients

To ensure the principle of proportionality, the elasticity coefficients (α_i) are calculated via Equation (15)

$$\alpha_i = \frac{\omega_i^0}{\sum \omega_i^0 - \omega_s^0} \tag{15}$$

where ω_s^0 represents the weight of the most important criterion and where ω_i^0 defines the original weights of all criteria ($\sum \omega_i^0 = 1$). During this calculation, the coefficient of elasticity of the most important criterion (α_s) is directly set to 1.

Step 3. Determination of the range for the most important criterion weight

The range of variation for the most important criterion weight is determined via Equation (16).

$$-\omega_s^0 \leq \Delta x \leq \sum \omega_i^0 - \omega_s^0 = min\left(\frac{\omega_i^0}{\alpha_i}\right) \tag{16}$$

Step 4. Determination of the new weights of the criteria under different scenarios

The emerging criterion weights under each scenario are calculated via Equations (17) and (18)."

$$\omega_s = \omega_s^0 + \alpha_s.\Delta x \tag{17}$$

$$\omega_i = \omega_i^0 - \alpha_i.\Delta x \tag{18}$$

In addition to this sensitivity analysis, the results of this ranking were compared with those derived from nine traditional MCDM approaches, namely, the MAIRCA (Pamucar et al., 2014), CODAS (Keshavarz-Ghorabaee et al., 2016), COCOSO (Yazdani et al., 2018), ROV (Yakowitz et al., 1993), MAUT (Keeney et al., 1979), ARAS (Zavadskas & Turskis, 2010), WEDBA (Rao et al., 2012), EDAS (Ghorabaee et al., 2015) and TOPSIS (Hwang & Yoon, 1981) methods.

4. Findings

This section presents the weighting of the eight criteria utilized in the research, the rankings of sixteen Associated Countries, and the results derived from the sensitivity analyses concerning the consistency of the MCDM method employed.

4.1. Determination of Criterion Weights

The evaluation criteria in the MCDM process were identified as "Participation" (C_1), "SME Participation" (C_2), "Net EU Contribution" (C_3), "SME Net EU Contribution" (C_4), "Applications" (C_5), "Success Rate" (C_6), "ERC Principal Investigators" (C_7), and "MSCA Participation" (C_8). Table 5 provides a detailed explanation of the criteria employed in the research, all of which are benefit oriented.

Table 5: **Description of the Criteria**

Code	Criterion	Definition
C_1	Participation	"Number of organisations involved in H2020 projects"
C_2	SME participation	"Number of SMEs involved in H2020 projects"
C_3	Net EU contribution	"Funding received by the project's participants after deduction of their linked third parties' funding"
C_4	SME Net EU contribution	"Total funding received by SME participants after deduction of their linked third parties' funding"
C_5	Applications	"Number of organisations applying for H2020 grants"
C_6	Success rate	"Ratio of retained applications to the total number of eligible applications received"
C_7	ERC principal investigators	"Number of European Research Council principal investigators involved in host organizations from the selected country"
C_8	MSCA participation	"Number of organizations financed under Marie Sklodowska-Curie Actions"

Source: (European Commission, 2025).

In the first stage of the criteria weighting process, the significance order of the eight criteria was determined by the consensus of the eight decision makers and as prescribed by the TrF-FUCOM method. Five of the eight decision-makers who participated in establishing the criteria weights were selected from among the experts with prior involvement in Horizon 2020 projects, who served as either executives or researchers. The remaining three participants were preferred from among experts employed at project coordination units affiliated with universities, public institutions, and nongovernmental organizations. Owing to the consensus among these decision-makers, who possess substantial expertise in their respective fields, it was concluded that the relative importance levels of the eight criteria should be established as $C_1 = C_2 > C_3 = C_4 > C_5 > C_6 > C_7 > C_8$. Following the establishment of the order of importance of the criteria, the relative superiority of each criterion was assessed via the linguistic scale presented in Table 3. The resulting coefficients are documented in Table 6.

Table 6: **Superiority Coefficients Among Criteria**

	Criterion	Score Index	Trapezoidal Fuzzy Measure
C_1	Participation	1	(1; 1; 1; 1)
C_2	SME participation	1	(1; 1; 1; 1)
C_3	Net EU contribution	2	(1; 1.5; 2.5; 3)
C_4	SME Net EU contribution	2	(1; 1.5; 2.5; 3)
C_5	Applications	3	(2; 2.5; 3.5; 4)
C_6	Success rate	4	(3; 3.5; 4.5; 5)
C_7	ERC principal investigators	5	(4; 4.5; 5.5; 6)
C_8	MSCA participation	6	(5; 5.5; 6.5; 7)

Taking into account the pairwise comparisons and utilizing Equations (1), (2), (3), and (4), the trapezoidal fuzzy vector for the criteria is represented as $\vartheta = (\tilde{\vartheta}_{1/2}, \tilde{\vartheta}_{2/3}, \tilde{\vartheta}_{3/4}, \tilde{\vartheta}_{4/5,} \tilde{\vartheta}_{5/6}, \tilde{\vartheta}_{6/7}, \tilde{\vartheta}_{7/8}\ \tilde{\vartheta}_{1/3}, \tilde{\vartheta}_{2/4},\ \tilde{\vartheta}_{3/5}, \tilde{\vartheta}_{4/6}, \tilde{\vartheta}_{5/7}, \tilde{\vartheta}_{6/8})$, with the corresponding numerical values denoted as:

$$\vartheta = [(1; 1; 1; 1), (1; 1.5; 2.5; 3), (0.333; 0.6; 1.667; 3), (0.667; 1; 2.333; 4), (0.75; 1; 1.8; 2.5),$$
$$(0.8; 1; 1.571; 2), (0.833; 1; 1.444; 1.75), (1; 1.5; 2.5; 3), (0.333; 0.9; 4.167; 9), (0.222; 0.6; 3.889; 12),$$
$$(0.5; 1; 4.2; 10), (0.6; 1; 2.829; 5), (0.667; 1; 2.27; 3.5)].$$

In line with the trapezoidal fuzzy vector of criteria, the optimization problem, which is detailed in Appendix I, was formulated through Equations (5) and (6) and solved via Lingo 20 optimization software. The fuzzy weights of the criteria and deviations from the maximum consistency (λ) values, derived from these calculations, are as follows:

$\tilde{p}_1 = (0.1883; 0.1883; 0.1883; 0.1883)$ $\quad \tilde{p}_2 = (0.1194; 0.2051; 0.2573; 0.2573)$
$\tilde{p}_3 = (0.0858; 0.1029; 0.1716; 0.1778)$ $\quad \tilde{p}_4 = (0.0363; 0.0783; 0.1512; 0.1512)$
$\tilde{p}_5 = (0.0206; 0.0619; 0.1240; 0.1240)$ $\quad \tilde{p}_6 = (0.0220; 0.0524; 0.1194; 0.1194)$
$\tilde{p}_7 = (0.0386; 0.0682; 0.1138; 0.1138)$ $\quad \tilde{p}_8 = (0.0538; 0.0830; 0.1214; 0.1292)$
$\lambda = 0{,}06899$

In the last stage, the trapezoidal fuzzy weights of the criteria were converted to crisp values via Equation (7), and the following results were obtained.

$R(\tilde{p}_1^*) = 0.1883$ $\quad R(\tilde{p}_2^*) = 0.2169$ $\quad R(\tilde{p}_3^*) = 0.1354$ $\quad R(\tilde{p}_4^*) = 0.1078$
$R(\tilde{p}_5^*) = 0.0861$ $\quad R(\tilde{p}_6^*) = 0.0809$ $\quad R(\tilde{p}_7^*) = 0.0861$ $\quad R(\tilde{p}_8^*) = 0.0986$

An exemplary calculation representing the determination of the crisp value for the second criterion is as follows.

$$R(\tilde{p}_2^*) = \frac{0.1194 + 2 * 0.2051 + 2 * 0.2573 + 0.2573}{6} = 0.2169$$

4.2. Ranking of Associated Countries

The Associated Countries identified as alternatives in the MCDM process are listed in alphabetical order as follows: Albania (AC_1), Armenia (AC_2), Bosnia and Herzegovina (AC_3), the Faroe Islands (AC_4), Georgia (AC_5), Iceland (AC_6), Israel (AC_7), Moldova (AC_8), Montenegro (AC_9), North Macedonia (AC_{10}), Norway (AC_{11}), Serbia (AC_{12}), Switzerland (AC_{13}), Tunisia (AC_{14}), Türkiye (AC_{15}), and Ukraine (AC_{16}).

The data accessible on the official website of the European Commission were compiled, and an initial decision matrix presented in Table 7 was formulated utilizing Equation (8).

Table 7: **Initial Decision Matrix**

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
AC_1	52	2	5,810,000	127,800	611	6.87	0	4
AC_2	45	4	4,170,000	163,800	312	11.86	0	11
AC_3	117	16	8,600,000	1,150,000	729	15.09	0	21
AC_4	31	13	4,640,000	2,030,000	156	16.67	0	2
AC_5	67	6	9,110,000	922,900	504	11.71	0	13
AC_6	387	113	142,700,000	50,830,000	1.926	18.64	5	52
AC_7	1,986	521	1,270,000,000	271,200,000	15.085	12.12	446	280
AC_8	82	13	7,370,000	1,540,000	549	14.39	0	14
AC_9	63	2	4,700,000	204,300	324	16.36	0	10
AC_{10}	119	17	14,300,000	3,040,000	899	10.34	0	4
AC_{11}	3,090	491	1,680,000,000	238,100,000	17.512	15.65	107	436
AC_{12}	586	125	134,900,000	28,770,000	3.979	12.39	2	109
AC_{13}	5,033	954	2,430,000,000	293,000,000	26.329	17.05	553	1.082
AC_{14}	95	1	13,000,000	157,500	700	12.57	0	23
AC_{15}	1,189	203	275,200,000	49,830,000	10.261	10.25	25	184
AC_{16}	332	82	49,290,000	16,180,000	2.834	9.10	1	97

Source: (European Commission, 2025).

A transformed initial matrix presented in Table 8 was created via Equation (9) because of the presence of nonpositive values in the original matrix.

Table 8: **Transformed İnitial Decision Matrix**

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
AC_1	53.0062	3.0010	5,810,001	127,801	612.0060	8.45	1	5.0019
AC_2	46.0062	5.0010	4,170,001	163,801	313.0060	13.44	1	12.0019
AC_3	118.0062	17.0010	8,600,001	1,150,001	730.0060	16.67	1	22.0019
AC_4	32.0062	14.0010	4,640,001	2,030,001	157.0060	18.25	1	3.0019
AC_5	68.0062	7.0010	9,110,001	922,901	505.0060	13.29	1	14.0019
AC_6	388.0062	114.0010	142,700,001	50,830,001	1,927.0060	20.22	6	53.0019
AC_7	1,987.0062	522.0010	1,270,000,001	271,200,001	15,086.0060	13.70	447	281.0019
AC_8	83.0062	14.0010	7,370,001	1,540,001	550.0060	15.97	1	15.0019
AC_9	64.0062	3.0010	4,700,001	204,301	325.0060	17.94	1	11.0019
AC_{10}	120.0062	18.0010	14,300,001	3,040,001	900.0060	11.92	1	5.0019
AC_{11}	3,091.0062	492.0010	1,680,000,001	238,100,001	17,513.0060	17.23	108	437.0019
AC_{12}	587.0062	126.0010	134,900,001	28,770,001	3,980.0060	13.97	3	110.0019
AC_{13}	5,034.0062	955.0010	2,430,000,001	293,000,001	26,330.0060	18.63	554	1,083.0019
AC_{14}	96.0062	2.0010	13,000,001	157,501	701.0060	14.15	1	24.0019
AC_{15}	1,190.0062	204.0010	275,200,001	49,830,001	10,262.0060	11.83	26	185.0019
AC_{16}	333.0062	83.0010	49,290,001	16,180,001	2,835.0060	10.68	2	98.0019

The RPAR value of the k^{th} alternative over the l^{th} alternative is calculated via Equation (10). The adjustment parameter denoted by ρ_j in this equation was determined by taking into account the conditions in Equation (11). The α and β values were considered to be 5 and 0.8, respectively, which are equivalent to the values specified in the method proposal. The ρ_j values obtained in this manner are $\rho_1 = 0.801$, $\rho_2 = 0.800$, $\rho_3 = 0.800$, $\rho_4 = 0.800$, $\rho_5 = 0.801$, $\rho_6 = 1.000$, $\rho_7 =$

0.800 and $\rho_8 = 0.801$. The RPAR matrix obtained in line with these calculations is summarized below.

$$RPAR = \begin{bmatrix} 1.000 & 0.953 & \dots & 0.109 & 0.233 \\ 1.194 & 1.000 & \dots & 0.145 & 0.267 \\ 2.705 & 2.249 & \dots & 0.222 & 0.424 \\ 2.323 & 1.868 & \dots & 0.187 & 0.324 \\ 1.887 & 1.628 & \dots & 0.164 & 0.321 \\ 21.047 & 17.775 & \dots & 0.626 & 1.563 \\ 91.573 & 81.127 & \dots & 2.810 & 11.779 \\ 2.523 & 2.093 & \dots & 0.199 & 0.375 \\ 1.202 & 1.042 & \dots & 0.177 & 0.307 \\ 3.327 & 2.897 & \dots & 0.191 & 0.409 \\ 83.553 & 74.702 & \dots & 2.511 & 8.155 \\ 17.405 & 14.776 & \dots & 0.617 & 1.520 \\ 121.418 & 108.140 & \dots & 4.275 & 16.438 \\ 1.509 & 1.392 & \dots & 0.176 & 0.346 \\ 28.230 & 24.629 & \dots & 1.000 & 2.935 \\ 11.461 & 9.450 & \dots & 0.426 & 1.000 \end{bmatrix}$$

An exemplary calculation for $RPAR_{2-1}$ is as follows.

$$RPAR_{2-1} = 0.1883 * \left(\frac{46.0062}{53.0062}\right)^{0.801} + 0.2169 * \left(\frac{5.0010}{3.0010}\right)^{0.800} + 0.1354 * \left(\frac{4{,}170{,}001}{5{,}810{,}001}\right)^{0.800} + 0.1078 * \left(\frac{163{,}801}{127{,}801}\right)^{0.800} + 0.0861 * \left(\frac{313.0060}{612.0060}\right)^{0.801} + 0.0809 * \left(\frac{13.44}{8.45}\right)^{1.000} + 0.0861 * \left(\frac{1}{1}\right)^{0.800} + 0.0986 * \left(\frac{12.0019}{5.0019}\right)^{0.801} = 1.194$$

On the other hand, the LPAR value of the k^{th} alternative over the l^{th} alternative was calculated via Equation (12), where the τ_j values were considered $\tau_1 = 0.9$, $\tau_2 = 1.0$, $\tau_3 = 1.1$, $\tau_4 = 1.2$, $\tau_5 = 1.3$, $\tau_4 = 1.4$, $\tau_5 = 1.5$ and $\tau_6 = 1.6$. The LPAR matrix obtained in line with these calculations is summarized below.

$$LPAR = \begin{bmatrix} 1.000 & 0.978 & \dots & 0.070 & 0.158 \\ 1.444 & 1.000 & \dots & 0.116 & 0.204 \\ 4.788 & 3.309 & \dots & 0.183 & 0.348 \\ 4.595 & 3.361 & \dots & 0.175 & 0.282 \\ 2.937 & 2.202 & \dots & 0.125 & 0.242 \\ 162.085 & 121.565 & \dots & 0.570 & 2.110 \\ 2032.854 & 1729.018 & \dots & 8.974 & 299.275 \\ 4.536 & 3.276 & \dots & 0.164 & 0.301 \\ 1.441 & 1.062 & \dots & 0.166 & 0.267 \\ 7.348 & 5.858 & \dots & 0.138 & 0.316 \\ 1246.631 & 944.993 & \dots & 4.091 & 48.275 \\ 102.180 & 73.041 & \dots & 0.525 & 1.796 \\ 3017.116 & 2347.942 & \dots & 14.673 & 421.121 \\ 2.501 & 1.745 & \dots & 0.137 & 0.273 \\ 212.577 & 156.193 & \dots & 1.000 & 7.298 \\ 56.841 & 38.093 & \dots & 0.320 & 1.000 \end{bmatrix}$$

An exemplary calculation for $LPAR_{2-1}$ is as follows.

$$LPAR_{2-1} = 0.1883 * \left(\frac{46.0062}{53.0062}\right)^{0.9} + 0.2169 * \left(\frac{5.0010}{3.0010}\right)^{1.0} + 0.1354 * \left(\frac{4{,}170{,}001}{5{,}810{,}001}\right)^{1.1} + 0.1078 * \left(\frac{163{,}801}{127{,}801}\right)^{1.2} + 0.0861 * \left(\frac{313.0060}{612.0060}\right)^{1.3} + 0.0809 * \left(\frac{13.44}{8.45}\right)^{1.4} + 0.0861 * \left(\frac{1}{1}\right)^{1.5} + 0.0986 * \left(\frac{12.0019}{5.0019}\right)^{1.6} = 1.444$$

The Aggregated Pairwise Adjusted Ratios (APAR) were calculated via Equation (13), where the aggregation parameter w was considered 0.5 in accordance with the recommendation of the proposers of the method. Matrix multiplication rules were taken into account for this procedure.

$$APAR = \begin{bmatrix} 1.000 & 0.965 & \dots & 0.089 & 0.196 \\ 1.319 & 1.000 & \dots & 0.131 & 0.236 \\ 3.747 & 2.779 & \dots & 0.202 & 0.386 \\ 3.459 & 2.615 & \dots & 0.181 & 0.303 \\ 2.412 & 1.915 & \dots & 0.145 & 0.281 \\ 91.566 & 69.670 & \dots & 0.598 & 1.836 \\ 1062.214 & 905.072 & \dots & 5.892 & 155.527 \\ 3.530 & 2.685 & \dots & 0.181 & 0.338 \\ 1.321 & 1.052 & \dots & 0.171 & 0.287 \\ 5.338 & 4.377 & \dots & 0.165 & 0.362 \\ 665.092 & 509.847 & \dots & 3.301 & 28.215 \\ 59.793 & 43.909 & \dots & 0.571 & 1.658 \\ 1569.267 & 1228.041 & \dots & 9.474 & 218.780 \\ 2.005 & 1.569 & \dots & 0.156 & 0.310 \\ 120.403 & 90.411 & \dots & 1.000 & 5.116 \\ 34.151 & 23.771 & \dots & 0.373 & 1.000 \end{bmatrix}$$

The final scores for each alternative are computed individually via Equation (14), and the alternatives are ranked in descending order based on their respective scores, as indicated in Table 9.

Table 9: **Final Scores and Orders of Associated Countries**

Country	S_i	Rank
Albania	0.00242	16
Armenia	0.00357	15
Bosnia and Herzegovina	0.00551	8
Faroe Islands	0.00500	9
Georgia	0.00394	14
Iceland	0.02000	5
Israel	0.29193	2
Moldova	0.00496	10
Montenegro	0.00469	11
North Macedonia	0.00450	12
Norway	0.13120	3
Serbia	0.01761	6
Switzerland	0.45588	1
Tunisia	0.00428	13
Türkiye	0.03313	4
Ukraine	0.01138	7

An exemplary calculation for the final score of AC_2 is as follows.

$$S_2 = \frac{1}{16}\left[\frac{1.319}{1.000 + 1.319 \dots + 34.151} + \frac{1.000}{0.965 + 1.000 + \dots + 23.771} + \dots + \frac{0.236}{0.196 + 0.236 + \dots + 1.000}\right] = 0.00357$$

4.3. Sensitivity analysis

The Global Robust Sensitivity approach was employed to validate the consistency of the ranking results derived from the M-OPARA method. Within this framework, each criterion was ranked based on its respective importance weight. As a rule of thumb, the elasticity coefficient for the most significant criterion (α_s) was determined to be 1, whereas the elasticity coefficients for the remaining criteria (α_i) were computed via Equation (15). The range of change for the most important criterion (Δx) was subsequently determined via Equation (16). The data regarding these values are summarized in Table 10 as follows.

Table 10: **Elasticity Coefficients for Each Criterion and Upper Bound for C_2**

Criterion	Weight	α_i	$\frac{\omega_i^0}{\alpha_i}$
C_2	0.2169	1	-
C_1	0.1883	0.2405	0.7831
C_3	0.1354	0.1729	0.7831
C_4	0.1078	0.1376	0.7831
C_8	0.0986	0.1260	0.7831
C_5	0.0861	0.1099	0.7831
C_7	0.0861	0.1099	0.7831
C_6	0.0809	0.1032	0.7831

Exemplary calculations for α_1 and the upper bound for C_2 are as follows.

$$\alpha_1 = \frac{0.1883}{1 - 0.2169} = 0.2405$$

$$\min\left(\frac{\omega_i^0}{\alpha_i}\right) = \min\left(\frac{0.1883}{0.2405}; \frac{0.1354}{0.1729}; \ldots; \frac{0.0809}{0.1032}\right) = 0.7831$$

Therefore, the range of change for the most important criterion C_2 is determined as follows:

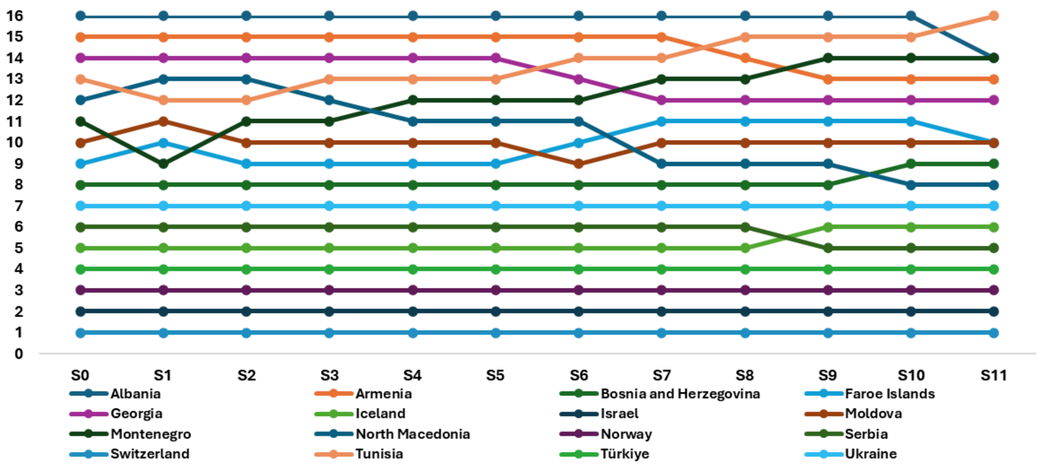
$$-0.2169 \leq \Delta x \leq 0.7831$$

On the basis of this interval calculated for the dominant criterion C_2, eleven distinct scenarios were developed via Equations (17) and (18) to analyse the changes observed in the C_2 criterion weight and corresponding weights for the remaining criteria. Table 11 presents a summary of the relative changes in criterion weights as observed across eleven distinct scenarios.

Table 11: **Criterion Weights under Different Scenarios**

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Δx	-0.2169	-0.1169	-0.0169	0.0831	0.1831	0.2831	0.3831	0.4831	0.5831	0.6831	0.7831
C_2	0.0000	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000
C_1	0.2405	0.2165	0.1924	0.1684	0.1443	0.1203	0.0962	0.0722	0.0481	0.0241	0.0000
C_3	0.1729	0.1556	0.1383	0.1211	0.1038	0.0865	0.0692	0.0519	0.0346	0.0173	0.0000
C_4	0.1376	0.1239	0.1101	0.0963	0.0826	0.0688	0.0550	0.0413	0.0275	0.0138	0.0000
C_8	0.1260	0.1134	0.1008	0.0882	0.0756	0.0630	0.0504	0.0378	0.0252	0.0126	0.0000
C_5	0.1099	0.0989	0.0879	0.0769	0.0659	0.0550	0.0440	0.0330	0.0220	0.0110	0.0000
C_7	0.1099	0.0989	0.0879	0.0769	0.0659	0.0550	0.0440	0.0330	0.0220	0.0110	0.0000
C_6	0.1032	0.0929	0.0826	0.0723	0.0619	0.0516	0.0413	0.0310	0.0206	0.0103	0.0000

Figure 1: **Observed Changes in the Rankings of Sixteen Associated Countries**



The alteration in the ranking of the sixteen Associated Countries under application of each scenario to the M-OPARA method is illustrated in Figure 1.

On the other hand, the ranking results obtained for sixteen Associated Countries were compared with the results obtained from nine different traditional MCDM methods. The correlation coefficients for the results obtained from each method are presented in Table 12.

Table 12: **Correlation Coefficients for the Results Obtained From Nine Methods**

	M-OPARA	MAIRCA	CODAS	COCOSO	ROV	MAUT	ARAS	WEDBA	EDAS
MAIRCA	0.965								
CODAS	0.935	0.971							
COCOSO	0.979	0.985	0.956						
ROV	0.965	1.000	0.971	0.985					
MAUT	0.765	0.803	0.900	0.785	0.803				
ARAS	0.979	0.918	0.882	0.950	0.918	0.688			
WEDBA	0.844	0.897	0.968	0.871	0.897	0.968	0.774		
EDAS	0.947	0.874	0.826	0.915	0.874	0.621	0.982	0.715	
TOPSIS	0.959	0.994	0.965	0.976	0.994	0.788	0.918	0.888	0.871

5. Results and Discussion

This study aimed to assess the performance rankings of sixteen countries participating in the Horizon 2020 programme as Associated Countries. The requisite data were obtained from the official website of the European Commission. Within the framework of the research workflow, the importance weights of eight distinct evaluation criteria were initially determined using the TrF-FUCOM method. By employing this methodology, the significance of the criteria was assessed in the following order: “SME Participation”, “Participation”, “Net EU Contribution”, “SME Net EU Contribution”, “MSCA Participation”, “Applications”, “ERC Principal Investigators”, and “Success Rate” ($\omega_2 > \omega_1 > \omega_3 > \omega_4 > \omega_8 > \omega_5 > \omega_7 > \omega_6$).

The significant influence of "SME Participation" and "Participation" criteria on the performance rankings of Associated Countries in Horizon 2020 projects may be perceived as strong indicators of these countries' willingness to engage in project activities. This situation aligns with the EU’s objective of stimulating economic growth through the support of SMEs, which are frequently acknowledged as the primary catalysts for job creation and technological advancement. In addition, this study reveals that SMEs play a pioneering role in commercializing innovations and facilitating the transition from research to market. The criteria of “Net EU Contribution” and “SME Net EU Contribution”, which may be considered direct outcomes of the “SME Participation” and “Participation” criteria, represent the extent to which countries fulfil their financing requirements through participation in Horizon 2020 projects. Countries that effectively maximize access to alternative sources of financing, while acknowledging the constraints imposed by limited resources, will be regarded as more successful in terms of overall project performance. The observation that the “MSCA Participation” criterion is ranked fifth, despite its significance, suggests that individual research initiatives are likely to be appreciated at a lower level than institutional initiatives are. The fact that the number of applications does not serve as a singular indicator of success may have led to “Applications” criterion being assigned a lower priority in the ranking. Similar to the “MSCA Participation” criterion, the relatively lower significance attributed to the “ERC Principal Investigators” criterion indicates a stronger emphasis on collective objectives than on individual initiatives. The positioning of the “Success Rate” criterion at the end of the list indicates that the act of merely submitting an application should not be acknowledged as an indicator of success. Conversely, this highlights the implementation of a rigorous review process focused on the quality of the projects.

Upon examining the numerical values of the criteria employed in the researches, it is often observed that there may be interactions and consequently correlations among these criteria. For example, a high correlation is expected between the number of “applications” to the program and the number of "participation" from a given country. In this context, it will be observed that there is a fairly high correlation coefficient of 0.984 between these two criteria. Apart from these two criteria, the correlation coefficients observed among the remaining ones are presented in Table 13. This situation demonstrates that the criteria may stimulate each other in a positive or negative manner.

Table 13: **Correlation Coefficients Among Criteria**

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_2	0.985						
C_3	0.986	0.982					
C_4	0.926	0.956	0.965				
C_5	0.984	0.983	0.973	0.950			
C_6	0.312	0.300	0.328	0.288	0.233		
C_7	0.856	0.923	0.884	0.902	0.869	0.225	
C_8	0.978	0.965	0.947	0.855	0.942	0.313	0.857

The success ranking of Associated Countries participating in the Horizon 2020 programme was determined through the M-OPARA method, and the resulting rankings emerged as Switzerland, Israel, Norway, Türkiye, Iceland, Serbia, Bosnia and Herzegovina, the Faroe Islands, Moldova, Montenegro, North Macedonia, Tunisia, Georgia, Armenia, and Albania.

A comprehensive analysis of the ranking results reveals the existence of factors such as countries' research and innovation capacities and the alignment of these countries with the priority areas identified by the EU. Advanced R&I ecosystems, the level of academic and technical infrastructure at universities and long-standing cooperation with EU institutions in Switzerland, Israel and Norway significantly affect this ranking. Moreover, these countries demonstrate exemplary outputs of university–industry cooperation, which results in a significantly superior position in terms of project performance that cannot be considered coincidental. Although countries such as Türkiye, Iceland, and Serbia did not occupy within the top three positions, they nonetheless attained significant success in terms of Horizon 2020 projects because of their endeavours to integrate with EU frameworks and align with EU objectives. Türkiye has significantly enhanced its participation in and utilization of the Horizon 2020 program, largely because of increased awareness of European Union opportunities, particularly through the ongoing contributions of The Scientific and Technological Research Council of Türkiye (TÜBİTAK). Nevertheless, structural challenges—including implementation difficulties, bureaucratic procedures, limited international networks, and deficiencies in research capabilities—have constrained Türkiye's ability to fully realize its potential in this context. Lower-ranked countries, including Ukraine, Bosnia and Herzegovina, and Moldova, are thought to have encountered barriers such as inadequate research infrastructure, lower levels of research and development expenditure, and insufficient administrative capacity to effectively manage complex European Union projects. Additionally, political and economic instability in certain regions is regarded as a significant impediment to participation in initiatives that require collaboration. Countries such as the Faroe Islands, Montenegro, North Macedonia, Tunisia, Georgia, Armenia, and Albania have a limited history of participation in EU research programmes. This circumstance poses challenges for these nations in gaining the requisite expertise necessary to thrive within the highly competitive environment of the Horizon 2020 programme. Nevertheless, Horizon 2020 has facilitated the integration of these countries into European research networks, thereby enabling them to capitalize on opportunities for capacity building and collaboration activities.

In the last stage of the research, the consistency of the M-OPARA method used to determine the success ranking of the Associated Countries under the Horizon 2020 programme was examined by two sensitivity analyses. Figure 2 demonstrates that the different rankings obtained by applying the Global Robust Sensitivity Analysis approach exhibit very consistent behaviour even under different criteria weights. Furthermore, a comparison was conducted with the results derived from nine distinct traditional MCDM methods. Table 12 indicates a highly satisfactory correlation between the results calculated via the M-OPARA method and those generated via the other methods.

The primary limitations of this research pertain to its exclusive focus on Associated Countries and its reliance on data supplied by the European Commission. Future research may also encompass EU member states. Upon the conclusion of the Horizon Europe program in 2027, a comprehensive comparative analysis with Horizon 2020 will be feasible. Furthermore, the outcomes of these implemented projects may be investigated in detail within the framework of Impact Analysis.

6. Conclusion

In this study, which aims to determine the performance ranking of the countries participating in the Horizon 2020 programme according to the status of Associated Country, eight different criteria were considered in the evaluation of sixteen different countries. The results of this ranking indicate that, despite not being members of the EU, countries possessing robust R&I competencies, well-established R&D ecosystems, effective university–industry collaboration capabilities, access to research networks, and alignment with the priority areas identified by the EU are among the most successful in this ranking. Despite certain shortcomings faced by countries positioned in the middle of the ranking that impede their desired achievements, the intensive efforts they have demonstrated over a short period may be regarded as promising indicators of their performance in the coming years. Although the countries at the bottom of the rankings have benefited from Horizon 2020 at a low level, they have gained experience in accessing opportunities to alternative sources of financing through the enhancement of project culture. It is proposed that they should consider such programs as launch points and opportunities to improve their R&I infrastructures.

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Appendix I

$MIN\ \lambda$
ST
$1\,l1 - 1\,s2 - \lambda <= 0$
$1\,l1 - 1\,s2 + \lambda >= 0$
$1\,m1 - 1\,n2 - \lambda <= 0$
$1\,m1 - 1\,n2 + \lambda >= 0$
$1\,n1 - 1\,m2 - \lambda <= 0$
$1\,n1 - 1\,m2 + \lambda >= 0$
$1\,s1 - 1\,l2 - \lambda <= 0$
$1\,s1 - 1\,l2 + \lambda >= 0$
$1\,l2 - 1\,s3 - \lambda <= 0$
$1\,l2 - 1\,s3 + \lambda >= 0$
$1\,m2 - 1.5\,n3 - \lambda <= 0$
$1\,m2 - 1.5\,n3 + \lambda >= 0$
$1\,n2 - 2.5\,m3 - \lambda <= 0$
$1\,n2 - 2.5\,m3 + \lambda >= 0$
$1\,s2 - 3\,l3 - \lambda <= 0$
$1\,s2 - 3\,l3 + \lambda >= 0$
$1\,l3 - 0.333\,s4 - \lambda <= 0$
$1\,l3 - 0.333\,s4 + \lambda >= 0$
$1\,m3 - 0.6\,n4 - \lambda <= 0$
$1\,m3 - 0.6\,n4 + \lambda >= 0$
$1\,n3 - 1.667\,m4 - \lambda <= 0$
$1\,n3 - 1.667\,m4 + \lambda >= 0$
$1\,s3 - 3\,l4 - \lambda <= 0$
$1\,s3 - 3\,l4 + \lambda >= 0$
$1\,l4 - 0.667\,s5 - \lambda <= 0$
$1\,l4 - 0.667\,s5 + \lambda >= 0$
$1\,m4 - 1\,n5 - \lambda <= 0$
$1\,m4 - 1\,n5 + \lambda >= 0$
$1\,n4 - 2.333\,m5 - \lambda <= 0$
$1\,n4 - 2.333\,m5 + \lambda >= 0$
$1\,s4 - 4\,l5 - \lambda <= 0$
$1\,s4 - 4\,l5 + \lambda >= 0$
$1\,l5 - 0.75\,s6 - \lambda <= 0$
$1\,l5 - 0.75\,s6 + \lambda >= 0$
$1\,m5 - 1\,n6 - \lambda <= 0$
$1\,m5 - 1\,n6 + \lambda >= 0$
$1\,n5 - 1.8\,m6 - \lambda <= 0$
$1\,n5 - 1.8\,m6 + \lambda >= 0$
$1\,s5 - 2.5\,l6 - \lambda <= 0$
$1\,s5 - 2.5\,l6 + \lambda >= 0$
$1\,l6 - 0.8\,s7 - \lambda <= 0$
$1\,l6 - 0.8\,s7 + \lambda >= 0$
$1\,m6 - 1\,n7 - \lambda <= 0$
$1\,m6 - 1\,n7 + \lambda >= 0$
$1\,n6 - 1.571\,m7 - \lambda <= 0$
$1\,n6 - 1.571\,m7 + \lambda >= 0$
$1\,s6 - 2\,l7 - \lambda <= 0$
$1\,s6 - 2\,l7 + \lambda >= 0$
$1\,l7 - 0.833\,s8 - \lambda <= 0$
$1\,l7 - 0.833\,s8 + \lambda >= 0$
$1\,m7 - 1\,n8 - \lambda <= 0$
$1\,m7 - 1\,n8 + \lambda >= 0$
$1\,n7 - 1.444\,m8 - \lambda <= 0$
$1\,n7 - 1.444\,m8 + \lambda >= 0$
$1\,s7 - 1.75\,l8 - \lambda <= 0$
$1\,s7 - 1.75\,l8 + \lambda >= 0$
$1\,l1 - 1\,s3 - \lambda <= 0$
$1\,l1 - 1\,s3 + \lambda >= 0$
$1\,m1 - 1.5\,n3 - \lambda <= 0$
$1\,m1 - 1.5\,n3 + \lambda >= 0$
$1\,n1 - 2.5\,m3 - \lambda <= 0$
$1\,n1 - 2.5\,m3 + \lambda >= 0$
$1\,s1 - 3\,l3 - \lambda <= 0$
$1\,s1 - 3\,l3 + \lambda >= 0$
$1\,l2 - 0.333\,s4 - \lambda <= 0$
$1\,l2 - 0.333\,s4 + \lambda >= 0$
$1\,m2 - 0.9\,n4 - \lambda <= 0$
$1\,m2 - 0.9\,n4 + \lambda >= 0$
$1\,n2 - 4.167\,m4 - \lambda <= 0$
$1\,n2 - 4.167\,m4 + \lambda >= 0$
$1\,s2 - 9\,l4 - \lambda <= 0$
$1\,s2 - 9\,l4 + \lambda >= 0$
$1\,l3 - 0.222\,s5 - \lambda <= 0$
$1\,l3 - 0.222\,s5 + \lambda >= 0$
$1\,m3 - 0.6\,n5 - \lambda <= 0$
$1\,m3 - 0.6\,n5 + \lambda >= 0$
$1\,n3 - 3.889\,m5 - \lambda <= 0$
$1\,n3 - 3.889\,m5 + \lambda >= 0$
$1\,s3 - 12\,l5 - \lambda <= 0$
$1\,s3 - 12\,l5 + \lambda >= 0$
$1\,l4 - 0.5\,s6 - \lambda <= 0$
$1\,l4 - 0.5\,s6 + \lambda >= 0$
$1\,m4 - 1\,n6 - \lambda <= 0$
$1\,m4 - 1\,n6 + \lambda >= 0$
$1\,n4 - 4.2\,m6 - \lambda <= 0$
$1\,n4 - 4.2\,m6 + \lambda >= 0$
$1\,s4 - 10\,l6 - \lambda <= 0$
$1\,s4 - 10\,l6 + \lambda >= 0$
$1\,l5 - 0.6\,s7 - \lambda <= 0$
$1\,l5 - 0.6\,s7 + \lambda >= 0$
$1\,m5 - 1\,n7 - \lambda <= 0$
$1\,m5 - 1\,n7 + \lambda >= 0$
$1\,n5 - 2.829\,m7 - \lambda <= 0$
$1\,n5 - 2.829\,m7 + \lambda >= 0$
$1\,s5 - 5\,l7 - \lambda <= 0$
$1\,s5 - 5\,l7 + \lambda >= 0$
$1\,l6 - 0.667\,s8 - \lambda <= 0$
$1\,l6 - 0.667\,s8 + \lambda >= 0$
$1\,m6 - 1\,n8 - \lambda <= 0$
$1\,m6 - 1\,n8 + \lambda >= 0$
$1\,n6 - 2.27\,m8 - \lambda <= 0$
$1\,n6 - 2.27\,m8 + \lambda >= 0$
$1\,s6 - 3.5\,l8 - \lambda <= 0$
$1\,s6 - 3.5\,l8 + \lambda >= 0$

$$0.167\,l1 + 0.333\,m1 + 0.333\,n1 + 0.167\,s1 + 0.167\,l2 + 0.333\,m2 + 0.333\,n2 + 0.167\,s2 + 0.167\,l3 + 0.333\,m3 + 0.333\,n3 + 0.167\,s3 + 0.167\,l4 + 0.333\,m4 + 0.333\,n4 + 0.167\,s4 + 0.167\,l5 + 0.333\,m5 + 0.333\,n5 + 0.167\,s5 + 0.167\,l6 + 0.333\,m6 + 0.333\,n6 + 0.167\,s6 + 0.167\,l7 + 0.333\,m7 + 0.333\,n7 + 0.167\,s7 + 0.167\,l8 + 0.333\,m8 + 0.333\,n8 + 0.167\,s8 = 1$$

$l1 - m1 <= 0$
$m1 - n1 <= 0$
$n1 - s1 <= 0$
$l2 - m2 <= 0$
$m2 - n2 <= 0$
$n2 - s2 <= 0$
$l3 - m3 <= 0$
$m3 - n3 <= 0$
$n3 - s3 <= 0$
$l4 - m4 <= 0$
$m4 - n4 <= 0$
$n4 - s4 <= 0$
$l5 - m5 <= 0$
$m5 - n5 <= 0$
$n5 - s5 <= 0$
$l6 - m6 <= 0$
$m6 - n6 <= 0$
$n6 - s6 <= 0$
$l7 - m7 <= 0$
$m7 - n7 <= 0$
$n7 - s7 <= 0$
$l8 - m8 <= 0$
$m8 - n8 <= 0$
$n8 - s8 <= 0$
$l1 > 0$
$l2 > 0$
$l3 > 0$
$l4 > 0$
$l5 > 0$
$l6 > 0$
$l7 > 0$
$l8 > 0$
$\lambda >= 0$
END