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Evaluating European Union Countries on Climate Change Management: A Fuzzy MABAC Approach to the Climate Change Performance Index

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Abstract: This study was undertaken to assess the implementation effectiveness of climate change management strategies across European Union (EU) member states, employing data from the annually published Climate Change Performance Index (CCPI). The index includes assessments for 36 countries in addition to the EU member states, with evaluations presented through linguistic values. To ascertain the rankings of the EU countries, a fuzzy set approach was adopted, applying the fuzzy Multi-Attributive Border Approximation area Comparison (MABAC) method. Weights were derived directly from the original CCPI report. The analysis revealed that Denmark secured the highest ranking, aligning with its position in the CCPI, albeit the ranking sequence determined through the fuzzy MABAC method diverged from the original report's order. This discrepancy is attributed to the distinct characteristics and specificities of the fuzzy set approach. Sensitivity analysis within this study highlighted that certain criteria exert a more pronounced influence on the rankings, suggesting that heightened emphasis on these specific criteria could enhance the positioning of individual EU countries. Furthermore, this research elucidates the application of fuzzy methodologies in climate change impact mitigation and provides a structured guideline for their implementation. The findings advocate for a nuanced understanding of criteria significance in climate change performance assessments, offering a comprehensive framework for evaluating and improving EU countries' climate management practices.

Keywords: Climate Change Performance Index (CCPI); Fuzzy set; European Union (EU); Multi-Attributive Border Approximation area Comparison (MABAC); Climate policy evaluation, Fuzzy logic analysis

1 Introduction

Climate change poses the most significant challenge to modern society. An increasing number of countries are actively addressing this issue to mitigate its environmental consequences. The rise in global temperatures, alterations in precipitation levels leading to floods or droughts [1], frequent extreme weather events, and various other factors underscore the urgency of implementing decisive measures in the battle against climate change. Furthermore, climate change disrupts ecosystems, causing harm to the economy and resulting in losses [2]. In response to these challenges, consumer habits and production methods are adapting to minimize the adverse effects of climate change arising from greenhouse gas emissions [3].

These transformations present challenges at the global, national, and local levels of management, prompting intensified efforts to address imminent issues and mitigate the impacts of climate change [4]. Concerns surrounding these issues have led to various bilateral meetings globally and nationally, resulting in specific agreements. One standout agreement is the Paris Agreement of 2015, where a consensus was reached at the global level regarding the human-induced impact of climate change, emphasizing the urgent need for action to alleviate these changes [5]. Under this agreement, 196 countries committed to limiting the increase in average temperature to reduce the risks and impacts of climate change. Achieving this requires a reduction in CO_2 emissions and greenhouse gases.

Consequently, the EU has set the ambitious goal of becoming climate-neutral by 2050, concurrently promoting the use of renewable sources and pollution reduction [3]. EU countries play a pivotal role in global efforts to decrease greenhouse gas emissions and combat climate change.

To assess the efficacy of these measures, the CCPI was established, encompassing 35 countries alongside the EU nations. However, this research will focus on data related to EU countries. The CCPI evaluates countries' efforts in reducing greenhouse gas emissions, utilizing renewable energy sources, enhancing energy efficiency, and other key aspects associated with environmental preservation and the fight against climate change. Published annually since 2005, this index serves as an independent tool for monitoring the success of initiatives aimed at reducing the impact of climate change.

Given the multitude of criteria and alternatives for monitoring the effectiveness of climate change impact reduction across various countries, this decision-making problem is addressed through the application of the multi-criteria analysis (MCDA) method [6]. Additionally, this paper employs these methods based on fuzzy set theory to analyze and rank the EU countries using data from the CCPI for 2024, sourced from the report published at the end of 2023. Due to the specific nature of country evaluations in this report, which employs a five-level value scale from very low to very high, fuzzy methods are essential. The fuzzy set is applicable when evaluations are imprecise and incomplete [7], especially when linguistic values are utilized in assessing alternatives [8]. The value scale in this context represents a linguistic evaluation applied by fuzzy methods. The role of the fuzzy set is to transform these values into fuzzy numbers and rank the EU countries based on the CCPI criteria for the year 2024. Through the integration of fuzzy methods and data from the CCPI report, the objective is to offer a comprehensive insight into the effectiveness of measures implemented by EU countries in addressing the challenges of climate change.

In light of the above, this paper aims to:

- Perform the ranking of EU countries in terms of CCPI;
- Adapt the linguistic evaluations within the CCPI report to apply fuzzy methods;
- Compare the obtained ranking with the results of the CCPI report;
- Examine how the application of criteria weights affects the ranking of EU countries in terms of CCPI;
- Give guidelines on how to improve the ranking of individual EU countries.

In accomplishing these research objectives, this study contributes by:

- Determining how well individual EU countries align with CCPI criteria;
- Establishing the ranking of EU countries in terms of CCPI and assessing any discrepancies from the report;
- Conducting sensitivity analysis with different weights to understand how specific criteria impact the ranking of EU countries.

In this manner, the paper scrutinizes the current climate performance of EU countries, underscoring the significance of the fight against climate change. The application of fuzzy methods facilitates a deeper understanding of the dynamic factors influencing climate performance, providing a foundation for refining existing strategies and policies towards a more sustainable future environment.

2 Literature Review

In this section, the papers that ranked countries according to climate change will be reviewed first, followed by an examination of papers that utilized the CCPI report.

In their paper, Stankevičienė and Borisova [9] assessed the impact of climate change on specific EU countries, focusing on economic and social factors as drivers of greenhouse gas emissions. The authors employed the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method for country ranking. Sciarra et al. [10] ranked countries based on sustainable development goals, incorporating climate change criteria. The results indicated a conflict between innovation and climate action, where an increase in innovative activities correlated with an increase in the impact of climate change, contrary to the desired reduction.

Saleem et al. [11] utilized index decomposition analysis to investigate greenhouse gas emissions, examining countries based on income level and geopolitical development over a 20-year period. They identified countries with the best indicators according to these criteria. Codal et al. [12] investigated climate change in the largest 20 member countries of the G20, using a multidimensional perspective. Their findings highlighted climate change as a significant factor in the ranking of these countries. Zhang et al. [13] emphasized the role of international cooperation in mitigating the impact of climate change. Using a non-compensatory composite approach, they created a new index, demonstrating its flexibility in terms of weights and data accuracy.

Singh et al. [14] studied resource availability and underestimated food security under future climate change scenarios. They ranked countries based on how their food production would be affected by climate change, emphasizing the need for prompt responses to potential changes. Oliver and Adkins [15] investigated students' responses from 72 countries to assess awareness of greenhouse gases. Their findings suggested that schools influence positive attitudes toward ecological protection and climate change reduction.

Puertas and Marti [3] used the CCPI report for 2021 in their paper, conducting a cluster analysis and contingency table. Results indicated that concern for combating climate change is independent of a country's wealth, and no common pattern could be observed based on the report. Epule et al. [16] utilized the African CCPI, differing from the classic report in criteria importance. The results highlighted North and South Africa's positive outcomes and provided guidelines for monitoring climate change impact in Africa.

Karman et al. [17] focused on countries' competitiveness in climate change, developing a specialized index based on the CCPI with 89 criteria, particularly in Poland. Nathwani et al. [18] used the corrected CCPI index to observe events during the COVID-19 pandemic, emphasizing the effectiveness of decarburization to reduce countries' impact on climate change. Elemam and Eldeeb [19] utilized the CCPI and adopted the Intergovernmental Panel on Climate Change (IPCC) to develop standards for evaluating climate change mitigation measures. These studies collectively indicate the versatility of the CCPI index for various purposes related to climate change impact reduction.

3 Methodology

As mentioned in the introduction of this paper, the CCPI report for 2024, issued at the end of 2023, is utilized. The publishers of this report are Climate Action Network International, covering 63 countries and the EU as a special community of countries.

This report comprises four main criteria, namely:

- GHG Emissions (C1)
- Renewable Energy (C2)
- Energy Use (C3)
- Climate Policy (C4)

Each of these criteria is further divided into auxiliary criteria, as presented in Figure 1. The markings of these auxiliary criteria will continue clockwise from the main criteria, with the auxiliary criterion "Current Level of GHG Emissions per Capita" marked as C11 and "Past Trend of GHG Emissions per Capita" marked as C12. Other auxiliary criteria follow a similar marking convention. The importance of these criteria is represented as the weight of these criteria and will be used when ranking the EU countries.

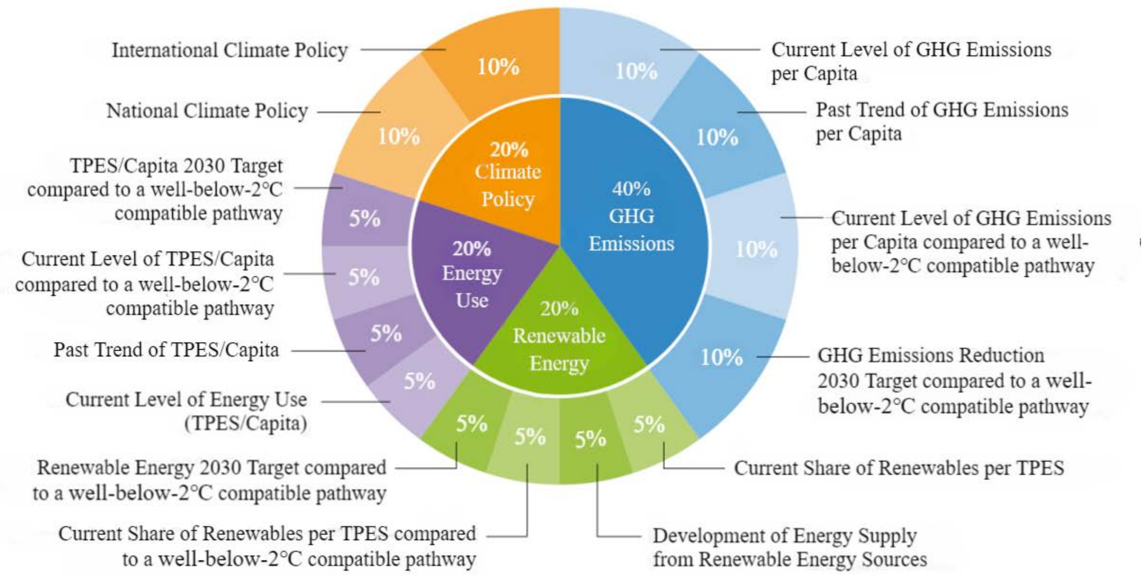

Figure 1. CCPI report criteria

Note: https://ccpi.org/methodology [20]

To rank these countries, the fuzzy MABAC method is employed. This method, designed by the authors Pamučar and Ćirović [21], determines the deviation of alternatives from average values. The choice of this method is based on its demonstrated effectiveness in previous research. The steps of the fuzzy MABAC method are as follows [22]:

Step 1: Formation of the initial decision matrix. This matrix begins with the EU countries, followed by values for the criteria. A linguistic decision matrix is first formed, and these values are then transformed into fuzzy numbers using the membership function (Table 1).

Step 2: Normalization of the initial matrix elements.

Table 1. Membership function for fuzzy numbers

Linguistic Values	Fuzzy Numbers
Very low (VL)	$(1, 1, 2)$
Low (L)	$(2, 3, 4)$
Medium (M)	$(4, 5, 6)$
High (H)	$(6, 7, 8)$
Very high (VH)	$(8, 9, 9)$

$$\tilde{t} = \left(\frac{x_{id}^{l} - x_{ij\,\min}^{l}}{x_{ij\,\min}^{u} - x_{ij\,\min}^{l}}, \frac{x_{id}^{m} - x_{ij\,\min}^{l}}{x_{ij\,\min}^{u} - x_{ij\,\min}^{l}}, \frac{x_{id}^{u} - x_{ij\,\min}^{l}}{x_{ij\,\min}^{u} - x_{ij\,\min}^{l}} \right) \tag{1}$$

where, l is the first fuzzy number, m is the second fuzzy number and u is the third fuzzy number.

Step 3: Calculation of the weighted matrix (V) elements.

$$\tilde{v}_{ij} = w_i \cdot \tilde{t}_{ij} + w_i \tag{2}$$

Step 4: Determination of the approximate border area matrix (G).

$$\tilde{g} = \left(\prod_{j=1}^{m} \tilde{v}_{ij} \right)^{1/m} \tag{3}$$

Step 5: Calculation of the matrix elements of alternatives' distance from the border approximate area.

$$\tilde{Q} = \tilde{V} - \tilde{G} \tag{4}$$

Step 6: Ranking of alternatives.

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{q}_{ij} \tag{5}$$

Step 7: Final ranking of alternatives by defuzzification of the obtained values $\tilde{S}_i$.

$$S = \frac{t_1 + 4t_2 + t_3}{6} \tag{6}$$

where, t_1 is the first fuzzy number, t_2 is the second fuzzy number and t_3 is the third fuzzy number.

After forming the ranking list of countries in terms of CCPI, a sensitivity analysis is performed at the end of this research. This analysis aims to correct the importance of the criteria and determine how changes in the importance of the criteria impact the ranking of countries [23]. This analysis identifies how each auxiliary criterion affects the ranking of EU countries.

4 Results

The first step in ranking the EU countries according to the CCPI is the formation of a linguistic decision matrix. This matrix is formed by extracting values from the CCPI report based on individual criteria for EU countries. Thus, this matrix involves decision-making with a total of 14 criteria for 27 EU countries (Table 2).

After forming this initial linguistic decision-making matrix (Table 2), it is necessary to transform these linguistic values into fuzzy numbers using the membership function. This transformation is done based on defined membership functions with appropriate fuzzy numbers, as presented in Table 1. Following this membership function, the linguistic value "very low" is transformed into a fuzzy number (1, 1, 2), and "low" into a fuzzy number (2, 3, 4). This process transforms all linguistic values into fuzzy numbers, creating an initial fuzzy decision matrix for ranking using the fuzzy MABAC method, and the steps of this method are applied.

The first step is the normalization of the initial fuzzy decision matrix. For this step, it is necessary to determine the criteria and whether the values should be as high or as low as possible. In this case, all values should be as large as possible, meaning the criteria used should be maximized, and Eq. (1) should be applied. It is crucial to identify the smallest and largest values of the fuzzy number according to individual criteria for the observed countries to perform the normalization process of the initial fuzzy decision matrix.

The second step of this method involves the calculation of the weighted decision matrix. In this step, the values from the normalized decision matrix are multiplied by the determined weights in the CCPI report, and the result is added together with these weights. This step is specific to the MABAC method compared to other MCDA methods. With these other methods, only the multiplication of the normalized decision matrix with the appropriate weights is performed; there is no additional addition of weights to this value. Applying Eq. (2), a weighted fuzzy decision matrix is formed (Table 3).

Table 2. Initial linguistic decision-making matrix

Country	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34	C41	C42
Austria	M	H	L	L	H	VL	L	M	L	M	VL	VL	M	M
Belgium	L	H	L	M	L	H	VL	L	VL	M	VL	VL	L	M
Bulgaria	L	L	L	M	L	VH	L	L	M	L	L	L	L	L
Cyprus	M	M	L	M	L	H	L	L	H	M	M	M	L	L
Croatia	H	L	L	L	M	VH	L	L	H	L	L	L	L	L
Czech Republic	VL	H	L	L	L	M	VL	L	VL	M	VL	VL	L	L
Denmark	L	H	M	H	VH	H	H	H	M	M	L	L	M	H
Estonia	VL	VH	M	M	M	H	M	VH	L	VH	VH	VL	M	M
Finland	L	VH	L	L	VH	M	H	H	VL	M	VL	VL	M	M
France	M	H	M	M	L	M	VL	VL	L	H	VL	VL	L	M
Germany	L	H	M	H	L	M	L	M	L	H	L	M	M	H
Greece	M	H	L	L	L	H	L	L	H	H	M	M	L	M
Hungary	M	M	M	L	L	H	VL	L	M	L	L	M	VL	VL
Ireland	VL	M	VL	M	L	H	L	L	M	H	L	M	L	M
Italy	M	M	L	L	L	L	L	M	M	M	L	M	L	L
Latvia	M	M	VL	L	H	M	H	H	M	L	M	M	L	M
Lithuania	H	M	H	M	M	H	M	M	M	VL	H	H	L	L
Luxembourg	VL	VH	VH	H	L	VH	L	L	VL	H	L	L	L	M
Malta	H	M	M	H	L	H	VL	L	VH	M	H	M	L	M
Netherlands	L	VH	L	M	L	VH	L	L	L	H	VL	M	M	H
Poland	L	M	VL	L	L	H	VL	L	M	L	VL	L	L	L
Portugal	H	VH	M	M	H	M	L	L	H	H	L	M	L	M
Romania	H	M	H	H	L	VL	VL	L	H	L	H	H	M	L
Slovakia	M	M	M	M	L	VL	VL	L	L	L	L	L	L	L
Slovenia	M	H	L	VL	L	H	VL	L	L	H	VL	VL	L	M
Spain	M	H	L	M	M	M	L	L	M	H	L	L	L	M
Sweden	VH	H	H	H	VH	M	H	H	VL	H	VL	VL	L	L

The next step in the fuzzy MABAC method is the determination of the approximate border area matrix (G). This involves finding the geometric mean of the values within the columns (Eq. (3)). Afterward, the value of G is subtracted from all the weighted values (Eq. (4)), and then all the values of the criteria for the observed EU countries are added (Eq. (5)). This value serves as the basis for ranking alternatives. However, to rank the EU countries, it is necessary to convert fuzzy values into crisp values (Eq. (6)).

The results of the fuzzy MABAC method show that Denmark is the best-ranked country, exhibiting the best performance in the Climate Change Performance Index. Conversely, the worst-ranked country is the Czech Republic, displaying the poorest results in this index. The specificity of the fuzzy MABAC method is such that certain countries received a positive result, while others received a negative result (Table 4). This is attributed to the deviation from the average values of individual EU countries; those with values higher than the average receive a positive fuzzy MABAC value, and vice versa. Consequently, the MABAC method categorizes countries into two clusters, showcasing one of the method's advantages, particularly in ranking alternatives. Thus, the objective for EU countries is to achieve a positive fuzzy MABAC value to enter the first cluster. Through this analysis, 15 countries had a positive value in the fuzzy MABAC method, while 12 countries had a negative value.

These results are compared with the results from the CCPI report. The most significant positive difference in the ranking is observed for Malta, which achieved a better ranking with the fuzzy MABAC method compared to its position in the CCPI report, by seven places. Cyprus follows, with an improved ranking by 6 places. Conversely, some countries obtained worse results with the fuzzy MABAC method than with the CCPI report. The Netherlands experienced the most significant decline, falling 6 places, followed by Spain, which fell 5 places. This discrepancy in rank order is attributed to the application of fuzzy numbers and the membership function of the classical evaluation present in the original CCPI report. Having established the differing rank orders, the next step is to examine how the weights of the criteria within these criteria affect the ranking order of the EU countries.

Table 3. Weighted decision matrix

Country	**C11**	**C12**	**C13**	...	**C42**
Austria	$(0.14, 0.15, 0.16)$	$(0.16, 0.17, 0.19)$	$(0.11, 0.13, 0.14)$		$(0.14, 0.16, 0.17)$
Belgium	$(0.11, 0.13, 0.14)$	$(0.16, 0.17, 0.19)$	$(0.11, 0.13, 0.14)$	...	$(0.14, 0.16, 0.17)$
Bulgaria	$(0.11, 0.13, 0.14)$	$(0.10, 0.11, 0.13)$	$(0.11, 0.13, 0.14)$		$(0.11, 0.13, 0.14)$
Cyprus	$(0.14, 0.15, 0.16)$	$(0.13, 0.14, 0.16)$	$(0.11, 0.13, 0.14)$	...	$(0.11, 0.13, 0.14)$
Croatia	$(0.16, 0.18, 0.19)$	$(0.10, 0.11, 0.13)$	$(0.11, 0.13, 0.14)$	...	$(0.11, 0.13, 0.14)$
Czech Republic	$(0.10, 0.10, 0.11)$	$(0.16, 0.17, 0.19)$	$(0.11, 0.13, 0.14)$	...	$(0.11, 0.13, 0.14)$
Denmark	$(0.11, 0.13, 0.14)$	$(0.16, 0.17, 0.19)$	$(0.14, 0.15, 0.16)$	$\cdots$	$(0.17, 0.19, 0.20)$
Estonia	$(0.10, 0.10, 0.11)$	$(0.19, 0.20, 0.20)$	$(0.14, 0.15, 0.16)$	$\cdots$	$(0.14, 0.16, 0.17)$
Finland	$(0.11, 0.13, 0.14)$	$(0.19, 0.20, 0.20)$	$(0.11, 0.13, 0.14)$	...	$(0.14, 0.16, 0.17)$
France	$(0.14, 0.15, 0.16)$	$(0.16, 0.17, 0.19)$	$(0.14, 0.15, 0.16)$	...	$(0.14, 0.16, 0.17)$
Germany	$(0.11, 0.13, 0.14)$	$(0.16, 0.17, 0.19)$	$(0.14, 0.15, 0.16)$	$\cdots$	$(0.17, 0.19, 0.20)$
Greece	$(0.14, 0.15, 0.16)$	$(0.16, 0.17, 0.19)$	$(0.11, 0.13, 0.14)$		$(0.14, 0.16, 0.17)$
Hungary	$(0.14, 0.15, 0.16)$	$(0.13, 0.14, 0.16)$	$(0.14, 0.15, 0.16)$		$(0.10, 0.10, 0.11)$
Ireland	$(0.10, 0.10, 0.11)$	$(0.13, 0.14, 0.16)$	$(0.10, 0.10, 0.11)$		$(0.14, 0.16, 0.17)$
Italy	$(0.14, 0.15, 0.16)$	$(0.13, 0.14, 0.16)$	$(0.11, 0.13, 0.14)$		$(0.11, 0.13, 0.14)$
Latvia	$(0.14, 0.15, 0.16)$	$(0.13, 0.14, 0.16)$	$(0.10, 0.10, 0.11)$	...	$(0.14, 0.16, 0.17)$
Lithuania	$(0.16, 0.18, 0.19)$	$(0.13, 0.14, 0.16)$	$(0.16, 0.18, 0.19)$	...	$(0.11, 0.13, 0.14)$
Luxembourg	$(0.10, 0.10, 0.11)$	$(0.19, 0.20, 0.20)$	$(0.19, 0.20, 0.20)$	...	$(0.14, 0.16, 0.17)$
Malta	$(0.16, 0.18, 0.19)$	$(0.13, 0.14, 0.16)$	$(0.14, 0.15, 0.16)$	...	$(0.14, 0.16, 0.17)$
Netherlands	$(0.11, 0.13, 0.14)$	$(0.19, 0.20, 0.20)$	$(0.11, 0.13, 0.14)$	...	$(0.17, 0.19, 0.20)$
Poland	$(0.11, 0.13, 0.14)$	$(0.13, 0.14, 0.16)$	$(0.10, 0.10, 0.11)$	...	$(0.11, 0.13, 0.14)$
Portugal	$(0.16, 0.18, 0.19)$	$(0.19, 0.20, 0.20)$	$(0.14, 0.15, 0.16)$		$(0.14, 0.16, 0.17)$
Romania	$(0.16, 0.18, 0.19)$	$(0.13, 0.14, 0.16)$	$(0.16, 0.18, 0.19)$	$\cdots$	$(0.11, 0.13, 0.14)$
Slovakia	$(0.14, 0.15, 0.16)$	$(0.13, 0.14, 0.16)$	$(0.14, 0.15, 0.16)$		$(0.11, 0.13, 0.14)$
Slovenia	$(0.14, 0.15, 0.16)$	$(0.16, 0.17, 0.19)$	$(0.11, 0.13, 0.14)$		$(0.14, 0.16, 0.17)$
Spain	$(0.14, 0.15, 0.16)$	$(0.16, 0.17, 0.19)$	$(0.11, 0.13, 0.14)$	$\cdots$	$(0.14, 0.16, 0.17)$
Sweden	$(0.19, 0.20, 0.20)$	$(0.16, 0.17, 0.19)$	$(0.16, 0.18, 0.19)$	...	$(0.11, 0.13, 0.14)$
(G)	$(0.13, 0.14, 0.15)$	$(0.15, 0.16, 0.17)$	$(0.13, 0.14, 0.15)$	...	$(0.13, 0.15, 0.16)$

To determine how changes in weights affect the ranking of alternatives, a sensitivity analysis is applied [24, 25]. Sensitivity analysis can be conducted in several ways that are present in practice [7, 26, 27]. One approach involves taking received weights and correcting them, while another forms new weights. Since this research used predetermined weights from the CCPI report, the latter method is employed. In this way, the weights are determined so that one criterion is given greater importance than the others. One criterion has seven times more weight than the other criteria, and these other criteria all have the same weight. As there are 14 criteria, 14 scenarios are formed in that way. Additionally, in the fifteenth scenario, the same importance is given to all criteria. Thus, 15 scenarios are formed for use in the sensitivity analysis (Table 5).

After carrying out sensitivity analysis scenarios, it is evident (Figure 2) that three scenarios, namely S1, S5, and S13, significantly impact the change in the ranking of EU countries in terms of CCPI. In these scenarios, substantial alterations in the ranking order are observed. For instance, in scenario S1, Belgium, which was frequently ranked second in most scenarios, plummeted to eighth place. Latvia and Ireland also experienced a decline in their rankings. In this scenario, the "Current Level of GHG Emissions per Capita" criterion gained seven times more importance than the other criteria. Consequently, countries with lower scores for this criterion witnessed a deterioration in their ranking compared to countries with better scores, resulting in an improved rank order. In scenario S5, the criterion "Current Share of Renewables per TPES" is assigned seven times more importance than other criteria. In scenario S13, the criterion "National Climate Policy" is given seven times more importance than other criteria. These scenarios further validate that these three criteria play a pivotal role in enhancing the results of EU countries in terms of CCPI. It underscores the imperative for EU countries to enhance their performance in these three criteria to achieve a superior ranking. The sensitivity analysis unequivocally demonstrates that these three criteria stand out in the ranking of countries. Conversely, the other scenarios did not significantly influence the change in ranking compared to the S0 scenario, which represents the initial scenario utilizing weights from the CCPI report. Across all scenarios, it remains evident that Denmark emerges as the best-ranked EU country, excelling in implementing measures to reduce the impact of climate change compared to other EU nations. Estonia closely follows, needing improvements in the "Current Level of GHG Emissions per Capita" and "National Climate Policy" criteria to surpass Denmark and secure the top-ranking position among EU countries in terms of protective measures against the consequences of climate change, as illustrated in scenario S5.

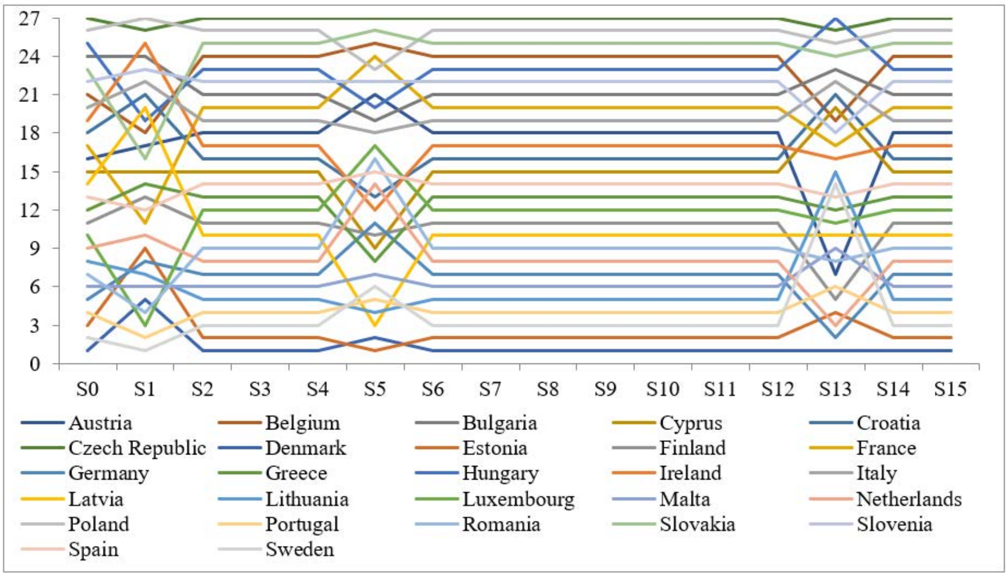

Figure 2. Results of sensitivity analyses

Table 4. Results of the ranking of countries using the fuzzy MABAC method

Country	$\tilde{S}_i$	S	Rank	CCPI	Rank	Difference
Austria	$(-0.263, -0.005, 0.260)$	-0.003	16	58.17	14	2
Belgium	$(-0.323, -0.071, 0.194)$	-0.069	21	55.00	18	3
Bulgaria	$(-0.369, -0.091, 0.168)$	-0.094	24	46.94	24	0
Cyprus	$(-0.276, 0.002, 0.267)$	0.000	15	53.09	21	-6
Croatia	$(-0.321, -0.043, 0.216)$	-0.046	18	57.32	16	2
Czech Republic	$(-0.405, -0.166, 0.099)$	-0.162	27	45.41	26	1
Denmark	$(-0.065, 0.213, 0.471)$	0.210	1	75.59	1	0
Estonia	$(-0.093, 0.165, 0.397)$	0.161	3	72.07	2	1
Finland	$(-0.192, 0.067, 0.310)$	0.064	11	61.11	11	0
France	$(-0.273, -0.021, 0.244)$	-0.019	17	57.12	17	0
Germany	$(-0.147, 0.131, 0.396)$	0.129	5	65.77	6	-1
Greece	$(-0.235, 0.043, 0.308)$	0.041	12	60.34	12	0
Hungary	$(-0.359, -0.122, 0.143)$	-0.117	25	45.93	25	0
Ireland	$(-0.310, -0.057, 0.208)$	-0.055	19	51.42	22	-3
Italy	$(-0.342, -0.064, 0.201)$	-0.066	20	50.60	23	-3
Latvia	$(-0.244, 0.022, 0.286)$	0.021	14	57.68	15	-1
Lithuania	$(-0.165, 0.107, 0.372)$	0.106	8	62.99	9	-1
Luxembourg	$(-0.157, 0.102, 0.334)$	0.097	10	65.09	7	3
Malta	$(-0.151, 0.120, 0.378)$	0.118	6	59.80	13	-7
Netherlands	$(-0.166, 0.106, 0.351)$	0.102	9	69.98	3	6
Poland	$(-0.407, -0.155, 0.110)$	-0.153	26	44.40	27	-1
Portugal	$(-0.124, 0.154, 0.404)$	0.149	4	67.48	5	-1
Romania	$(-0.157, 0.108, 0.373)$	0.108	7	61.50	10	-3
Slovakia	$(-0.354, -0.089, 0.176)$	-0.089	23	54.47	19	4
Slovenia	$(-0.322, -0.078, 0.186)$	-0.075	22	53.57	20	2
Spain	$(-0.244, 0.034, 0.299)$	0.032	13	63.37	8	5
Sweden	$(-0.082, 0.164, 0.397)$	0.162	2	69.39	4	-2

Table 5. Scenarios when conducting sensitivity analysis

Scenario	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34	C41	C42
S0	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.10
S1	0.35	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S2	0.05	0.35	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S3	0.05	0.05	0.35	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S4	0.05	0.05	0.05	0.35	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S5	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S6	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S7	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.05	0.05	0.05	0.05
S9	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.05	0.05	0.05
S10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.05	0.05
S11	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.05
S12	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.05
S13	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.05
S14	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.35
S15	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07

5 Discussion

Climate change has become an increasingly discussed problem worldwide. Various bilateral meetings have taken place on a global scale, proposing concrete measures that all signatory countries must adhere to. The EU has set the ambitious goal of achieving climate neutrality by 2050. This research delves into understanding how EU countries influence climate change. To achieve this, the study utilized the CCPI report, encompassing all EU countries along with 36 others. The CCPI report issued by Climate Action Network International consists of four main criteria, each having a set of auxiliary criteria. The GHG emissions, renewable energy, and energy use criteria are further divided, while the climate policy criterion is subdivided into two auxiliary criteria [20]. According to this report, specific weights were assigned to these criteria, with the auxiliary criteria of the first and fourth criteria valued at 10% and those of the second and third criteria valued at 5%. In this way, the first criterion, GHG emissions, contributes 40% of the total value, while the other criteria contribute 20%. These weights were also taken into account in this research.

This paper evaluated selected countries using linguistic values ranging from very low to very high, categorized into five levels. In the original report, these assessments were converted into numerical values, serving as the foundation for ranking EU countries. In contrast, the presented research took a distinct approach to country ratings by embracing a fuzzy set. This methodology involves the conversion of linguistic values into fuzzy numbers through a specified membership function. Fundamentally, this membership function translates linguistic values into triangular fuzzy numbers. To apply these numerical representations effectively, fuzzy MCDA methods were developed. These methods incorporate fuzzy operations that facilitate standard mathematical procedures, including addition, subtraction, multiplication, and division. The majority of MCDA methods precisely employ these operations.

The MABAC method was chosen for ranking countries using linguistic values. This method belongs to the classic methods that rank the average value of alternatives according to certain criteria. For this purpose, the geometric mean is used, and the values of alternatives are compared with that mean. In addition, this method also applies complex linear normalization, which normalizes fuzzy values into values ranging from zero to one. The lowest values of the alternatives according to individual criteria are given the value of zero, while the highest values are given the value of one. In this way, the alternatives that have the lowest value according to a particular criterion are placed in a subordinate position. The next characteristic of this method is the way in which the weighted decision matrix is calculated. In most cases, the value of the normalized decision matrix is multiplied by certain weights. In the case of the MABAC method, a weight value is added to that value. In this way, the importance of weight in ranking alternatives is emphasized. These are just some of the specifics that set the MABAC method apart from other MCDA methods, which is why this method was taken into account when determining the ranking.

The fuzzy MABAC method results divided EU countries into two clusters: those with scores above and below the average. The 12 countries scoring below average need additional measures to reduce their impact on climate change. Additionally, a comparison of the fuzzy MABAC method results with the original CCPI report ranking revealed differences. Some countries were better ranked using the fuzzy MABAC method, while others were ranked lower. This discrepancy can be attributed to the use of fuzzy numbers, where a very low value transformed into a non-fuzzy assessment becomes 1, while the fuzzy value is represented as (1, 1, 2). This discrepancy in values contributes to the ranking differences, emphasizing the importance of considering the membership function of fuzzy numbers in these methods. Among the 27 EU countries, six had the same ranking in both approaches. Denmark consistently emerged as the top-ranked EU country in both methods, serving as a model for other EU nations in addressing climate change impact reduction.

To assess the influence of criteria on the ranking order, a sensitivity analysis was conducted. The initial step involved the creation of a scenario [8]. In this applied sensitivity analysis, 15 scenarios were employed. These scenarios were designed to assign seven times more importance to one criterion than to other criteria, exploring how that specific criterion was affected in the ranking while accounting for other criteria. In the fifteenth scenario, equal importance was assigned to all criteria. The application of these scenarios revealed results indicating that out of 14 auxiliary criteria, three played a pivotal role in the ranking of EU countries. These criteria were: current level of GHG emissions per capita (C11), current share of renewables per TPES (C21), and national climate policy (C41). These criteria were deemed instrumental for EU countries to improve their ranking, requiring special attention.

6 Conclusions

This research aimed to rank EU countries based on their impact on climate change using the fuzzy MABAC method. The main findings of this study are outlined below:

- The developed methodology demonstrated the applicability of the fuzzy set-in ranking EU countries when linguistic evaluations are employed;

- EU countries exhibit diverse policies to mitigate the effects of climate change, resulting in their division into two clusters—those below and above the average;

- The ranking order derived from the fuzzy MABAC method differs from the ranking order provided by the CCPI report;

- The sensitivity analysis confirmed the significant influence of three auxiliary criteria on the ranking of alternatives;

- The research offered guidelines to EU countries on enhancing measures to mitigate the impact of climate change based on these findings.

However, like any other research, this study has certain limitations. These limitations are associated with the specificity of the fuzzy set. The results obtained using the fuzzy MABAC method revealed differences between this ranking and the ranking in the original CCPI report. Future research should investigate whether these variations result from the application of the MABAC method, requiring the application of other fuzzy methods for comparison. Additionally, an exploration of whether the steps of the MABAC method contributed to this ranking should be undertaken. Consequently, different normalization techniques should be applied in future research to minimize the normalization's impact on the formation of the ranking order.

Despite these limitations, the research has provided valuable insights into the positioning of EU countries relative to others and proposed guidelines for improving climate change mitigation policies. Without these guidelines, achieving the goal of all EU countries becoming climate-neutral by 2050 would be challenging.

Author Contributions

Conceptualization, A.P., A.Š. and Š.M.; methodology, A.P. and A.Š.; software, I.H.; validation, A.P. and Š.M.; formal analysis, A.P.; investigation, I.H.; resources, Š.M.; data curation, A.P.; writing-original draft preparation, A.P. and A.Š.; writing-review and editing, A.Š. and Š.M.; visualization, Š.M.; supervision, I.H.; project administration, A.P.; funding acquisition, A.P. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

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