ANALYSIS OF CLIMATE CHANGE PERFORMANCE OF G7 COUNTRIES BASED ON AHP-CODAS METHODS

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ABSTRACT

Recently, due to the importance of climate change issues, it has been studied from different angles, and as a result, numerous articles have appeared in the literature. Nevertheless, there are few works on the analysis of climate change problems based on multi-criteria decision-making methods. The application of multi-criteria decision-making methods in this issue ensures as accurate results as possible because the weighting coefficients of the criteria are determined mathematically, and not based on subjective assessment. With this in mind, this study analyses the climate change performance of the G7 countries based on the AHP (Analytic Hierarchy Process) and CODAS (COmbinative Distance-based ASsessment) methods. The method was implemented based on available data of CCPI (Climate Change Performance Index) criteria for 2024. According to the AHP method, the most important criterion is greenhouse gas emissions. By reducing greenhouse gas emissions, the negative effects of climate change on the G7 countries can be mitigated. In terms of climate change performance, Germany ranks first. Ranking after Germany: European Union, United Kingdom, Italy, France, Japan, United States and Canada. Climate change is greater in the European Union than in the United Kingdom, Japan, the United States, and Canada. Climate changes in Germany are greater than in Italy and France. Climate change in Italy is greater than in France. However, regardless of the differences in climate change among the G7 countries, in order to mitigate the negative effect of climate change, it is necessary to reduce greenhouse gas emissions, increase the use of renewable energy in total consumption, and define an adequate climate policy strategy.

***Keywords*:** *GHG emission, renewable energy, energy use, climate policy*

INTRODUCTION

The issue of climate change management is very significant [1 - 4]. The causes of climate change are greenhouse gas emissions, water shortages due to increased consumption, global warming, energy use, etc. Climate change affects biodiversity, agriculture, forestry, and human health [5]. Investments in the function of protection (i.e. mitigation of negative effects) from climate change are economically profitable. The strategic dimensions of climate change management are mitigation, adaptation, technology, and financing.

In the analysis of climate change performance, in addition to classical methods, multi-criteria decision-making methods are increasingly used because they are based on a mathematical approach to determining the weighting coefficients of the criteria used to measure climate change performance and ranking alternatives [6 - 8]. This provides more accurate research results on the very current problem of climate change. It also enables the setting of more realistic relevant measures in the function of improving climate change performance (reducing greenhouse gas emissions, increasing the use of renewable energy in total consumption, defining an adequate climate policy strategy).

The research of the problem presented in this paper is based on the data of CCPI (Climate Change Performance Index) criteria for 2024. Two methods were applied: AHP (Analytic Hierarchy Process) method and CODAS (COmbinative Distance-based ASsessment) method. Using the first method, the weighting coefficients of the criteria are determined and, based on that, their significance. By applying the second method, using the weighting coefficients of the criteria determined with the AHP method, the alternatives are ranked. The CODAS method, which is the general case for multi-criteria decision-making methods, gives more accurate results compared to the CCPI because it simultaneously analyses the observed climate change criteria in an integrated manner, whereas the CCPI takes them individually. The weighting coefficients of the criteria are determined mathematically and not based on subjective assessment, as is the case with the CCPI.

MATERIALS AND METHODS

In this study, a comparative analysis of performance indicators of climate change of the G7 countries was performed using the AHP and CODAS methods. Their theoretical and methodological characteristics are briefly presented below.

AHP method

Given the fact that the weighting coefficients of the criteria are determined with the AHP method, its theoretical and methodological characteristics are briefly presented below.

The AHP method consists of the following steps:

Step 1. Forming a matrix of comparison pairs:

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \quad (1)$$

Step 2. Normalization of the comparison pair matrix:

$$a_{ij}^{*} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}},\ i,j = 1,\ldots,n \quad (2)$$

Step 3. Determination of relative importance, i.e. vector weights:

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}^{*}}{n},\ i = 1,\ldots, n \quad (3)$$

The consistency index (CI) is a measure of the deviation of n from the largest eigenvalue λ_{max} and can be represented by the following formula:

$$CI = \frac{\lambda_{max} - n}{n} \quad (4)$$

If CI < 0.1, the estimated values of the coefficients a_{ij} are consistent, and the deviation of λ_{max} from n is negligible. In other words, this means that the AHP method accepts an inconsistency of less than 10 %.

CR = CI/RI can be calculated, where RI is the random index.

CODAS method

The CODAS method is a more recent method of multi-criteria decision-making (MCDM)

developed based on Euclidean and Hamming distance measures, for selecting the best alternative among the available options. The basic principle of the CODAS method is that the best alternative should have the greatest distance from the negative ideal solution. In the case when the Euclidean distances of two alternatives have the same value, then the Hamming distances are compared to choose the best alternative [9].

The CODAS method consists of the following steps:

Step 1. Defining the decision matrix.

Decision-makers evaluate alternatives according to each attribute (criterion).

$$\left[x_{ij}\right]_{n\ x\ m}=\begin{bmatrix}\tilde{x}_{11}\tilde{x}_{12} & \cdots & \tilde{x}_{1m}\\ \vdots & \ddots & \vdots\\ \tilde{x}_{n1}\tilde{x}_{n2} & \cdots & \tilde{x}_{nm}\end{bmatrix} \quad (5)$$

where x_{ij} shows the value rating of the i-th ($i \in \{1, 2, \ldots, n\}$) alternative in relation to the j-th attribute ($j \in \{1, 2,\ldots,m\}$).

Step 2. Calculation of the normalized decision matrix.

The decision matrix is linearly normalized using the following equation:

$$\tilde{n}_{ij}=\begin{cases}\tilde{x}_{ij}/\max_k \tilde{x}_{kj} & \text{if} \quad j\in N_b\\ \min_k \tilde{x}_{kj}/\tilde{x}_{ij} & \text{if} \quad j\in N_c\end{cases} \quad (6)$$

N_b represents sets of useful, i.e. revenue (higher value is desirable), and N_c non-useful (cost) attributes (lower value is desirable).

Step 3. Calculation of weighted normalized decision matrix.

The weighted normalized decision matrix is determined using the following equation:

$$s_{ij}= w_j \tilde{n}_{ij} \quad (7)$$

where $w_j \in [0, 1]$ represents the weight coefficient assigned by the decision maker for different attributes $\sum_{j=1}^{m} w_j = 1$.

Step 4. Identifying negative ideal solutions.

Negative ideal solutions (NI) are obtained by applying the following equation:

$$NI = \left[ni_j\right]_{1\ x\ m} \quad (8)$$
$$ni_j = \min_i s_{ij}$$

Step 5. Calculation of Euclidean (ED) and Hamming (HD) distances of alternatives from the negative ideal solution.

The Euclidean and Hamming distances of the alternatives from the negative ideal solution are calculated using the following equations:

$$ED_i = \sqrt{\sum_{j=1}^{m}\left(s_{ij} - ni_j\right)^2} \quad (9)$$

$$HD_i = \sum_{j=1}^{m}\left|s_{ij} - ni_j\right| \quad (10)$$

Step 6. Constructing a relative assessment matrix.

The relative assessment matrix (Ra) is obtained using the following formula:

$$Ra = \left[p_{il}\right]_{n\ x\ n} \quad (11)$$

$$p_{il} = (ED_i - ED_l) + \left(\delta(ED_i - ED_l)\right) x \left((HD_i - HD_l)\right) \quad (12)$$

where $i, i \in \{1, 2,\ldots,n\}$ and δ is a threshold function defined as follows (the authors of [9] mistakenly replaced the 0 and 1 here):

$$\delta(x)=\begin{cases}0 & \text{if} \quad |x| \geq \rho\\ 1 & \text{if} \quad |x| < \rho\end{cases} \quad (13)$$

The value of the threshold parameter ρ is between 0.01 and 0.05. It can also be determined by the decision maker. If the difference between the Euclidean distances of two alternatives is less than a defined threshold value, then they are compared according to the Hamming distance.

Step 7. Assigning a grade (AS) to each alternative.

AS value of each alternative is calculated as follows:

$$AS_i = \sum_{l=1}^{n} p_{il} \qquad (14)$$

According to the higher rating, the most suitable alternative is chosen.

Step 8. Ranking of alternatives according to AS value.

Alternatives are ranked by AS value in descending order. The alternative with the highest AS value is the best option among the alternatives.

In the case of climate change performance analysis of the G7 countries, the AHP method is used to determine the weighting coefficients of the observed criteria. The CODAS method is used to rank the alternatives (G7 countries) while respecting the established weighting coefficients of the selected criteria for climate change analysis. It considers all criteria simultaneously and therefore provides more accurate results of analyses of the climate change performance of the G7 countries.

The climate change problem of G7 countries is analysed in this study based on AHP and CODAS methods. The weighting coefficients of the criteria were determined using the AHP method. Using the CODAS method, the performance positioning of alternatives is determined. The key issue is the choice of criteria. The choice of criteria should correspond to the nature of the research problem. Consequently, the research of the climate change performance positioning of the G7 countries in this study based on the AHP-CODAS method was carried out using the CCPI criteria for 2024, namely: C1 - GHG (GreenHouse Gas) emissions, C2 - Renewable energy, C3 - Energy use and C4 - Climate policy (Figure 1). They fully correspond to the character of the problem of climate change performance evaluation, in the specific case of the G7 countries. Alternatives are the G7 countries: A1 - Germany, A2 - European Union, A3 - United Kingdom, A4 - France, A5 - Italy, A6 - United States, A7 - Japan and A8 - Canada. Criteria and alternatives with corresponding data are shown in Table 1.

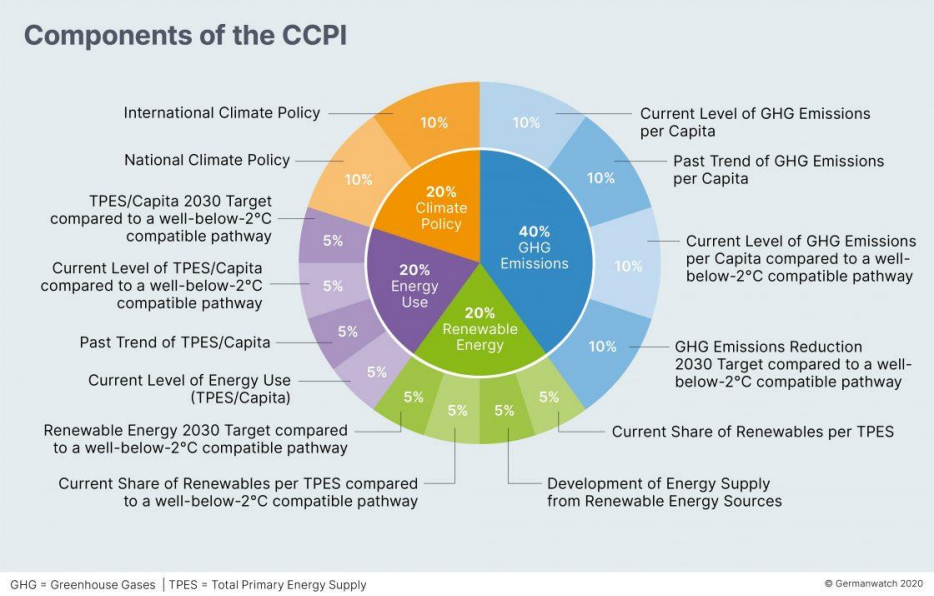

Figure 1. Components of the CCPI [10]

Table 1. CCPI ranking 2024, G7 countries [11]

Rank	GHG emissions - 40 % weighting	Renewable energy - 20 % weighting	Energy use - 20 % weighting	Climate policy - 20 % weighting
14. Germany (Score 65.77 High)	28.47	7.38	14.54	15.39
16. European Union (27) (Score 64.71 High)	26.31	7.46	13.72	17.22
20. United Kingdom (Score 62.36 Medium)	30.95	5.20	16.63	9.58
37. France (Score 57.12 Low)	27.02	4.55	12.84	12.71
44. Italy (Score 50.60 Low)	23.20	7.38	13.52	6.49
57. United States (Score 42.79 Very low)	16.88	3.03	6.69	16.20
58. Japan (Score 42.08 Very low)	21.42	5.00	13.15	2.50
62. Canada (Score 31.55 Very low)	14.59	3.40	4.04	9.52

RESULTS AND DISCUSSION

The basic original empirical data for the analysis of the problem discussed in this paper are displayed in Table 1. The data in Table 1 in the first column show the CCPI ranking of the G7 countries. Germany is ranked fourteenth (65.77). The European Union took the sixteenth place (64.71). The United Kingdom is positioned in the twentieth place (62.36). France is in the thirty-seventh place (57.12). Italy is ranked forty-fourth (50.60). The United States took the fifty-seventh place (42.79). Japan is ranked fifty-eighth (42.08). Canada is positioned in the sixty-second place (31.55). Therefore, according to CCPI, climate change is high in Germany and the European Union. In the United Kingdom, the climate change is medium. Climate change is low in France. The United States, Japan, and Canada have very low climate change. Table 2 shows the correlation of the criteria.

The data in Table 2 show a strong correlation between greenhouse gas emissions and energy use, at the level of statistical significance. There is a strong correlation between renewable energy and energy use, at the level of statistical significance. Therefore, greenhouse gas emissions can be significantly reduced with the increase of renewable energy in total consumption in the G7 countries.

Table 2. Correlation of criteria

Correlations					
		C1	C2	C3	C4
C1	Pearson correlation	1	0.625	0.931**	0.158
	Sig. (2-tailed)		0.098	0.001	0.709
	N	8	8	8	8
C2	Pearson correlation	0.625	1	0.710*	0.084
	Sig. (2-tailed)	0.098		0.048	0.844
	N	8	8	8	8
C3	Pearson correlation	0.931**	0.710*	1	- 0.102
	Sig. (2-tailed)	0.001	0.048		0.810
	N	8	8	8	8
C4	Pearson correlation	0.158	0.084	- 0.102	1
	Sig. (2-tailed)	0.709	0.844	0.810	
	N	8	8	8	8
** Correlation is significant at the 0.01 level (2-tailed)					
* Correlation is significant at the 0.05 level (2-tailed)					

The ranking of G7 countries based on the AHP and CODAS methods is presented in the continuation of this study [12 - 21]. The weighting coefficients of the criteria were determined using the AHP method (Table 3, Figure 2).

Table 3. Weighting coefficients of criteria, AHP method

		1	2	3	4	Weights
		C1	C2	C3	C4	
1	C1	1.00	1.00	2.00	2.00	0.3327
2	C2	1.00	1.00	1.50	2.50	0.3228
3	C3	0.50	0.67	1.00	2.00	0.2124
4	C4	0.50	0.40	0.50	1.00	0.1321
						1.0000
Consistency ratio 0.0151						

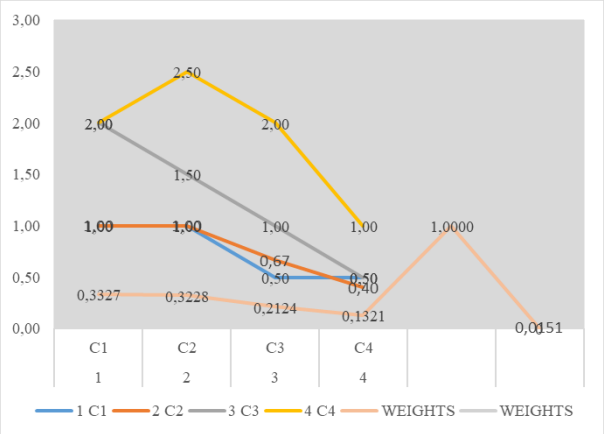

Figure 2. Weighting coefficients of criteria, AHP method

The data in Table 3 show that in this particular case, the most important criterion is C1 (GHG emissions). Climate change targets can be achieved by reducing greenhouse gas emissions. For example, greenhouse gas emissions can be reduced through energy efficiency and the use of renewable energy sources, low-carbon transport, forestry, water management and agriculture, and waste management.

The performance ranking of the alternatives (climate changes of the G7 countries) in this study, using the calculated weighting coefficients of the criteria using the AHP method, was performed using the CODAS method [22 - 29]. The procedure and results of the application of the CODAS method in the evaluation of the climate change performance of the G7 countries are shown in Tables 4 - 7 and Figure 3.

Table 4. Initial and normalised matrix

Initial matrix				
Weights of criteria	0.3327	0.3228	0.2124	0.1321
Type of criteria	1	1	1	1
	C1	C2	C3	C4
A1	28.47	7.38	14.54	15.39
A2	26.31	7.46	13.72	17.22
A3	30.95	5.2	16.63	9.58
A4	27.02	4.55	12.84	12.71
A5	23.2	7.38	13.52	6.49
A6	16.88	3.03	6.69	16.2
A7	21.42	5	13.15	2.5
A8	14.59	3.4	4.04	9.52
MAX	30.95	7.46	16.63	17.22
MIN	14.59	3.03	4.04	2.5
Normalised matrix				
Weights of criteria	0.3327	0.3228	0.2124	0.1321
Type of criteria	1	1	1	1
	C1	C2	C3	C4
A1	0.9199	0.9893	0.8743	0.8937
A2	0.8501	1.0000	0.8250	1.0000
A3	1.0000	0.6971	1.0000	0.5563
A4	0.8730	0.6099	0.7721	0.7381
A5	0.7496	0.9893	0.8130	0.3769
A6	0.5454	0.4062	0.4023	0.9408
A7	0.6921	0.6702	0.7907	0.1452
A8	0.4714	0.4558	0.2429	0.5528

Table 5. Weighted normalized matrix

Weighted normalized matrix								
							Threshold parameter	
	C1	C2	C3	C4	ED	HD	ρ	0.02
A1	0.3060	0.3193	0.1857	0.1181	0.2923	0.5704		
A2	0.2828	0.3228	0.1752	0.1321	0.2840	0.5542		
A3	0.3327	0.2250	0.2124	0.0735	0.2618	0.4849		
A4	0.2905	0.1969	0.1640	0.0975	0.2024	0.3901		
A5	0.2494	0.3193	0.1727	0.0498	0.2441	0.4325		
A6	0.1815	0.1311	0.0854	0.1243	0.1131	0.1636		
A7	0.2303	0.2164	0.1680	0.0192	0.1618	0.2750		
A8	0.1568	0.1471	0.0516	0.0730	0.0562	0.0699		
A-	0.1568	0.1311	0.0516	0.0192				

Table 6. Relative assessment matrix

Relative assessment matrix								
	C1	C2	C3	C4	C5	C6	C7	C8
A1	0.0000	0.0245	0.0305	0.0900	0.0482	0.1792	0.1305	0.2361
A2	- 0.0245	0.0000	0.0222	0.0816	0.0399	0.1709	0.1221	0.2278
A3	- 0.0305	- 0.0222	0.0000	0.0595	0.0701	0.1487	0.1000	0.2056
A4	- 0.0900	- 0.0816	- 0.0595	0.0000	- 0.0418	0.0892	0.0405	0.1462
A5	- 0.0482	- 0.0399	- 0.0701	0.0418	0.0000	0.1310	0.0823	0.1879
A6	- 0.1792	- 0.1709	- 0.1487	- 0.0892	- 0.1310	0.0000	- 0.0487	0.0569
A7	- 0.1305	- 0.1221	- 0.1000	- 0.0405	- 0.0823	0.0487	0.0000	0.1057
A8	- 0.2361	- 0.2278	- 0.2056	- 0.1462	- 0.1879	- 0.0569	- 0.1057	0.0000

Table 7. Ranking

	Alternatives	AS	Ranking
Germany	A1	0.739	1
European Union (27)	A2	0.640	2
United Kingdom	A3	0.531	3
France	A4	0.003	5
Italy	A5	0.285	4
United States	A6	- 0.711	7
Japan	A7	- 0.321	6
Canada	A8	- 1.166	8

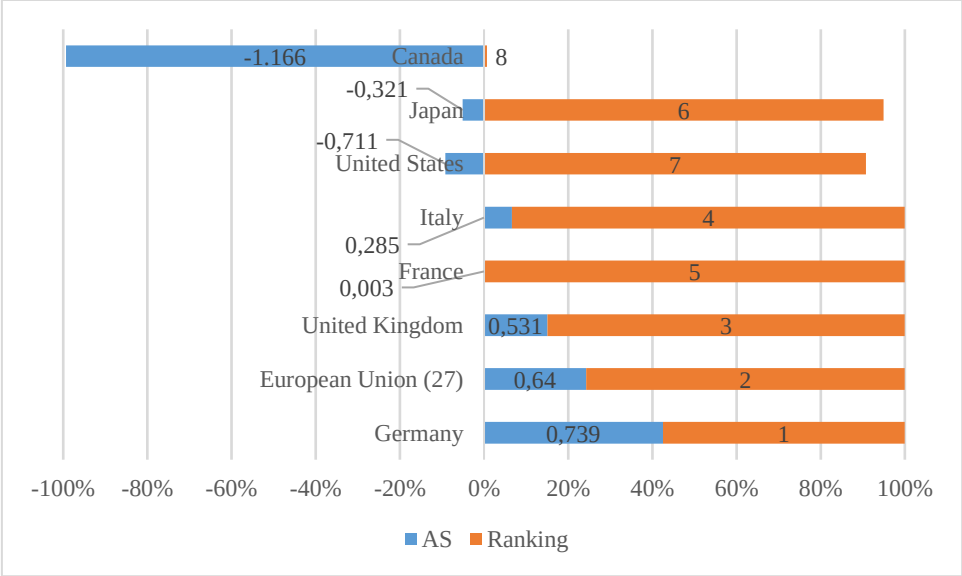

Figure 3. Ranking of G7 countries

The data in Table 7 show that in terms of climate change performance, Germany is in the first place. Ranking after Germany: European Union, United Kingdom, Italy, France, Japan, United States and Canada. Climate change is greater in the European Union than in the United Kingdom, Japan, the United States, and Canada. Climate changes in Germany are greater than in Italy and France. Climate change in Italy is greater than in France. However, regardless of the differences in climate change among the G7 countries, to mitigate the negative effect of climate change, it is necessary to reduce greenhouse gas emissions, increase the use of renewable energy in total consumption, and define an adequate climate policy strategy.

Generally speaking, the application of multi-criteria decision-making methods in the

analysis of climate change problems gives more accurate results. They are the product of a mathematical approach to determining weighting coefficients of criteria and ranking alternatives. This enables appropriate measures to be taken to mitigate the negative effects of climate change. This is unequivocally confirmed by the results of the research on climate change problems of the G7 countries based on the AHP-CODAS method, compared with the CCPI ranking. For the sake of illustration, the weight coefficient of criterion C1 (GHG emissions) according to the CCPI is 40.00 % and according to the AHP method it is 33.27 %. Therefore, it is recommended to use multi-criteria decision-making methods in the evaluation of climate change problems.

CONCLUSION

In recent times, the problem of climate change has become more pronounced. It is investigated from different angles. In this study, in order to obtain the most accurate representation of the problem of climate change, the G7 countries were ranked based on multi-criteria decision-making methods, namely the AHP-CODAS method. Using the AHP method, the weighting coefficients of the criteria were determined. In this case, the most important criterion is C1 (GHG emissions). By reducing the emission of phases with greenhouse effects, the negative effects of climate change in the G7 countries can be significantly mitigated. Using the CODAS method, relying on the determined weighting coefficients of the AHP method, the G7 countries were ranked according to climate change performance. The ranking of the G7 countries in the descending order is as follows: Germany, European Union, United Kingdom, Italy, France, Japan, United States and Canada. Climate change is greater in the European Union than in the United Kingdom, Japan, the United States, and Canada. In Germany, climate changes are greater than in Italy and France. In Italy, climate change is greater than in France. The observed criteria in this particular case are nothing but factors of climate change. To mitigate the negative effects of climate change, the G7 countries should reduce greenhouse gas emissions, increase the use of renewable energy in total consumption, and define an adequate climate policy strategy. In this context, significant financial resources are needed for investments in new technology, the effects of which are visible in the long term.

As for the CCPI, the AHP-CODAS method provides more accurate results of the climate change analysis of the G7 countries. This is because the AHP-CODAS method simultaneously integrates several criteria, whose weighting coefficients are determined mathematically and not based on subjective assessment, as is the case with the CCPI.

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