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Sensitivity Analysis in Multi-Criteria Decision-Making Problems

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Abstract

The aim of this study is to present a determination and sensitivity model for analysts used in the application of multi-criteria decision-making (MCDM) methods. It is advised to apply these actions in this situation of "sensitivity analysis based on a variation of criteria weight, sensitivity analysis based on rank reversal feature and comparison analysis with results obtained from different sequencing methods" for stability and sensitivity model. In the application part of the model, as an alternative, the Fragile Five countries, the unemployment rate, the state budget, the GDP growth, inflation, the current account balance, and the credit default swap were used as criteria. The criteria were weighted by Method based on the Removal Effects of Criteria (MEREC) method, and the ranking of the alternatives was carried out by the Integrated Simple Weighted Sum-Product (WISP) method. The model was found to be sensitive to changes in the weight coefficients with varying weights applied to the criteria throughout 22 scenarios during the method's application phase. The model is then shown to provide reliable outcomes in a dynamic context through 4 distinct situations produced in the rank reversal stage. A ranking comparison with other widely used techniques, including PIV, CoCoSo, COPRAS, WEDBA, TOPSIS, and SAW, was conducted to assess the dependability of the MEREC-WISP-based model. It was discovered that the findings had a good correlation.

Keywords: Sensitivity and Stability Analysis, Bibliometry Analysis, MCDM.

Çok Kriterli Karar Verme Problemlerinde Duyarlılık Analizi

Öz

Bu çalışmanın amacı, çok kriterli karar verme (ÇKKV) yöntemlerinin uygulanmasında kullanılan çalışmalar için bir kararlılık ve duyarlılık modeli önermektir. Bu kapsamda kararlılık ve duyarlılık analizi için "kriter ağırlığının varyasyonuna dayalı duyarlılık analizi, sıra ters çevirme özelliğine dayalı duyarlılık analizi ve farklı sıralama metotlarından elde edilen sonuçlar ile karşılaştırma analizi" adımlarının birlikte kullanılması önerilmiştir. Metodun uygulama kısmında alternatif olarak Kırılgan Beşli ülkeleri, bu ülkelere ait işsizlik oranı, devlet bütçesi, GSYİH büyümesi, enflasyon, cari hesap dengesi, risk primi kriter olarak kullanılmıştır. Kriterler MEREC ile ağırlıklandırılmış, alternatiflerin sıralanması ise WISP ile gerçekleştirilmiştir. Metodun uygulama safhasında 22 senaryo üzerinden kriterlere atanan farklı ağırlıklar ile modelin ağırlık katsayılarındaki değişikliklere duyarlı olduğu bulunmuştur. Modelin sıra ters çevirme adımında oluşturulan 4 farklı senaryo üzerinden modelin dinamik bir ortamda geçerli sonuçlar sağladığı görülmüştür. MEREC-WISP tabanlı modelin güvenilirliği için PIV, CoCoSo, COPRAS, WEDBA, TOPSIS ve SAW gibi yaygın olarak kullanılan bazı yöntemlerle bir sıralama karşılaştırması yapılmış ve sonuçların yüksek korelasyona sahip olduğu görülmüştür.

Anahtar Kelimeler: Duyarlılık ve Kararlılık Analizi, Bibliyometri Analizi, ÇKKV.

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Introduction

Multi-Criteria Decision Making (MCDM) has been an important discipline that has been widely applied in many decision-making problems since its appearance in the literature in the 1950s and 1960s and its development in the 1970s. The MCDM is a decision-making technique that allows the selection or ranking of the most appropriate alternative in a decision problem consisting of more than two alternatives and multiple criteria. The main purpose of MCDM is not to solve a decision problem, but to offer solutions to the decision-maker.

Since MCDM studies have been conducted for more than half a century, a significant number of studies have taken their place in the literature. Especially in recent years, the diversity of MCDM has been increased by developing many hybrid models by combining different methods in weighting the criteria that constitute the decision problem and listing the alternatives. There is no consensus in the literature for a model or test to check the suitability of the methods for studies and to determine the reliability of the results. However, studies in the literature have suggested the use of sensitivity analysis in the efficient implementation of MCDM approaches to evaluate the stability of the best option under changes in input parameters due to a lack of controllability or mistake in calculating accurate information. The stability or behavior of the analysis against minor preferences changes that take place throughout the solution process or minor changes in the parameter values supplied can be referred to as sensitivity analysis (Pamučar and Ćirović, 2015). Sensitivity analysis provides an MCDM model and dependable instruments for describing the uncertainty linked to the problem being analyzed. In this study, the stability and sensitivity model for the analyzes performed with MCDM methods was presented and the application of the recommendations was shown with the MEREC-WISP methods newly introduced to the literature.

The article consists of three parts: introduction, literature review and application part. In the introduction, the importance and purpose of the study and the sensitivity of previous studies on MCDM in the literature section were examined by bibliometric analysis. In the material and method section, the underlying math and procedures of the new MEREC and WISP methods are given. The operational steps of the recommended stability and sensitivity analysis are presented in the application section with explanations. A general evaluation is made in the conclusion section.

1. Literature Review

In the literature section, the MEREC method used as a method in this study and the application areas of the WISP method is briefly mentioned. Similarly, information was given about the MCDM studies for which sensitivity analysis was applied.

There are very few studies because the MEREC method has just been introduced to the literature. Introduced by Keshavarz-Ghorabaee et al. (2021) as an objective criteria weighting method. In the Keshavarz-Ghorabaee (2021) study, logistics companies were used to determine suitable distribution locations and Goswami et al. (2021) were used to select renewable energy sources in India.

There are very few studies because the WISP method has just been introduced to the literature. It was introduced by Stanujkić et al. (2021a) as a method of sorting out alternatives. Stanujkić et al. (2021b) Compared the WISP method with current MCDM techniques using the Python programming language.

In their sensitivity analyses applied to MCDM problems, Rashid et al. (2021) and Ecer (2021) looked at sensitivity with changes in criteria weights. Gorcun et al. (2021) first examined the effect of changing the weights of input and output factors on the ranking results, then performed sensitivity analysis by comparing the results of the proposed model with the results of different fuzzy techniques. Wang et al. (2021) Sensitivity analysis was performed with changes in the criteria weight obtained by using FAHP. Boyacı, Şişman (2021), and Kumar et al. (2021) conducted a sensitivity analysis to examine the impact of modifications to the weight values of the criteria on the ranking of alternatives. Blagojevi et al(2021) .'s sensitivity analysis, comparison analysis with other fuzzy techniques, simulations of criteria weight values, and computation of the Spearman correlation coefficient were used to corroborate the findings. Amin et al. (2020) Sensitivity analysis were performed regarding the distinctive coefficient of Gray Relation Analysis. Stević et al. (2020) conducted a comprehensive sensitivity analysis to confirm the results of the newly introduced MARCOS method.

1.1. Bibliometric Analysis of Sensitivity Analysis in MCDM Studies

A statistical technique called bibliometrics may statistically and mathematically examine research publications on a certain topic. Bibliometric indicators assess local, national, and global efforts to accomplish a certain aim (Rosas et al., 2011). SciVerse Scopus was chosen for the current study’s data access. Elsevier established the bibliographic database Scopus in November 2004. In the study, no time limit was made in the search for the start year. The search was implemented at a time interval (December 26, 2021) to eliminate bias that may arise as a result of the constant updating of the Scopus database. Two separate searches were conducted in the Scopus database. First, 25.907 documents made by MCDM methods were obtained within the specified time limit. Then, it was seen that the number of sensitivity analysis studies applied to the studies carried out with the MCDM methods specified in the purpose of the study was 1.916 documents. In order to reach these results, "multi-criteria decision-making" and "multi-criteria decision-making and sensitivity analysis" were questioned. In the study, VOSviewer software was preferred to produce visualization maps based on network data and to use mapping and clustering techniques to visualize similarities. This software is designed for use in the analysis of bibliometric networks.

The sample, which emerged based on the searches made through the Scopus database for sensitivity analysis applied to studies related to MCDM methods, consists of 1.916 documents, including articles (1.644), conference papers (192), reviews (48), book chapters (24), conference reviews (7), note (1).

It is seen in Figure 1 that the studies for sensitivity analysis continue increasingly, from 1983 to 2021. For this reason, it is seen that the accumulation of knowledge created by sensitivity analysis over the years and the need for sensitivity analysis in the literature continue to increase.

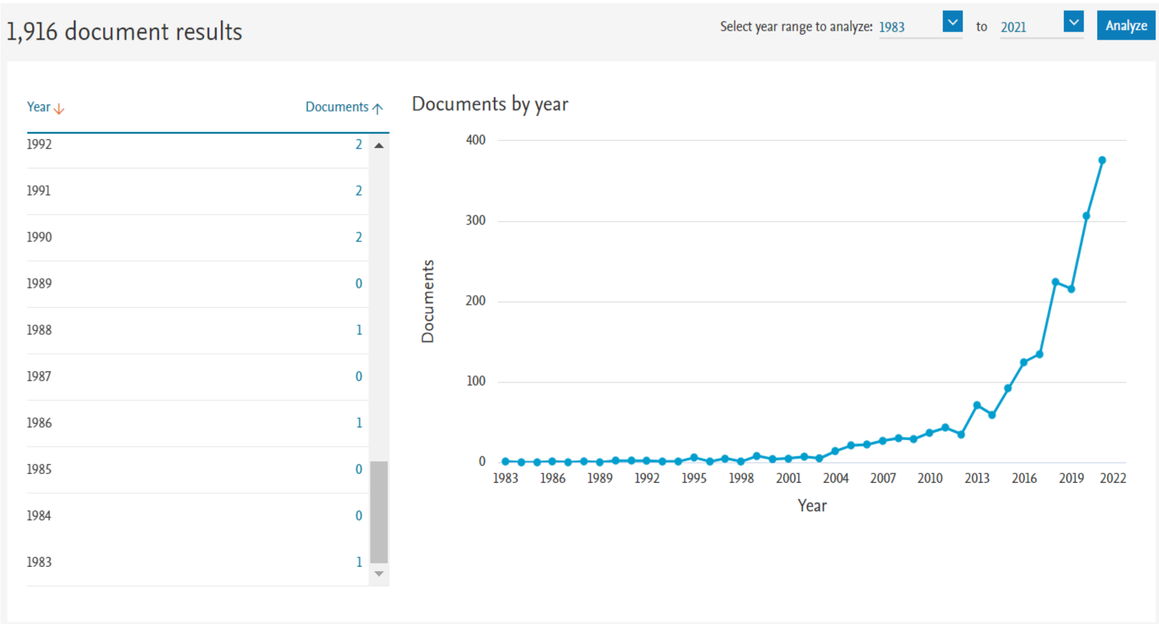

Figure 1. Distribution of Publications with Sensitivity Analysis by Year

The colorized visual network analysis of the author who contributed the most to the sensitivity analysis literature through the VOSviewer software is shown in Figure 2.

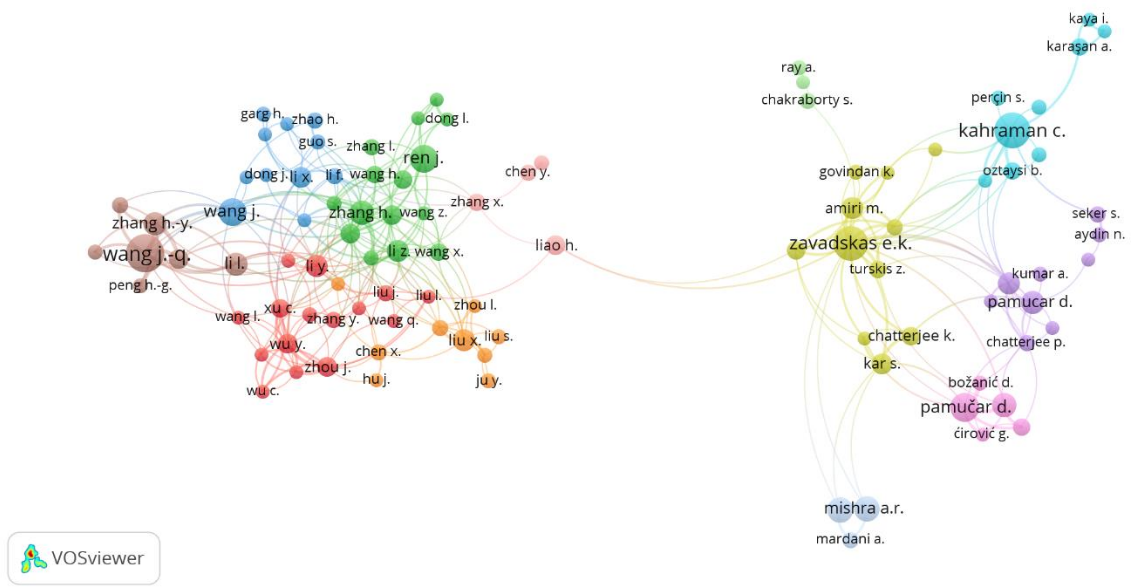

Figure 2. Bibliometric Network Analysis of Article Authors

The width of the circles in Figure 2 indicates the number of publications of the authors, the colors of the circles indicates the common work of the authors, and the connections between the circles indicate the work of the authors with each other. Looking at the size of the clusters, Kahraman, Zavadskas, Pamucar (Pamučar), Wang-J and Ren are the most cited authors in their groups. The map generally consists of two groups. It shows that the writers in each group are in a close relationship within themselves and are related to each other in their groups.

The concept of “sensitivity analysis” applied in the studies and the most studied terms are given in Figure 3. Similar colors when creating Figure 3 show the names of other techniques studied in “sensitivity analysis”.

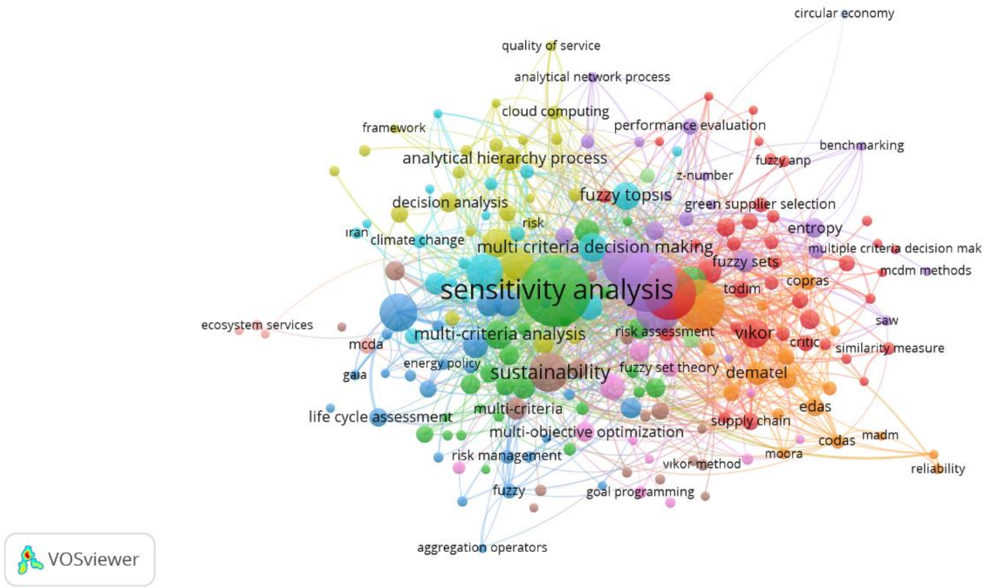

Figure 3. Bibliometric Network Analysis of Keywords Used in Studies

According to Figure 3, the width of the circles refers to the number of uses of keywords, different colors indicate the use of a keyword with other keywords, and the lines indicate their relationship with each other. Accordingly, AHP, TOPSIS, VIKOR, DEMATEL, Fuzzy Theory, SAW, EDAS are the concepts used with sensitivity analysis.

In addition, the distribution of studies on sensitivity analysis by country was colored using the VOSviewer program and given in Figure 4. In the same way, the width of the circles refers to the number of publications in the countries, the same colors represent the citations of the works, and the lines refer to the publication ties between countries.

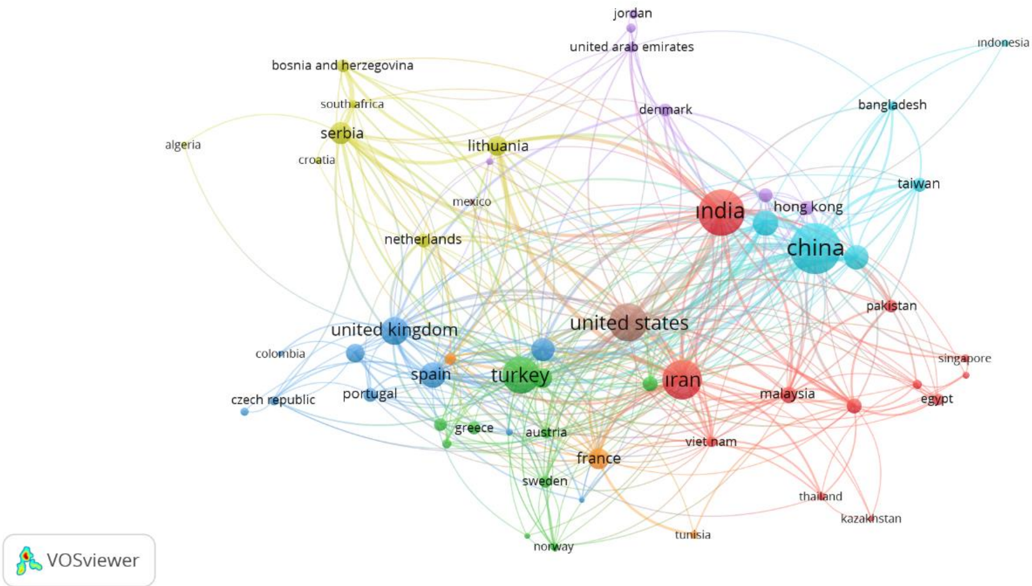

Figure 4. Bibliometric Network Analysis of the Distribution of Studies by Published Countries

China, the country with the most references to sensitivity analysis, is also in relations with India and Iran from its own group and the USA, Turkey and the UK from other groups. China, India, Iran, the United States and Turkey are also leading positions among themselves.

2. Material and Method

This study's objective is to jointly offer the sensitivity and stability studies for the correctness of the analyses conducted following the resolution of the MCDM difficulties. To do this, it was first determined how the proposed adjustments to the criteria weights would affect the outcome. This sensitivity method is demonstrated by the MEREC method. In the second step of the stability model presented, the effect of the rank reversal feature on the results was examined. In the third step of the model, a comparison analysis with other MCDM methods was performed. Steps 2 and 3 of the model are demonstrated on the WISP method. In the first stage of the presented stability and sensitivity model, the definition of the problem consists of determining the criteria and alternatives. In the second step, the criteria are weighted using MEREC, and the alternatives are ranked using WISP. In the final stage, sensitivity analysis is performed. This 3-stage hybrid MCDM methodology is given in Figure 5.

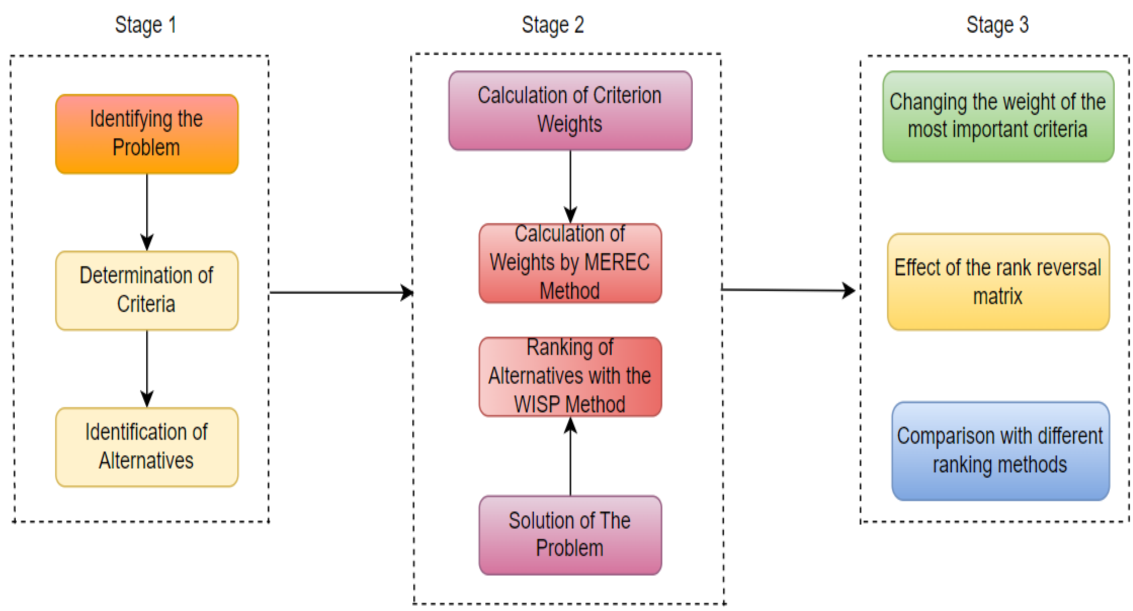

Figure 5. Flowchart of the Method

2.1. MEREC Method

MEREC, Ghorabaee et al. were included in the family of MCDM methods as objective weighting methods in 2021. The difference from other methods is that it uses the removal effect of the effect of each criteria on the total performance of the alternatives to calculate the importance levels of the criteria. In the proposed method, the removal of a criteria has a greater weight, when it leads to a greater impact on the overall performance of the alternatives. In this respect, in addition to weighting each criteria, it can help decision-makers keep certain criteria out of the decision-making process. A logarithmic function was used to measure the total performance of the alternatives (Keshavarz-Ghorabaee et al., 2021).

The foundation of MEREC is the interaction between the decision matrix or input and how the options affect the performance or output. Larger weights are given to criteria whose effects on performances are more significant. First, a measure for the alternatives' performance must be established using the MEREC approach. A simple logarithmic measure of equal weights was used by the architects of the method to calculate the performance of the alternatives, and an absolute deviation measure was used to determine the effects of removing each criteria. This metric indicates the variance between how well an alternative performs overall and how well it performs when a criteria is eliminated. The process steps used to calculate objective weights by the MEREC method are given below (Keshavarz-Ghorabaee et al., 2021):

Step 1: Criteria of the decision matrix

This step creates a decision matrix that shows the ratings or values of each alternative for each criteria. The elements of this matrix are represented by x_{ij} and these elements must be greater than zero (x_{ij}>0). If there are negative values in the decision matrix, they should be converted to positive values using an appropriate technique. Suppose n are alternatives and m are the criteria, and the shape of the decision matrix is like Equation (1).

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \ddots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix} \tag{1}$$

Since the natural logarithm function is used, there is a problem in the data group containing negative values. Several remediation methods have been proposed to work around this problem. One of these is the use of Z-score standardization transformation (Zhang et al., 2014). This transformation is given in Equality (2).

$$z_{ij} = \frac{\left(x_{ij} - \bar{X}_j\right)}{\sigma_j} \tag{2}$$

$\bar{X}_j$ and σ_j are mean and standard deviations of criteria j. respectively. Then, coordinate transformation is performed with Equation (3) and the data is made positive.

$$z'_{ij} = z_{ij} + A \tag{3}$$

Here z'_{ij} represents the standard value after conversion, $z'_{ij} > 0$, A represents the displacement width ($A > \left|minz_{ij}\right|$). It should be noted that the closer the value A is to the value $\left|minz_{ij}\right|$, the more important the result of the evaluation. The decision matrix now uses z'_{ij} values with positive transformations instead of x_{ij} values.

Step 2: Obtaining the normalized decision matrix (N)

In this stage, the components of the decision matrix are scaled using a straightforward linear normalization. n^x_{ij} designates the components of the normalized matrix. The criteria are normalized differently according to the characteristics of benefit and cost. The normalized form according to the characteristics of benefit ($j \in B$) and cost ($j \in C$) is given in Equation (4).

$$n_{ij}^{x} = \begin{cases} \dfrac{\min\limits_{k} x_{kj}}{x_{ij}} & j \in B \\ \dfrac{x_{ij}}{\max\limits_{k} x_{kj}} & j \in C \end{cases} \tag{4}$$

Step 3: Calculation of the overall performance (S_i) of alternatives

In this phase, the total performance of the alternatives is determined using a logarithmic metric with equal criteria weights. Compared to the normalized values obtained from the previous step, smaller n_{ij}^{x} values can be made to give higher performance values (S_i). Equation (5) is used for this calculation.

$$S_i = ln\left(1 + \left(\frac{1}{m}\sum_{j}\left|ln\left(n_{ij}^{x}\right)\right|\right)\right) \tag{5}$$

Step 4: Calculation of the performance of alternatives by removing each criteria

Similar to the previous phase, the logarithmic measure is applied in this stage. The performance of the alternatives is determined based on the elimination of each criteria independently in this step as opposed to step 3, which is the difference. Therefore, the performance set m associated with criteria m occurs. The calculation of the $i.$ alternative to the removal of criteria $j.$ by showing the overall performance of S'_{ij} is given in Equation (6).

$$S'_{ij} = ln\left(1 + \left(\frac{1}{m}\sum_{k,k\neq j}\left|ln\left(n_{ij}^{x}\right)\right|\right)\right) \tag{6}$$

Step 5: Calculation of the sum of absolute deviations

Based on the values derived from Steps 3 and 4, the elimination impact of criteria $j.$ is estimated in this step. Let the effect of removing criteria $j.$ be indicated by E_j. E_j values can be calculated using Equation (7).

$$E_j = \sum_{j}\left|S'_{ij} - S_i\right| \tag{7}$$

Step 6: Determination of the final weights of the criteria

In this step, the objective weight of each criteria is calculated using the lifting effects (E_j) of Step 5. w_j means the weight of criteria j. Equation (8) is used to calculate w_j.

$$w_j = \frac{E_j}{\sum_k E_k} \quad (8)$$

2.2. WISP Method

In order to choose the best option based on the combination of the Weighted Sum (WS) and Weighted Product (WP) techniques, Stanujkic et al. presented WISP into the literature in 2021. The WISP technique incorporates four utility measures to determine the total usefulness of the alternatives, implies the execution of a much simpler normalization procedure, and makes it much easier to sort them out. The WISP method is significantly based on the MULTIMOORA method as well as the WASPAS and CoCoSo methods. The calculation procedure of the new approach for an MCDM problem with m alternative and n criteria can be sorted using the following steps (Stanujkić et al., 2021a):

Step 1: Creation of the decision matrix

$D = \left[x_{ij}\right]_{mxn}$, here x_{ij} shows the performance or grade of alternative i. for criteria j., m indicates the number of alternatives, and n indicates the number of criteria.

Step 2: Creation of normalized decision matrix

The elements of the normalized decision matrix are calculated by Equation (9) without converting the effect of non-useful criteria into the effect of useful criteria.

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

Step 3: Calculation of the values of the four auxiliary measures

u_i^{wsd} and u_i^{wpd} in equations (10) and (11) show the difference between the effect of useful and non-beneficial criteria on the final utility of alternative i obtained on the basis of the WS and WP models, respectively. u_i^{wsr} and u_i^{wpr} in Equations (12) and (13) indicate the ratio between the effect of the useful to the non-beneficial and are the non-beneficial criteria for the final utility of alternative i' obtained on the basis of the WS and WP models, respectively.

$$u_i^{wsd} = \sum_{j \in \Omega_{max}} r_{ij} w_i - \sum_{j \in \Omega_{min}} r_{ij} w_i \tag{10}$$

$$u_i^{wpd} = \prod_{j \in \Omega_{max}} r_{ij} w_i - \prod_{j \in \Omega_{min}} r_{ij} w_i \tag{11}$$

$$u_i^{wsr} = \frac{\sum_{j \in \Omega_{max}} r_{ij} w_i}{\sum_{j \in \Omega_{min}} r_{ij} w_i} \tag{12}$$

$$u_i^{wpr} = \frac{\prod_{j \in \Omega_{max}} r_{ij} w_i}{\prod_{j \in \Omega_{min}} r_{ij} w_i} \tag{13}$$

Step 4: Calculation of normalized values of values of four utility measures

The utility measure values $\bar{u}_i^{wsd}$, $\bar{u}_i^{wpd}$, $\bar{u}_i^{wsr}$ and $\bar{u}_i^{wpr}$ in equations (14), (15), (16) and (17) are the normalized values of u_i^{wsd}, u_i^{wpd}, u_i^{wsr} and u_i^{wpr}.

$$\bar{u}_i^{wsd} = \frac{u_i^{wsd}}{\left(1 + u_{max_i}^{wsd}\right)} \tag{14}$$

$$\bar{u}_i^{wpd} = \frac{u_i^{wpd}}{\left(1 + u_{max_i}^{wpd}\right)} \tag{15}$$

$$\bar{u}_i^{wsr} = \frac{u_i^{wsr}}{\left(1 + u_{max_i}^{wsr}\right)} \tag{16}$$

$$\bar{u}_i^{wpr} = \frac{u_i^{wpr}}{\left(1 + u_{max_i}^{wpr}\right)} \tag{17}$$

u_i^{wsd} and u_i^{wsr} values can be positive, negative, and zero. Therefore, they must be mapped to the range (0, 1) using Equation (14) and (17) before calculating the total utility of each alternative.

Step 5: Calculation of the overall utility (u_i) of each alternative

Using Equation (18), the overall utility values of the alternatives are calculated.

$$u_i = \frac{\bar{u}_i^{wsd} + \bar{u}_i^{wpd} + \bar{u}_i^{wsr} + \bar{u}_i^{wpr}}{4} \tag{18}$$

The option that offers the most overall benefit is the most popular.

2.3. Stability and Sensitivity Analysis

In order tofurther investigate the capacity of the proposed MCDM model to compromise apparent performance and address uncertainty, three different sensitivity analyses were presented to investigate the effect of different parameters on the final rankings of alternatives:

- Sensitivity analysis based on variation of criteria weight
- Sensitivity analysis based on rank reversal
- Sensitivity analysis of ranking stability based on different ranking methodologies

There is no consensus on how to determine the quality of stability and sensitivity analysis, that is, the quality of a decision method and the reliability of the results. While sensitivity analysis is not performed in most of the MCDM problems, only different methods are compared in a certain part. This situation both prevents the application of a common sensitivity analysis and casts a shadow on the stability of the results. In particular, the lack of a study on stability causes the use of methods that are not suitable for the purpose in many problems. In their study in Arslan and Bircan (2020), they classified the methods according to their normalization and ranking methods. In this study, in order to be reliable in a decision-making problem, it was proposed to perform sensitivity analysis based on both criteria weight, rank reversal feature and comparison with different methods.

2.3.1. Sensitivity analysis based on variation of criteria weight

After determining the “most important criteria” on the basis of the weights estimated using the criteria weighting method, the weight sensitivity analysis is performed by changing the “most important criteria” weight to observe the effect of the proposed model on the ranking performance. Sensitivity analysis process steps based on weight change are given (Yazdani et al., 2019a):

Step 1: Determination of the weight elasticity coefficient

The number that expresses the relative balance of other weights in relation to certain changes in the weight of the most important criteria during sensitivity analysis is called the weight elasticity coefficient (α_c). This value is always defined as “1” for the most important criteria. For other criteria, Equation (19) is used.

$$\alpha_c = \frac{w_c^0}{1 - w_s} \qquad (19)$$

w_c^0: the original value of the changed weight

w_s: weight of the most important criteria

Step 2: Determining parameter Δx

The parameter Δx represents the amount of change applied to the weight set according to the associated elasticity coefficients. The change in the weight of the most important criteria should be limited. Otherwise, weights may take negative values and violate the weight proportionality constraint. When the Δx parameter is positive, it may show an increase in relative severity, or it may show a decrease when it is negative. The limits for Δx are defined as the amount of the highest weight change in the most critical criteria in the negative and positive directions. The limit of the variable Δx is calculated using Equation (20).

$$-w_s \leq \Delta x \leq min\{w_c^o / \alpha_c\} \quad (20)$$

Step 3. Calculation of new criteria weights

Equation (21) is used to determine the new weights of the other criteria for the weights of the most important criteria.

$$w_s = w_s^o + \alpha_s \Delta x \quad (21)$$

$$w_c = w_c^o - \alpha_c \Delta x \quad (22)$$

w_s^o: the original weight of the criteria subjected to sensitivity analysis

w_c^o: the original value of the changing weights

This new set of criteria weights must always meet the universal condition of weight proportionality, i.e. $\sum w_s + \sum w_c = 1$.

Any change in the criteria weights, which is then calculated by the sorting method, can in some cases significantly change the order of the alternatives. Sensitivity analysis was performed to check whether such a situation existed and to ensure the stability and robustness of the application.

2.3.2. Sensitivity analysis based on rank reveral

One of the ways to check the stability of MCDM methods is to add new alternatives to the original cluster or remove weak alternatives from the cluster. In such cases, it is expected that the MCDM method will not show a serious change in the ranking of alternatives. This phenomenon is called the “rank reversal problem” and has been given considerable attention in the literature (Verly and De Smet, 2013; García-Cascales and Lamata, 2012). One of the ways to test the validity of the results obtained from the model for decision-making is to create dynamic matrices and then analyze the solutions that the model offers under the newly created conditions.

2.3.3. Sensitivity analysis of ranking stability based on different ranking methodologies

In many complex decision environments, sensitivity analysis is also performed by comparing the result of a model with other available and well-structured methods to examine the robustness and reliability of the ranking scores of the alternatives (Yazdani et al., 2019b; Stević and Brković, 2020). It clarifies how different MCDM anatomies can produce similar or different ranking scores. In addition, the high correlation coefficient between ranking scores can also provide a pragmatic confirmation and agreement pathway. This can also be considered a global strategy to compare the decision results of implementations in practice (Stević and Brković, 2020).

3. Application

In this study, a realistic decision problem was created to show the stability and sensitivity analysis method steps offered for MCDM applications.

3.1. Description of data

Countries known as the fragile five, consisting of India, Brazil, Indonesia, Turkey and South Africa, are alternatives to the study. The evaluation criteria included in the study (Eyupoglu (2016), Antanasijević et al. (2017), Costa et al. (2019), Belke (2020), Arsu and Ayçin (2021), Kuncova and Seknickova (2021) were determined by using the studies in the previous literature and given in Table 1. The last column of Table 1 also shows the characteristics of the criteria.

Table 1. Evaluation Criteria

Symbol	Criteria	Characteristic
C1	Unemployment Rate (%)	Minimum (cost)
C2	State Budget (% of GDP)	Maximum (benefit)
C3	GDP growth (annual-%)	Maximum (benefit)

C4	Inflation (annual-%)	Minimum (cost)
C5	Current Account Balance (% of GDP)	Maximum (benefit)
C6	Credit Default Swap (CDS)	Minimum (cost)

All data used in the performance analysis of the countries were compiled from the Trading Economics and World Government Bonds reports on 14.12.2021 and shown in Table 2.

Table 2. Data of the Fragile Five

Alternatives	C1	C2	C3	C4	C5	C6
Brazil	12,60	-13,40	10,74	10,25	-0,72	208
Indonesia	6,49	-6,50	3,51	1,60	-0,44	91
India	6,90	0,90	8,40	4,35	0,90	108
Turkey	11,20	-3,40	21,31	19,58	-5,10	434
South Africa	34,90	-10,00	2,90	4,90	2,20	313

Source: Trading Economics, World Government Bonds, (2021).

3.2. MEREC Method Application

Since the natural logarithm function is used in the method, negative values in C2 and C5 criteria pose a problem. Before starting the analysis, one of the correction methods, Z-score standardization transformation, was applied and the results of the processing steps are given in Table 3.

Table 3. Mean and Standard Deviation of Negative Data

	C1	C2	C3	C4	C5	C6
Alternatives	min	max	max	min	max	min
Brazil	12,6	-13,4	10,74	10,25	-0,72	208
Indonesia	6,49	-6,5	3,51	1,6	-0,44	91
India	6,9	0,9	8,4	4,35	0,9	108
Turkey	11,2	-3,4	21,31	19,58	-5,1	434
South Africa	34,9	-10	2,9	4,9	2,2	313
Mean		-6,48			-0,632	
Standard Deviation		5,572881			2,755671	

Standardized data according to the Z-score are given in Table 4. This table also shows the offset width A.

Table 4. Standardized Data

	C1	C2	C3	C4	C5	C6
Alternatives	min	max	max	min	max	min

Brazil	12,600	-1,242	10,740	10,250	-0,032	208,000
Indonesia	6,490	-0,004	3,510	1,600	0,070	91,000
India	6,900	1,324	8,400	4,350	0,556	108,000
Turkey	11,200	0,553	21,310	19,580	-1,621	434,000
South Africa	34,900	-0,632	2,900	4,900	1,028	313,000
max	34,900	1,324	21,310	19,580	1,028	434,000
min	6,490	-1,242	2,900	1,600	-1,621	91,000
A		1,243			1,622	

Then the data made positive by coordinate transformation is given in Table 5.

Table 5. Coordinate Transformational Data

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
Alternatives	min	max	max	min	max	min
Brazil	12,600	0,001	10,740	10,250	1,590	208,000
Indonesia	6,490	1,239	3,510	1,600	1,692	91,000
India	6,900	2,567	8,400	4,350	2,178	108,000
Turkey	11,200	1,796	21,310	19,580	0,001	434,000
South Africa	34,900	0,611	2,900	4,900	2,650	313,000
max	34,900	2,567	21,310	19,580	2,650	434,000
min	6,490	0,001	2,900	1,600	0,001	91,000

Now, the decision matrix in Table 2 can be replaced by the positive transformational values in Table 5. The normalized values of the criteria according to their benefit and cost characteristics are given in Table 6.

Table 6. Normalized Decision Matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
Alternatives	min	max	max	min	max	min
Brazil	0,361032	1	0,270019	0,523493	0,000387	0,479263
Indonesia	0,18596	0,001027	0,826211	0,081716	0,000364	0,209677
India	0,197708	0,000496	0,345238	0,222165	0,000283	0,248848
Turkey	0,320917	0,000709	0,136086	1	1	1
South Africa	1	0,002081	1	0,250255	0,000232	0,721198

Then the overall performance of the alternatives is calculated and given in Table 7. Decision makers should calculate according to Equation (5) to obtain the overall performance of the alternatives. To clarify the calculation process, an example is presented below.

$$S_1 = ln\left(1 + \left(\frac{|ln0{,}361032| + |ln1| + \cdots + |ln0{,}000387| + |ln0{,}479263|}{6}\right)\right) = 1{,}07425$$

Table 7. Overall Performance Values

Alternatives	Si
Brazil	1,07425
Indonesia	1,494373
India	1,517324
Turkey	1,004503
South Africa	1,310744

The overall performance of the alternatives, calculated according to the extraction of each criteria separately, is given in Table 8. To clarify the calculation process, below is an example. S'_{11} is Brazil's overall performance with regard to the extraction of C1.

$$S'_{11} = ln\left(1 + \left(\frac{|ln1| + |ln0{,}270019| + \cdots + |ln0{,}000387| + |ln0{,}479263|}{6}\right)\right) = 1{,}014505$$

Table 8. General Performance Values of Alternatives

Alternatives	C1	C2	C3	C4	C5	C6
Brazil	1,014505	1,07425	0,996796	1,03671	0,481478	1,031479
Indonesia	1,429395	1,196835	1,487208	1,396028	1,143231	1,434174
India	1,456251	1,191411	1,477677	1,460772	1,162601	1,465149
Turkey	0,932605	0,41992	0,874692	1,004503	1,004503	1,004503
South Africa	1,310744	0,985741	1,310744	1,246473	0,839189	1,295948

The sum of the absolute deviations for the lifting effect of criteria j. is calculated and given in Table 9. Decision makers calculate the removal effect of each criteria on the overall performance of alternatives with the deviation-based formula of Equation (7). An example is provided to clarify the calculation process.

$$E_1 = |1{,}014505 - 1{,}07425| + |1{,}429395 - 1{,}494373| + \cdots + |1{,}310744 - 1{,}310744| = 0{,}257694$$

Table 9. The Sum of Absolute Deviations

	C1	C2	C3	C4	C5	C6	Total
$\boldsymbol{E_i}$	0,257694	1,533038	0,254077	0,256709	1,770192	0,169941	4,241651

Finally, the objective weight of each criteria is calculated using buoyancy effects and given in Table 10. An example is given to clarify the calculation process.

Table 10. Weight Values of Criteria

	C1	C2	C3	C4	C5	C6	Total
$\boldsymbol{w_i}$	0,060753	0,361425	0,0599	0,060521	0,417336	0,040065	1

It can be said that the C5 criteria is the most important criteria with a value of 0.417336, while the C6 criteria is the least important criteria with a value of 0.040065.

3.3. WISP Method Application

The matrix in Table 5 where the coordinate transformation has been made is taken as the decision matrix and the normalized version is given in Table 11.

Table 11. Normalized Decision Matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
Alternatives	min	max	max	min	max	min
Brazil	0,361032	0,000496	0,503989	0,523493	0,600093	0,479263
Indonesia	0,18596	0,482774	0,164711	0,081716	0,63844	0,209677
India	0,197708	1	0,394181	0,222165	0,821959	0,248848
Turkey	0,320917	0,69945	1	1	0,000232	1
South Africa	1	0,23814	0,136086	0,250255	1	0,721198

Then the weighted normalized decision matrix multiplied by MEREC weights is given in Table 12.

Table 12. Weighted Normalized Decision Matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
Alternatives	min	max	max	min	max	min
Brazil	0,021934	0,000179	0,030189	0,031682	0,25044	0,019202
Indonesia	0,011298	0,174486	0,009866	0,004946	0,266444	0,008401
India	0,012011	0,361425	0,023612	0,013446	0,343033	0,00997
Turkey	0,019497	0,252799	0,0599	0,060521	9,7E-05	0,040065
South Africa	0,060753	0,08607	0,008152	0,015146	0,417336	0,028895

The values of the four auxiliary measures were calculated using equations (9)-(12) and given in Table 13.

Table 13. Auxiliary Measurement Values

Alternatives	$\boldsymbol{u_i^{wsd}}$	$\boldsymbol{u_i^{wpd}}$	$\boldsymbol{u_i^{wsr}}$	$\boldsymbol{u_i^{wpr}}$
Brazil	0,207991	-1,19892E-05	3,856319	0,101496
Indonesia	0,426153	0,000458222	18,29242	977,2455
India	0,692642	0,002925771	20,55119	1818,051
Turkey	0,192713	-4,58058E-05	2,604841	0,031079
South Africa	0,406763	0,000266219	4,881564	11,01294

The normalized version of the auxiliary measure values calculated using Equation (13)-(16) and the general utility of each alternative are calculated and the rankings of the alternatives are given in Table 14.

Table 14. Normalized Values of Auxiliary Measures and General Utility Values of Alternatives

Alternatives	$\bar{u}_i^{wsd}$	$\bar{u}_i^{wpd}$	$\bar{u}_i^{wsr}$	$\bar{u}_i^{wpr}$	u_i	Rank
Brazil	0,122879	-1,19542E-05	0,178938	5,57959E-05	0,100602	4
Indonesia	0,251768	0,000456886	0,848789	0,537228282	0,367005	2
India	0,409208	0,002917236	0,953599	0,999450263	0,455241	1
Turkey	0,113854	-4,56721E-05	0,120868	1,70852E-05	0,078225	5
South Africa	0,240313	0,000265442	0,22651	0,006054221	0,155696	3

Among the fragile 5 whose financial performance is ranked according to the WISP method, India ranks first, while Turkey ranks last.

3.4. Application of Sensitivity Analysis Based on Variation of Criteria Weight

Any change in the weights of the criteria calculated by the MEREC method can significantly change the order of alternatives in some cases. A sensitivity analysis was performed to check if such a situation existed and to ensure the stability and robustness of the application. First, it is assumed that the weight coefficient (α_s) of the most important criteria (here C5) is the same as for the other criteria (α_c). It is estimated using the Equation (19) given in Table 15.

Table 15. Coefficient of Weight Flexibility for Varying Weights

Criteria	Calculated Weights	α_c	Δx
w5	0,4173	1	
w1	0,0608	0,1043	0,5829
w2	0,3614	0,6203	0,5826
w3	0,0599	0,1028	0,5827
w4	0,0605	0,1039	0,5823
w6	0,0401	0,0688	0,5828

Then the weight change limiting limits (Δx) for the criteria "C5" are calculated. This is between -0,4173 and 0,5827. Beyond these limits, the weights of criteria "C5" will take negative values. Once these limits were defined, the new weight was calculated with 22 sets of scenarios using Equation (21) and (22) as shown in Table 16. It is also shown in Table 16 that when $\Delta x = 0$, the criteria weights are equal to the original weight.

Table 16. New Criteria Weights

Scenario	Δx	w1	w2	w3	w4	w5	w6	Total
S1	-0,4173	0,1043	0,6203	0,1028	0,1039	0,0000	0,0688	1,0000
S2	-0,4	0,1025	0,6095	0,1010	0,1021	0,0173	0,0676	1,0000
S3	-0,35	0,0972	0,5785	0,0959	0,0969	0,0673	0,0641	1,0000

S4	-0,3	0,0920	0,5475	0,0907	0,0917	0,1173	0,0607	1,0000
S5	-0,25	0,0868	0,5165	0,0856	0,0865	0,1673	0,0573	1,0000
S6	-0,2	0,0816	0,4855	0,0805	0,0813	0,2173	0,0538	1,0000
S7	-0,15	0,0764	0,4545	0,0753	0,0761	0,2673	0,0504	1,0000
S8	-0,1	0,0712	0,4235	0,0702	0,0709	0,3173	0,0469	1,0000
S9	-0,05	0,0660	0,3924	0,0650	0,0657	0,3673	0,0435	1,0000
S10	0	0,0608	0,3614	0,0599	0,0605	0,4173	0,0401	1,0000
S11	0,05	0,0555	0,3304	0,0548	0,0553	0,4673	0,0366	1,0000
S12	0,1	0,0503	0,2994	0,0496	0,0501	0,5173	0,0332	1,0000
S13	0,15	0,0451	0,2684	0,0445	0,0449	0,5673	0,0298	1,0000
S14	0,2	0,0399	0,2374	0,0393	0,0397	0,6173	0,0263	1,0000
S15	0,25	0,0347	0,2064	0,0342	0,0346	0,6673	0,0229	1,0000
S16	0,3	0,0295	0,1753	0,0291	0,0294	0,7173	0,0194	1,0000
S17	0,35	0,0243	0,1443	0,0239	0,0242	0,7673	0,0160	1,0000
S18	0,4	0,0190	0,1133	0,0188	0,0190	0,8173	0,0126	1,0000
S19	0,45	0,0138	0,0823	0,0136	0,0138	0,8673	0,0091	1,0000
S20	0,5	0,0086	0,0513	0,0085	0,0086	0,9173	0,0057	1,0000
S21	0,55	0,0034	0,0203	0,0034	0,0034	0,9673	0,0022	1,0000
S22	0,5827	0,0000	0,0000	0,0000	0,0000	1,0000	0,0000	1,0000

The rankings obtained by recalculating the performances of the fragile 5 with the 22 weight sets in Table 16 are given in Figure 6.

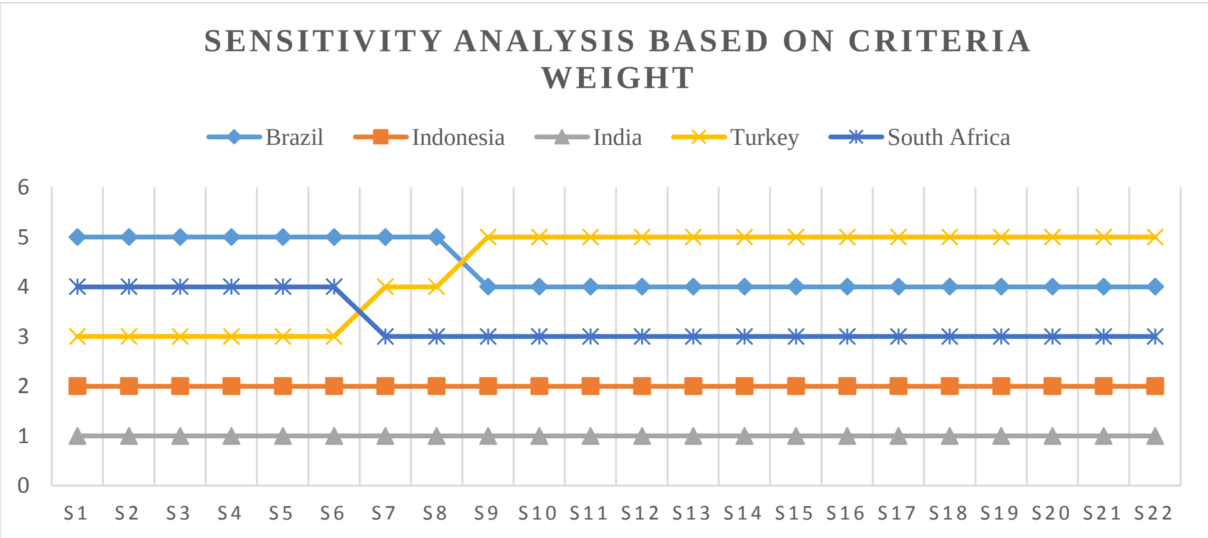

Figure 6. Changes to the Rankings of Alternatives

It shows that assigning different weights to criteria over 22 sets causes a change in the order of some alternatives and confirms that the model is sensitive to changes in weight coefficients. These changes are confirmed by the Spearman order correlation values of the rankings over different data sets and are given in Figure 7.

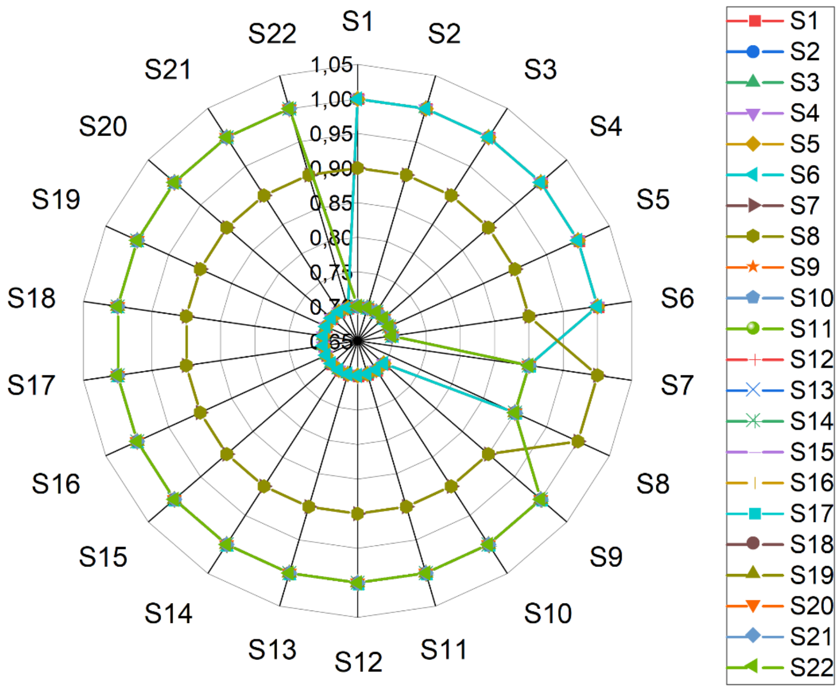

Figure 7. Spider Diagram of Spearman Coefficient Correlation for 22 Sets

The Spearman sequence coefficient correlation was obtained by comparing the starting rows of the proposed model in Table 15 with the rows from different weight change sets. As can be seen in Figure 7, the correlation coefficients obtained are statistically significant.

3.5. Rank Reversal Based Sensitivity Analysis Application

If the ranking of the alternatives reveals any logical inconsistencies that manifest as unfavorable alterations, there may be a fault with the mathematical underpinnings of the used technique. A test that takes into consideration the model's resilience to the rank reversal problem should be run for this purpose. Four scenarios were constructed for the test in which the modification of the decision matrix's components was simulated. As a rule, 4 scenarios should be created (one less than the total number of alternatives). Typically, four scenarios should be developed (one less than the total number of alternatives). The fragile five are sorted in accordance with the outcomes depicted in the S0 scenario after the first trial using the WISP approach is completed (original sequence). In the next scenario (S1), the country that reaches the fewest rankings is eliminated. After that, the remaining 4 countries are sorted again. Thus, a total of 4 scenarios (S1-S4) are created, whereby the worst-ranked country from the set is eliminated in each subsequent scenario, and the rankings are given in Figure 8.

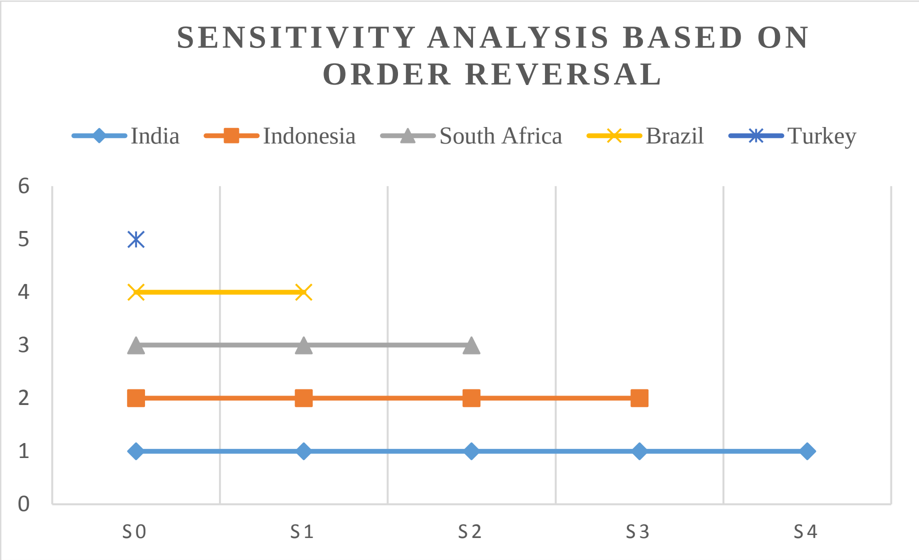

Figure 8. Results of Rank Reversal Analysis

Figure 8 makes it abundantly evident that the WISP model delivers reliable findings in a dynamic setting and that it has a robust resistance to the rank reversal problem. The advantages in the top ranking are maintained in every circumstance.

3.6. Sensitivity Analysis of Ranking Stability Based on Different Ranking Methodologies

In order to calculate the stability of the ranking, a comparative analysis is performed with multi-criteria decision-making methods based on different ranking methodologies. In many complex decision environments, the robustness and reliability of the ranking scores of alternatives are examined by comparing the result of one model with other available and established methods. A similar ranking comparison was made with some commonly used methods, such as PIV (Mufazzal and Muzakkir, 2018), CoCoSo (Yazdani et al., 2019a), COPRAS (Zavadskas and Kaklauskas, 1996), WEDBA (Rao and Singh, 2012), TOPSIS (Hwang and Yoon, 1981), and SAW (Maccrimmon, 1968) to select the best country and explain the reliability of the proposed MEREC-WISP based model. These techniques were selected due to their wide range of benefits, practical use, and capacity to effectively sort out options in multi-criteria selection environments. Figure 9 presents the ranking outcomes as a consequence.

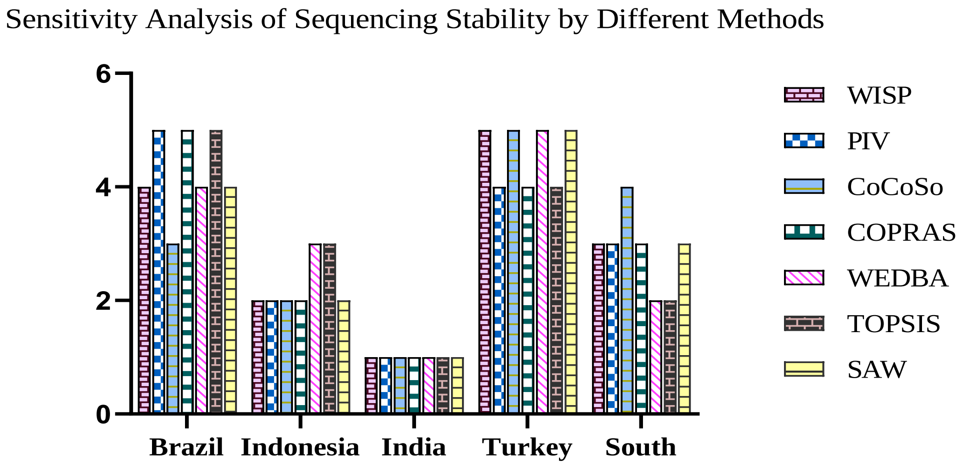

Figure 9. Ranking of the Fragile Quintet According to Different MCDM Methods

According to Figure 9, among the fragile 5, India ranked first in all methods, Indonesia ranked second in other methods except WEDBA and TOPSIS, Brazil and South Africa ranked differently according to methods, Turkey ranked fourth in PIV, COPRAS methods, and last in WISP, CoCoSo, WEDBA, TOPSIS and SAW methods. Spearman Rank Correlation (SRC) was used to determine this relationship between the results obtained by different methods. A comparison of the rankings by applying the SRC is given in Table 17.

Table 17. SCR Values of Tested Methods

	Correlations						
	WISP	**PIV**	**CoCoSo**	**COPRAS**	**WEDBA**	**TOPSIS**	**SAW**
WISP	1,000	,900	,900	,900	,900	,900	1,000
PIV		1,000	0,700	1,000	0,800	0,800	,900
CoCoSo			1,000	0,700	0,700	0,700	,900
COPRAS				1,000	0,800	0,800	,900
WEDBA					1,000	1,000	,900
TOPSIS						1,000	,900
SAW							1,000

With an average correlation value of 0.917 between the other six MCDM techniques of the proposed model and the WISP approach used, the resulting ranking can be said to be confirmed and reliable.

4. Result

Finding an efficient and logical answer to decision-making issues requires a very clear formulation of the research's objective. However, some criteria must be specified, and the chosen criteria must be given the best possible weighting. Nowadays, answers to all types of issues are put forth in every sector using science-based multi-criteria decision-making techniques that enable researchers to select the most suitable and efficient answer out of all the options.

In this study, it was seen that 1.916 out of 25.907 publications in the MCDM field were related to sensitivity analysis in the SciVerse Scopus access system by bibliometry analysis until 2021. This indicates that sensitivity analysis was performed in only 7.4% of the studies. The number of publications on sensitivity analysis in the MCDM field has increased significantly since 2013, and studies published between 2013 and 2019 received more citations on average. One or more steps of the proposed method were applied in the studies where sensitivity analysis was performed, and no recommendation was made for stability and sensitivity analysis for other studies. Regardless of the field and method in which the MCDM studies are conducted, the impact of several factors on the final rankings of the alternatives should be investigated with three different stability and sensitivity analyzes. In this study, the use of these three applications together is presented as a determination and sensitivity method. In this context, the recommended stability and sensitivity method steps should be performed in order to accept the results obtained from any method. Correlation coefficients based on the variation of the weight of the criteria in this method should be relationally significant. In the order reversal feature, the first order superiorities must be preserved. The correlation coefficients obtained in the comparison based on different ranking methodologies should also be relationally significant.

A real decision problem was used to illustrate the steps of applying the presented determination and sensitivity method. In this context, Brazil, Indonesia, India, Turkey and South African countries were taken as alternatives, and state budget, current account balance, inflation, GDP growth, the unemployment rate and credit default swap of these countries were used as criteria.

Sensitivity analysis was carried out to assess the stability and robustness of the application and to determine whether any changes in criteria weights significantly altered the order of alternatives in some circumstances. First, 22 new weight sets were created by making changes in the value of the most important criteria, namely the weight coefficient of the current account balance. The rankings of the alternatives were calculated again with different weights to the criteria over 22 sets. The model has been verified to be sensitive to changes in weight coefficients. As in the case of Yazdani et al. (2019b), these changes become more apparent as the number of alternatives increases. In addition, in all 22 different weight sets created with varying weight coefficients, India ranked first and Indonesia ranked second. Between the 6th set and the 9th set, Turkey's ranking varies. After the ninth set, Turkey took the last place. South Africa and Brazil have had differences in rankings in different data sets. The importance of these changes over different data sets was confirmed by the Spearman order correlation values. In sensitivity analysis based on the rank reversal, new alternatives are added to the original set or weak alternatives are removed from the cluster to check the stability of MCDM methods. In this study, it was preferred to remove weak alternatives from the cluster. 4 scenarios were created in which the change in the elements of the decision matrix was simulated. In the first experiment, the results were ranked to form the original sequence. In each subsequent scenario, the ranking was recalculated by subtracting the country in the last row. It has been demonstrated that the WISP model can produce accurate results in a dynamic setting and that it is strongly resistant to the rank reversal problem. In studies where there is a large number of alternatives, such as Feng et al. (2021), the strength of resistance in the ranking will be revealed more clearly.

In the sensitivity analysis of ranking determination based on different ranking methodologies, an analysis is made by comparing the rankings obtained with multi-criteria decision-making methods. A similar ranking comparison was made with some commonly used methods such as TOPSIS, CoCoSo, WEDBA, COPRAS, PIV and SAW to select the best country and explain the reliability of the proposed MEREC-WISP based model. While India ranked first according to all methods, the rankings of the countries showed some differences compared to other methods. As in the studies of Erdogan et al. (2021) and Lo et al. (2021), it can be said that the ranking of the proposed MEREC-WISP model is confirmed and reliable with an average correlation value of 0.917 between the rankings obtained by the other six MCDM techniques.

Fuzzy MCDM methods may also be preferred for sensitivity analysis in future studies. Different steps may also be suggested for the recommended method of stability and sensitivity.

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GENİŞLETİLMİŞ ÖZET

Karar verme problemlerinde etkin ve akılcı bir çözüm bulmak için yapılan araştırmanın amacının net bir şekilde formüle edilmesi çok önemlidir. Bununla birlikte bazı kriterlerin tanımlanması ve seçilen kriterlerin en uygun yöntemle ağırlıklandırılması gerekir. Araştırmacıların mevcut alternatifler arasından en etkili ve uygun çözümü seçmesine olanak tanıyan bilimsel temelli çok kriterli karar verme (ÇKKV) yöntemleriyle günümüzde her alanda ve her türden probleme çözüm önerilmektedir.

Bu çalışmanın amacı, ÇKKV yöntemlerinin uygulanmasında kullanılan araştırmalar için bir belirleme ve duyarlılık modeli sunmaktır. Bu bağlamda kararlılık ve duyarlılık analizi için "kriter ağırlık değişimine dayalı duyarlılık analizi, sıra ters çevirme özelliğine dayalı duyarlılık analizi ve farklı sıralama yöntemlerinden elde edilen sonuçlarla karşılaştırma analizi" adımlarının birlikte kullanılması önerilmiştir.

ÇKKV, 1950'li ve 1960'lı yıllarda literatürde yer almasından ve 1970'li yıllardaki gelişiminden bu yana birçok karar verme probleminde yaygın olarak uygulanan önemli bir disiplin olmuştur. ÇKKV, ikiden fazla alternatif ve çoklu kriterden oluşan karar probleminde en uygun alternatifin seçilmesini veya sıralanmasını sağlayan bir karar verme tekniğidir. ÇKKV'nin temel amacı bir karar problemini çözmek değil, karar vericiye çözümler sunmaktır.

ÇKKV çalışmaları yarım yüzyılı aşkın süredir yapıldığından literatürde önemli sayıda çalışma bulunmaktadır. Özellikle son yıllarda karar problemini oluşturan kriterlerin ağırlıklandırılmasında ve alternatiflerin sıralanmasında farklı yöntemler birleştirilip birçok hibrit model geliştirilerek ÇKKV çeşitliliği arttırılmıştır. Literatürde, yöntemlerin çalışmalara uygunluğunu kontrol etmek ve sonuçların güvenilirliğini belirlemek için bir model veya test konusunda fikir birliği yoktur. Çok kriterli karar verme problemlerinin birçoğunda duyarlılık analizi yapılmazken, belli bir kısmında sadece farklı yöntemlerle kıyaslama yapılmaktadır. Bu durum hem ortak bir duyarlılık analizi uygulamasına engel olmakta, hem de sonuçların kararlılığına gölge düşürmektedir. Özellikle kararlılığa dair bir çalışma yapılmaması, birçok problemde amaca uygun olmayan yöntemlerin kullanılmasına neden olmaktadır. Bununla birlikte, hassas bilgilerin tahmininde kontrol edilebilirlik eksikliği veya hata nedeniyle giriş parametrelerindeki değişiklikler altında en iyi alternatifin kararlılığını değerlendirmek için ÇKKV yöntemlerini etkili bir şekilde uygulamak için duyarlılık analizi kullanılmaktadır. Duyarlılık analizi, analiz edilen problemle ilişkili belirsizlikleri karakterize etmek için bir ÇKKV modeli ve geçerli araçlar sağlar. Bu çalışmada ÇKKV yöntemleri ile yapılan çalışmalar için kararlılık ve duyarlılık modeli sunulmuş ve bunun uygulanması literatüre yeni giren MEREC-WISP yöntemleri ile gösterilmiştir.

MEREC, girdi veya karar matrisi arasındaki ilişkiye ve alternatiflerin çıktı veya performansı üzerindeki etkisine dayandırılmıştır. Bu yöntem kriter ağırlıklarını belirlemek için her bir kriterin alternatiflerin performansı üzerindeki kaldırma etkisini kullanır. Performanslar üzerinde daha yüksek etkiye sahip olan kriterlere daha büyük ağırlıklar atanır. MEREC yönteminde öncelikle alternatiflerin performansları için bir ölçünün belirlenmesi gerekir. Yöntemin mimarları tarafından alternatiflerin performanslarını hesaplamak için eşit ağırlıklarda basit bir logaritmik ölçü ve her bir kriteri kaldırmanın etkilerini belirlemek için de mutlak sapma ölçüsü kullanılmıştır. Bu ölçü, genel olarak bir alternatifin performansı ile bir kriteri kaldırmadaki performansı arasındaki farkı yansıtmaktadır. WISP yöntemi çok daha basit bir normalizasyon prosedürünün uygulanmasını öngörür, alternatiflerin genel faydasını tanımlamak için dört fayda ölçüsü içerir ve bunların çok daha kolay bir şekilde sıralanmasını sağlar. WISP yöntemi, MULTIMOORA yönteminin yanı sıra WASPAS ve CoCoSo yöntemlerine önemli ölçüde dayanmaktadır.

Bibliyometri, belirli bir konuyla ilgili araştırma makalelerini matematiksel yollarla nicel olarak analiz edebilen istatistiksel bir yöntemdir. Bibliyometrik göstergelerle, belirli bir çalışma konusu için ulusal ve uluslararası çabalar değerlendirilir. Bu çalışmada, verilere erişmek için SciVerse Scopus seçilmiştir. Çalışmada başlangıç yılı arayışında herhangi bir zaman sınırı konulmamıştır. Arama, Scopus veritabanının sürekli güncellenmesinin bir sonucu olarak ortaya çıkabilecek önyargıları ortadan kaldırmak için bir zaman aralığında (26 Aralık 2021) uygulanmıştır. Scopus veritabanında iki ayrı arama yapıldı. İlk olarak ÇKKV yöntemleri ile yapılan 25.907 doküman belirtilen süre içerisinde elde edilmiştir. Daha sonra çalışmanın amacında belirtilen ÇKKV yöntemleri ile yapılan çalışmalara uygulanan duyarlılık analizi çalışmalarının sayısının 1.916 olduğu görülmüştür. Bu, duyarlılık analizinin çalışmaların sadece % 7.4'ünde yapıldığını göstermektedir. ÇKKV alanında duyarlılık analizi ile ilgili yayın sayısı 2013 yılından bu yana belirgin bir şekilde artmış ve 2013-2019 yılları arasında yayınlanan yayınlara ortalama olarak daha fazla atıf alınmıştır. Bu sonuçlara ulaşmak için "çok kriterli karar verme" ve "çok kriterli karar verme ve duyarlılık analizi" sorgulanmıştır. ÇKKV yöntemlerine ilişkin çalışmalara uygulanan duyarlılık analizi için Scopus veri tabanı üzerinden yapılan araştırmalara dayanarak ortaya çıkan örneklem, makaleler (1.644), konferans bildirileri (192), derleme (48), kitap bölümleri (24), konferans incelemeleri (7), notlar (1) dahil olmak üzere toplam 1.916 belgeden oluşmaktadır. Çalışmada, ağ verilerine dayalı görselleştirme haritaları üretmek ve benzerlikleri görselleştirmek için haritalama ve kümeleme tekniklerini kullanmak üzere VOSviewer yazılımı tercih edilmiştir. Bu yazılım bibliyometrik ağların analizinde kullanılmak üzere tasarlanmıştır. Duyarlılık analizi çalışmalarının 1983 yılından 2021 yılına kadar artarak devam ettiği görülmüştür. VOSviewer programı ile duyarlılık analizi literatürüne en fazla katkı sağlayan yazarların Kahraman, Zavadskas, Pamucar (Pamučar), Wang-J, Ren olduğu görülmüştür. Çalışmalarda uygulanan "duyarlılık analizi" kavramı ile en çok çalışılan terimlerin AHP, TOPSIS, VIKOR, DEMATEL, Bulanık Teori, SAW, EDAS olduğu görülmüştür. Ayrıca duyarlılık analizi ile ilgili çalışmaların ülkelere göre dağılımında VOSviewer programını kullanarak, Çin, Hindistan, İran, ABD ve Türkiye lider konumdadır.

Duyarlılık analizinin yapıldığı çalışmalarda önerilen yöntemin bir veya daha fazla basamağı uygulanmış, diğer çalışmalar için kararlılık ve duyarlılık analizi için herhangi bir öneride bulunulmamıştır. ÇKKV çalışmalarının yapıldığı alan ve yöntem ne olursa olsun, farklı parametrelerin alternatiflerin nihai sıralamasına etkisi üç farklı kararlılık ve duyarlılık analizi ile araştırılmalıdır. Bu çalışmada üç uygulamanın birlikte kullanımı bir belirleme ve duyarlılık yöntemi olarak önerilmiştir. Bu bağlamda, herhangi bir yöntemden elde edilen sonuçların kabul edilmesi için önerilen kararlılık ve duyarlılık yöntemi adımları uygulanmalıdır. Bu yöntemdeki kriterlerin ağırlığının değişimine dayanan korelasyon katsayıları ilişkisel olarak anlamlı olmalıdır. Sıra ters çevirme özelliğinde birinci dereceden üstünlüklerin korunması gerekmektedir. Farklı sıralama metodolojilerine dayalı karşılaştırmada elde edilen korelasyon katsayıları da ilişkisel olarak anlamlı olmalıdır. Önerilen kararlılık ve duyarlılık yöntemi uygulama adımlarını göstermek için gerçek bir karar problemi kullanılmıştır. Bu kapsamda Brezilya, Endonezya, Hindistan, Türkiye ve Güney Afrika ülkeleri alternatif olarak alınmış, bu ülkelerin işsizlik oranı, devlet bütçesi, GSYH büyümesi, enflasyon, cari işlemler dengesi ve risk primi kriter olarak kullanılmıştır.

İlk olarak, kriter ağırlıklarındaki herhangi bir değişikliğin bazı durumlarda alternatiflerin sırasını önemli ölçüde değiştirip değiştirmediğini kontrol etmek için, uygulamanın kararlılığı ve sağlamlığı kontrol edilir. Bunun için en önemli kriter olan cari hesap dengesinin ağırlık katsayısında değişiklikler yapılarak 22 set yeni ağırlık verisi oluşturulmuştur. Alternatiflerin sıralaması yeni 22 set üzerinden kriterlere göre farklı ağırlıklarla hesaplandı. Modelin ağırlık katsayılarındaki değişikliklere duyarlı olduğu doğrulanmıştır.

İkinci olarak, sıra ters çevirme özelliğine dayalı duyarlılık analizinde ÇKKV yöntemlerinin kararlılığını kontrol etmek için ya orijinal sete yeni alternatifler eklenir ya da zayıf alternatifler setten çıkarılır. Bu çalışmada zayıf alternatiflerin kümeden çıkarılması tercih edilmiştir. Karar matrisinin elemanlarındaki değişimin simüle edildiği 4 senaryo oluşturuldu. Sonuçlar, ilk deneyin orijinal diziyi oluşturacağı şekilde sıralandı. Sonraki her senaryoda, sıralama son satırdaki ülke çıkarılarak yeniden hesaplandı. WISP modelinin dinamik bir ortamda geçerli sonuçlar sağladığı gösterilmiştir ve modelin sıra ters çevirme problemine karşı direncinin güçlü olduğu görülmüştür. Alternatif sayısının çok olduğu çalışmalarda sıralamadaki direncin gücü daha net ortaya çıkacaktır.

Son olarak, farklı sıralama metodolojilerine dayalı duyarlılık analizinde, elde edilen sıralamalar farklı ÇKKV yöntemleri ile karşılaştırılarak bir analiz yapılır. Benzer bir sıralama karşılaştırması, en iyi ülkeyi seçmek ve önerilen MEREC-WISP tabanlı modelin güvenilirliğini açıklamak için PIV, CoCoSo, COPRAS, WEDBA, TOPSIS ve SAW gibi yaygın olarak kullanılan bazı yöntemlerle yapılmıştır. Önerilen MEREC-WISP modeline ait sıralamanın, diğer altı ÇKKV ile elde edilen sıralamalar arasında ortalama 0,917 korelasyon değeri ile güvenilir olduğu söylenebilir.

Potansiyel bir araştırma konusu olabilecek farklı değerlendirme kriterleri veya farklı ÇKKV yöntemleri (WASPAS, CODAS, DNMA, vb.) ve bunların çeşitli uzantıları (küresel bulanık kümeler, Pisagor bulanık kümeleri, sezgisel bulanık kümeler, vb.) olabileceğinden, gelecekteki çalışmalar için araştırma konusu olabilir. Sunulan kararlılık ve duyarlılık modeli için farklı adımlar da önerilebilir.