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A novel approach for the assessment of logistics performance index of EU countries

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Abstract: The impact of logistics performance in the era of sustainable mobility on the overall economic development of a country is inevitable. It can even be said that it represents an extremely important component in identifying economic conditions and provides the possibility of defining adequate strategies. In this paper, the evaluation of European Union member countries was carried out on the basis of the logistics performance index (LPI) in accordance with the latest report of the World Bank (WB). A unique and original MCDM (Multiple-criteria decision-making) approach has been created, and it involves the application of four methods: CRITIC (Criteria Importance Through Intercriteria Correlation), MEREC (Method based on the Removal Effects of Criteria), Entropy and Fuzzy ROV (Range of Value). The weighting coefficients of six factors were obtained with the first three methods in crisp form, so they were converted into TFN (Triangular Fuzzy Number). The Fuzzy ROV method has been created for the first time in the literature and represents a great contribution from the methodological aspect. The results of the developed model and applied steps show that there are certain differences in the rankings compared to the World Bank report, with a note that the best-ranked countries have maintained their positions. Also, verification tests of originally obtained results were created, with an emphasis on the importance of evaluation parameter values and their impact on the LPI ranking.

Keywords: Logistics performance index, Fuzzy ROV method, EU, logistics

1. Introduction

In modern business conditions, a competitive and efficient logistics system has become imperative in the development and creation of advantages on the regional, and especially on the global market. An adequate level of logistics performance competitiveness has a positive effect on both the business results of an individual company and the overall logistics efficiency of the country in which the company operates. The developed countries of the world are aware of the positive trend of development and investment in logistics and, through a large number of strategies and policies, they strive to improve this area as much as possible. High-quality logistics performance has a positive impact on the volume of international trade. On the other hand, countries with poor logistics infrastructure, as well as with low-quality logistics service, can represent an obstacle in the international supply chain. As a result, such countries are often, to a greater or lesser extent, excluded from certain international flows, and thus their economic and financial growth and development stagnates. For this very reason, it is crucial for countries to constantly monitor, measure and compare their logistics performance with the logistics performance of other countries in order to find solutions for their own growth and progress in the field of logistics and logistics services. For the adoption of any action plan or policy, such as infrastructure investments or changes in national regulations and laws, an in-depth assessment of the country's logistics performance is necessary, resulting in a clear and comprehensive set of parameters that evaluate the quality of logistics performance. In order to achieve a more efficient logistics system, particular attention should be paid to the LPI, which facilitates the identification of the state in the field of logistics in all countries of the world. The LPI is a set of qualitative and quantitative indicators that help build a country's logistics profile. It is calculated by the WB and is an indicator of the quality of the country's logistics environment. LPI results can be used to compare countries, but also at the level of research within one country, which makes it a comprehensive international tool for comparison, measuring logistics performance, as well as achieving facilitation in international transport cooperation.

The subject of the research in this paper is the analysis of the state of logistics in European Union countries from the aspect of LPI scores. The focus and main analysis is based on the 2023 results, which are available in the World Bank reports. The aims of the research are the development and application of a subjective-objective MCDM model for determining the values of weighting criterion coefficients, and the evaluation of EU countries based on LPI scores. Special emphasis is on the importance of sensitivity analysis. The obtained results can help in understanding and improving logistics performance, which can ultimately lead to improvements in international trade and cooperation between countries. It should be emphasized that a novel approach related to the extension of the ROV method with TFN, which facilitates the precise evaluation of a larger set of alternative solutions, has been developed in the literature.

In addition to the introductory considerations, the paper consists of the following sections. Section 2 shows the importance of measuring and monitoring the LPI, and the application of different MCDM approaches for their ranking. Section 3 includes a detailed description of the F-ROV algorithm with an emphasis on the normalization procedure. Also, it is emphasized that three objective methods were used to determine factor weights, and that they were converted into TFN. Section 4 presents the results, which include a detailed description of the application of the novel fuzzy approach. In Section 5, verification tests are performed, and they include testing the influence of the change in factor weights, analysis with other approaches, changing the size of a decision matrix, and calculating the correlation of the ranks of alternative solutions. Finally, concluding considerations are given with a clear direction for improving the LPI assessment methodology.

2. Literature review

A review of previous research related to logistics performance of countries, their monitoring and measurement, as well as their importance and impact on the economy, is presented in this section. In addition, the importance of the application of methods and models of multi-criteria decision-making in the evaluation of alternatives, i.e. the ranking of the results of the logistics performance quality of countries, was pointed out. Logistics includes a large number of processes, activities, functions, as well as participants, which must be coordinated in a way that enables all parties participating in the implementation of logistics services to fulfill their requirements. The conditions prevailing in the global market require companies to constantly improve in order to maintain their competitive position. In order for companies to be able to work on improving their performance, it is necessary to monitor and record the results of the processes, activities and functions they implement. In addition to individual performance indicators of each company, the results at the level of the country in which the company operates are also extremely important.

The LPI of countries can be found in the data calculated and published by the WB since 2007. World Bank data on LPI values represent the most comprehensive international tool for measuring and comparing logistics performance (Aytekin et al. 2023). Measuring logistics performance and understanding its indicators are more important today than ever before in the context of major changes in the global market that have occurred since 2018, primarily due to the COVID-19 pandemic, which has caused major disruptions in the receipt and shipment of goods. In order for countries to be able to cope adequately with new changes in the market, it is necessary to understand, measure and monitor logistics performance, both their own and the logistics performance of countries in the region and throughout the world (Arvis et al. 2023).

Poor logistics performance is an obstacle to trade and foreign direct investment, and therefore an obstacle to economic growth and development. In order to develop a logistics competitive advantage, governments must assess the current logistics system at the country level and identify which subsystems need to be optimized, developed, created or completely eliminated through policies and initiatives (Jhavar et al. 2017). Adequate analysis of logistics performance can help countries improve the efficiency of freight transport, and help identify those countries that can be helpful in overcoming their own obstacles and shortcomings through cooperation (Ojala and Çelebi, 2015).

As already pointed out, in order to achieve high-quality logistics performance, it is necessary to monitor and measure it constantly. The measurement and evaluation of logistics performance is successfully implemented using various methods and integrated models of multi-criteria decision-making (MCDM). Thus for example, in their research, [Isik et al. \(2020\)](#) apply SV and MABAC methods within an integrated MCDM model for the analysis and evaluation of logistics performance in 11 selected countries of Central and Eastern Europe. The fact that the ranking results obtained by applying the model are the same as the ranking results of the World Bank suggests that the applied model is consistent and reliable to use. [Biswas and Anand \(2020\)](#) compare the LPI results of BRICS countries (Brazil, Russia, India, China, South Africa) and G7 countries (Canada, France, Germany, Italy, Japan, United Kingdom and USA) using an integrated PSI and PIV model. Based on the research results, the authors came to the conclusion that the developed G7 countries are more competitive than the BRICS countries in terms of logistics performance quality. The new methodology for measuring logistics performance of OECD countries (The Organization for Economic Cooperation and Development) involves the integration of CRITIC, SAW and Peters' fuzzy regression method, and was applied in the paper by [Çakır, 2016](#)), and proved to be a suitable alternative approach in assessing logistics performance of the countries. [Yildirim and Mercangoz \(2020\)](#) also considered the assessment of LPI results of OECD countries in their research. [Ulutaş and Karaköy \(2021\)](#) integrate the grey SWARA and grey MOORA method in evaluating the logistics performance of countries in transition. Infrastructure was determined as the most important criterion, and the best-ranked country in transition was Serbia. [Özceylan et al. \(2016\)](#) analyzed and assessed logistics performance in the provinces of Turkey using the AHP-TOPSIS and ANP-TOPSIS models, in which a total of 16 geographic and economic indicators were observed. The authors came to the conclusion that the methodology used provides the possibility of analyzing the impact that the observed indicators have on the quality of the country's logistics performance, as well as the possibility of creating a map of the country's logistics performance using a GIS system. In the research by [Mercangoz et al. \(2020\)](#), the authors try to eliminate the uncertainty that inevitably occurs due to the nature of problems that require multi-criteria decision making. In this sense, they use grey system theory in combination with multi-criteria decision-making methods, i.e. form an integrated grey numbers-COPRAS (Complex Proportional Assessment) model, and conclude that it can be effectively used to assess the LPI scores of countries.

The study by [Yu and Hsiao \(2016\)](#) has presented an alternative Meta-DEA–AR approach intended for the evaluation of the efficiency of the logistics performance index of certain countries, which also takes into account differences in the level of income of those countries. The results of the study indicate that the final ranking of the LPI results of the countries obtained by the proposed alternative model is largely comparable to the results of the World Bank ranking. [Mešić et al. \(2022\)](#) apply an integrated CRITIC-MARCOS MCDM model to evaluate the LPI results of the Western Balkan countries. [Rezaei et al. \(2018\)](#) assessed the importance of each of the six criteria used in the calculation of the final LPI scores, using the BWM (Best Worst Method). They came to the conclusion that even though the weights have only a slight influence on the ranking due to the correlation between the LPI indicators, they can influence the formation of different policy priorities in the calculation of LPI values. In the study by [Çalık et al. \(2022\)](#), a large number of MCDM methods were integrated: AHP (Analytic Hierarchy Process), FAHP (Fuzzy AHP), PFAHP (Pythagorean fuzzy AHP), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), VIKOR (*Višekriterijumska Optimizacija i Kompromisno Rešenje*, in Serbian), CODAS (Combinative Distance-based Assessment) and BCM (Base Criterion Method), with the aim of pointing out the importance of precise determination of criterion weights, and that changes in criterion weight values significantly affect the final evaluation results. [Ulutaş and Karaköy \(2019\)](#) obtained the values of weighting coefficients by integrating the subjective method - SWARA, and the objective method - CRITIC, while they used the PIV method to evaluate EU countries. In that way, they tried to balance the differences in the final ranking of the alternatives that occur in relation to the different values of the weighting coefficients of criteria. The research by [Stević et al. \(2022\)](#) is another research in which the integrated CRITIC-MARCOS model confirmed the significant

influence of the values of the weighting coefficients of criteria on the final ranking of solutions. Namely, in the research, the Balkan countries were evaluated, and then 36 new scenarios were formed as part of the sensitivity analysis with changed values of the weighting coefficients of the criteria. The obtained results showed that the final ranking of the solutions changed depending on the extent of the change in the values of individual criteria.

3. Methods

3.1. Methods for determining criteria weights

In this paper, a novel F-ROV algorithm for the evaluation of potential solutions, and, in this specific case, for ranking the LPI of EU countries, was developed. In addition, for the purpose of determining the weighting coefficients of the six factors on the basis of which the LPI ranking was performed, three methods were applied: CRITIC (Huskanović et al. 2023), MEREC (Keshavarz-Ghorabae et al. 2021) and Entropy (Puška et al. 2023; Chatterjee and Chakraborty, 2023). It is important to note that the obtained weighting coefficients are converted to TFN in the following way:

$$TFN = (l, m, u) \Rightarrow l = \min(w_1, w_2, w_3), m = \min(w_1, w_2, w_3) < \max(w_1, w_2, w_3), u = \max(w_1, w_2, w_3) \quad (1)$$

3.2. A novel Fuzzy Range of Value method

Since the three methods have already been exploited many times in various studies, in this section of the paper, only a novel algorithm of the F-ROV method is presented, and it consists of the steps shown below. In general, the ROV method has not been often applied to solve MCDM problems, despite its advantages shown in the paper (Zavadskas et al. 2018) when a rough extension of this method was performed.

Step 1. Determining the set of elements of the MCDM model

Step 2. Defining a fuzzy initial decision matrix $\mathfrak{S}_{ij} = (\mathfrak{S}_{ij}^l, \mathfrak{S}_{ij}^m, \mathfrak{S}_{ij}^u)_{n \times m}$. This matrix is obtained on the basis of a linguistic scale when experts evaluate potential solutions.

Step 3. Carrying out the procedure of normalization, which implies a multi-phase procedure. First, it is necessary to define the elements \mathfrak{R}_j and \mathbb{R}_j :

$$\mathfrak{R}_j = (\mathfrak{R}_j^l, \mathfrak{R}_j^m, \mathfrak{R}_j^u) = \max(\mathfrak{S}_{ij}) \quad (2)$$

$$\mathbb{R}_j = (\mathbb{R}_j^l, \mathbb{R}_j^m, \mathbb{R}_j^u) = \min(\mathfrak{S}_{ij}) \quad (3)$$

After that, it is required to determine the difference between the values in the initial matrix and the minimum value κ_{ij} , and the difference between the maximum and minimum values of TFN, which is denoted by ς_j :

$$\kappa_{ij} = (\kappa_{ij}^l, \kappa_{ij}^m, \kappa_{ij}^u) = \mathfrak{S}_{ij} - \mathbb{R}_j = (\mathfrak{S}_{ij}^l - \mathbb{R}_j^u, \mathfrak{S}_{ij}^m - \mathbb{R}_j^m, \mathfrak{S}_{ij}^u - \mathbb{R}_j^l) \quad (4)$$

$$\varsigma_j = (\varsigma_j^l, \varsigma_j^m, \varsigma_j^u) = \mathfrak{R}_j - \mathbb{R}_j = (\mathfrak{R}_j^l - \mathbb{R}_j^u, \mathfrak{R}_j^m - \mathbb{R}_j^m, \mathfrak{R}_j^u - \mathbb{R}_j^l) \quad (5)$$

Then, the final normalized fuzzy values are obtained by applying the following expression:

$$\mathfrak{g}_{ij} = (\mathfrak{g}_{ij}^l, \mathfrak{g}_{ij}^m, \mathfrak{g}_{ij}^u) = 1 + \left(\frac{\kappa_{ij}}{\varsigma_j} \right) = \left(\left(1 + \frac{\kappa_{ij}^l}{\varsigma_j^u} \right), \left(1 + \frac{\kappa_{ij}^m}{\varsigma_j^m} \right), \left(1 + \frac{\kappa_{ij}^u}{\varsigma_j^l} \right) \right) \quad (6)$$

In the final fuzzy normalized matrix, in rare cases, it may arise situations when the basic concept of TFN is not satisfied, then it is necessary to apply the following:

$$\text{if } \mathcal{G}_{ij}^m \leq, \mathcal{G}_{ij}^l \text{ then } , \mathcal{G}_{ij}^m = \mathcal{G}_{ij}^l, \quad \text{if } \mathcal{G}_{ij}^u \leq, \mathcal{G}_{ij}^m \text{ then } , \mathcal{G}_{ij}^u = \mathcal{G}_{ij}^m \quad (7)$$

Eqs. (4)-(6) are applied for the criteria with a desirable maximum value, while for the criteria with a desirable minimum value the following procedure (8) is carried out:

$$\mathcal{G}_{ij} = (\mathcal{G}_{ij}^l, \mathcal{G}_{ij}^m, \mathcal{G}_{ij}^u) = 1 + \left(\frac{\mathbb{R}_j}{\mathbb{S}_{ij}} \right) = \left(\left(1 + \frac{\mathbb{R}_j^l}{\mathbb{S}_{ij}^l} \right), \left(1 + \frac{\mathbb{R}_j^m}{\mathbb{S}_{ij}^m} \right), \left(1 + \frac{\mathbb{R}_j^u}{\mathbb{S}_{ij}^u} \right) \right) \quad (8)$$

Step 4. Multiplication of the matrix \mathcal{G}_{ij} with the values of the factor w_j .

$$\nu_{ij} = (\nu_{ij}^l, \nu_{ij}^m, \nu_{ij}^u) = \mathcal{G}_{ij} \otimes w_j = (\mathcal{G}_{ij}^l \otimes w_j^l, \mathcal{G}_{ij}^m \otimes w_j^m, \mathcal{G}_{ij}^u \otimes w_j^u) \quad (9)$$

Step 5. Determining the sum of the previous matrix in accordance with the orientation of the criteria, where the values for the max criteria T_i^+ and for the min criteria T_i^- are added separately.

$$T_i^+ = \sum_{j=1}^m (\nu_{ij}^+) \quad (10)$$

$$T_i^- = \sum_{j=1}^m (\nu_{ij}^-) \quad (11)$$

Step 6. The alternatives are sorted in descending order, and according to the defuzzified value:

$$\Lambda_i = \left(\frac{T_i^+ + T_i^-}{2} \right) \quad (12)$$

4. Results

In order to evaluate the LPI, the latest report of the World Bank has been used, and its ratings for all EU countries are presented in Table 1. Although it is already a well-known fact, it should be noted that the LPI is evaluated based on six criteria ([Hadžikadunić et al. 2023](#)): customs (C₁), infrastructure (C₂), ease of arranging shipments (C₃), quality of logistics services (C₄), tracking and tracing of consignments (C₅), and timeliness, i.e. delivery of shipments within scheduled time (C₆).

Table 1. LPI score of EU countries for 2023

Alternative		C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
A ₁	Austria	3.7	3.9	3.8	4.0	4.2	4.3
A ₂	Belgium	3.9	4.1	3.8	4.2	4.0	4.2
A ₃	Bulgaria	3.1	3.1	3.0	3.3	3.3	3.5
A ₄	Czech Republic	3.0	3.0	3.4	3.6	3.2	3.7
A ₅	Denmark	4.1	4.1	3.6	4.1	4.3	4.1
A ₆	Estonia	3.2	3.5	3.4	3.7	3.8	4.1
A ₇	Finland	4.0	4.2	4.1	4.2	4.2	4.3
A ₈	France	3.7	3.8	3.7	3.8	4.0	4.1
A ₉	Greece	3.2	3.7	3.8	3.8	3.9	3.9
A ₁₀	Croatia	3.0	3.0	3.6	3.4	3.4	3.2
A ₁₁	Ireland	3.4	3.5	3.6	3.6	3.7	3.7
A ₁₂	Italy	3.4	3.8	3.4	3.8	3.9	3.9
A ₁₃	Cyprus	2.9	2.8	3.1	3.2	3.4	3.5
A ₁₄	Latvia	3.3	3.3	3.2	3.7	3.6	4.0

A ₁₅	Lithuania	3.2	3.5	3.4	3.6	3.1	3.6
A ₁₆	Luxembourg	3.6	3.6	3.6	3.9	3.5	3.5
A ₁₇	Hungary	2.7	3.1	3.4	3.1	3.4	3.6
A ₁₈	Malta	3.4	3.7	3.0	3.4	3.4	3.2
A ₁₉	The Netherlands	3.9	4.2	3.7	4.2	4.2	4.0
A ₂₀	Germany	3.9	4.3	3.7	4.2	4.2	4.1
A ₂₁	Poland	3.4	3.5	3.3	3.6	3.8	3.9
A ₂₂	Portugal	3.2	3.6	3.1	3.6	3.2	3.6
A ₂₃	Romania	2.7	2.9	3.4	3.3	3.5	3.6
A ₂₄	Slovakia	3.2	3.3	3.0	3.4	3.3	3.5
A ₂₅	Slovenia	3.4	3.6	3.4	3.3	3.0	3.3
A ₂₆	Spain	3.6	3.8	3.7	3.9	4.1	4.2
A ₂₇	Sweden	4.0	4.2	3.4	4.2	4.1	4.2

It should be emphasized that for the purpose of determining the weighting coefficients of the six factors on the basis of which the LPI ranking was performed, three methods were applied: CRITIC, MEREC and Entropy, and the results given in Table 2 were obtained.

Table 2. Values of w_j calculated with three methods

CRITIC	0.153	0.154	0.219	0.127	0.155	0.192
MEREC	0.198	0.211	0.123	0.150	0.173	0.145
Entropy	0.215	0.233	0.106	0.135	0.184	0.126

Using Eq. (1), the fuzzy weights of the criteria are obtained, and then they are used in the F-ROV method, obtaining the following values:

$$w_1 = (0.153, 0.198, 0.215), w_2 = (0.154, 0.211, 0.233), w_3 = (0.106, 0.123, 0.219)$$

$$w_4 = (0.127, 0.135, 0.150), w_5 = (0.155, 0.173, 0.184), w_6 = (0.126, 0.145, 0.192)$$

After that, it is necessary to form a fuzzy initial matrix, which is shown in Table 3.

Table 3. Initial F-ROV matrix

	C1			C2			C3			C4			C5			C6		
A1	5	5	7	5	7	7	5	5	7	5	7	7	7	7	9	7	9	9
A2	5	7	7	7	7	9	5	5	7	7	7	9	5	7	7	7	7	9
A3	1	3	3	1	3	3	1	1	3	3	3	5	3	3	5	3	5	5
A4	1	1	3	1	1	3	3	3	5	3	5	5	1	3	3	5	5	7
A5	7	7	9	7	7	9	3	5	5	7	7	9	7	9	9	7	7	9
A6	1	3	3	3	5	5	3	3	5	5	5	7	5	5	7	7	7	9
A7	5	7	7	7	7	9	7	7	9	7	7	9	7	7	8	7	9	9
A8	5	5	7	5	5	7	5	5	7	5	5	7	5	7	7	7	7	9
A9	1	3	3	5	5	7	5	5	7	5	5	7	5	7	7	5	7	7
A10	1	1	3	1	1	3	3	5	5	3	3	5	3	3	5	1	3	3
A11	3	3	5	3	5	5	3	5	5	3	5	5	5	5	7	5	5	7
A12	3	3	5	5	5	7	3	3	5	5	5	7	5	7	7	5	7	7
A13	1	1	3	1	1	1	1	3	3	1	3	3	3	3	5	3	5	5
A14	3	3	5	3	3	5	1	3	3	5	5	7	3	5	5	5	7	7
A15	1	3	3	3	5	5	3	3	5	3	5	5	1	3	3	3	5	5
A16	3	5	5	3	5	5	3	5	5	5	7	7	3	5	5	3	5	5
A17	1	1	1	1	3	3	3	3	5	1	3	3	3	3	5	3	5	5
A18	3	3	5	5	5	7	1	1	3	3	3	5	3	3	5	1	3	3
A19	5	7	7	7	7	9	5	5	7	7	7	9	7	7	9	5	7	7
A20	5	7	7	7	9	9	5	5	7	7	7	9	7	7	9	7	7	9
A21	3	3	5	3	5	5	3	3	5	3	5	5	5	5	7	5	7	7

A22	1	3	3	3	5	5	1	3	3	3	5	5	1	3	3	3	5	5
A23	1	1	1	1	1	3	3	3	5	3	3	5	3	5	5	3	5	5
A24	1	3	3	3	3	5	1	1	3	3	3	5	3	3	5	3	5	5
A25	3	3	5	3	5	5	3	3	5	3	3	5	1	1	3	3	3	5
A26	3	5	5	5	5	7	5	5	7	5	7	7	7	7	9	7	7	9
A27	5	7	7	7	7	9	3	3	5	7	7	9	7	7	9	7	7	9

The initial matrix for the F-ROV method is defined by transforming the values from Table 1 as follows: LPI score values 2.7-2.8=(1,1,1); 2.9-3.0=(1,1,3); 3.1-3.2=(1,3,3); 3.3-3.4=(3,3,5); 3.5-3.6=(3,5,5); 3.7-3.8=(5,5,7), 3.9-4.0=(5,7,7), 4.1-4.2=(7,7,9) and 4.3=(7,9,9).

The normalized F-ROV matrix (Table 4) is obtained by applying Eqs. (2)-(7), and all criteria are modeled with the desired max value.

Table 4. Normalized F-ROV matrix

	C1			C2			C3			C4			C5			C6		
A1	1.50	1.67	2.00	1.50	1.75	2.00	1.25	1.67	2.50	1.25	2.00	2.50	1.50	1.75	3.00	1.50	2.00	3.00
A2	1.50	2.00	2.00	1.75	1.75	2.33	1.25	1.67	2.50	1.50	2.00	3.00	1.25	1.75	2.50	1.50	1.67	3.00
A3	1.00	1.33	1.33	1.00	1.25	1.33	0.75	1.00	1.50	1.00	1.00	2.00	1.00	1.25	2.00	1.00	1.33	2.00
A4	1.00	1.00	1.33	1.00	1.00	1.33	1.00	1.33	2.00	1.00	1.50	2.00	0.75	1.25	1.50	1.25	1.33	2.50
A5	1.75	2.00	2.33	1.75	1.75	2.33	1.00	1.67	2.00	1.50	2.00	3.00	1.50	2.00	3.00	1.50	1.67	3.00
A6	1.00	1.33	1.33	1.25	1.50	1.67	1.00	1.33	2.00	1.25	1.50	2.50	1.25	1.50	2.50	1.50	1.67	3.00
A7	1.50	2.00	2.00	1.75	1.75	2.33	1.50	2.00	3.00	1.50	2.00	3.00	1.50	1.75	2.75	1.50	2.00	3.00
A8	1.50	1.67	2.00	1.50	1.50	2.00	1.25	1.67	2.50	1.25	1.50	2.50	1.25	1.75	2.50	1.50	1.67	3.00
A9	1.00	1.33	1.33	1.50	1.50	2.00	1.25	1.67	2.50	1.25	1.50	2.50	1.25	1.75	2.50	1.25	1.67	2.50
A10	1.00	1.00	1.33	1.00	1.00	1.33	1.00	1.67	2.00	1.00	1.00	2.00	1.00	1.25	2.00	0.75	1.00	1.50
A11	1.25	1.33	1.67	1.25	1.50	1.67	1.00	1.67	2.00	1.00	1.50	2.00	1.25	1.50	2.50	1.25	1.33	2.50
A12	1.25	1.33	1.67	1.50	1.50	2.00	1.00	1.33	2.00	1.25	1.50	2.50	1.25	1.75	2.50	1.25	1.67	2.50
A13	1.00	1.00	1.33	1.00	1.00	1.00	0.75	1.33	1.50	0.75	1.00	1.50	1.00	1.25	2.00	1.00	1.33	2.00
A14	1.25	1.33	1.67	1.25	1.25	1.67	0.75	1.33	1.50	1.25	1.50	2.50	1.00	1.50	2.00	1.25	1.67	2.50
A15	1.00	1.33	1.33	1.25	1.50	1.67	1.00	1.33	2.00	1.00	1.50	2.00	0.75	1.25	1.50	1.00	1.33	2.00
A16	1.25	1.67	1.67	1.25	1.50	1.67	1.00	1.67	2.00	1.25	2.00	2.50	1.00	1.50	2.00	1.00	1.33	2.00
A17	1.00	1.00	1.00	1.00	1.25	1.33	1.00	1.33	2.00	0.75	1.00	1.50	1.00	1.25	2.00	1.00	1.33	2.00
A18	1.25	1.33	1.67	1.50	1.50	2.00	0.75	1.00	1.50	1.00	1.00	2.00	1.00	1.25	2.00	0.75	1.00	1.50
A19	1.50	2.00	2.00	1.75	1.75	2.33	1.25	1.67	2.50	1.50	2.00	3.00	1.50	1.75	3.00	1.25	1.67	2.50
A20	1.50	2.00	2.00	1.75	2.00	2.33	1.25	1.67	2.50	1.50	2.00	3.00	1.50	1.75	3.00	1.50	1.67	3.00
A21	1.25	1.33	1.67	1.25	1.50	1.67	1.00	1.33	2.00	1.00	1.50	2.00	1.25	1.50	2.50	1.25	1.67	2.50
A22	1.00	1.33	1.33	1.25	1.50	1.67	0.75	1.33	1.50	1.00	1.50	2.00	0.75	1.25	1.50	1.00	1.33	2.00
A23	1.00	1.00	1.00	1.00	1.00	1.33	1.00	1.33	2.00	1.00	1.00	2.00	1.00	1.50	2.00	1.00	1.33	2.00
A24	1.00	1.33	1.33	1.25	1.25	1.67	0.75	1.00	1.50	1.00	1.00	2.00	1.00	1.25	2.00	1.00	1.33	2.00
A25	1.25	1.33	1.67	1.25	1.50	1.67	1.00	1.33	2.00	1.00	1.00	2.00	0.75	1.00	1.50	1.00	1.00	2.00
A26	1.25	1.67	1.67	1.50	1.50	2.00	1.25	1.67	2.50	1.25	2.00	2.50	1.50	1.75	3.00	1.50	1.67	3.00
A27	1.50	2.00	2.00	1.75	1.75	2.33	1.00	1.33	2.00	1.50	2.00	3.00	1.50	1.75	3.00	1.50	1.67	3.00

In the normalized matrix, the values \mathfrak{R}_j and \mathbb{R}_j are first calculated, and for C1 they are $\mathfrak{R}_1 = (7, 7, 9)$ and $\mathbb{R}_1 = (1, 1, 1)$ in order to calculate the values κ_{ij} , and ς_j : $\kappa_{11} = (4, 4, 6) = (5 - 1, 5 - 1, 7 - 1)$, $\varsigma_1 = (6, 6, 8) = (7 - 1, 7 - 1, 9 - 1)$. Then, the final normalized fuzzy values are obtained by applying the expression: $\mathfrak{g}_{11} = (1.50, 1.67, 2.00) = \left(\left(1 + \frac{4}{8} \right), \left(1 + \frac{4}{6} \right), \left(1 + \frac{6}{6} \right) \right)$.

The formation of the weighted normalized F-ROV matrix is performed using Eq. (9), and the values are given in Table 5.

Table 5. Weighted normalized F-ROV matrix

	C1			C2			...	C5			C6		
A1	0.230	0.329	0.430	0.231	0.370	0.466	...	0.232	0.303	0.553	0.189	0.290	0.575
A2	0.230	0.395	0.430	0.270	0.370	0.544	...	0.194	0.303	0.461	0.189	0.242	0.575
A3	0.153	0.263	0.287	0.154	0.264	0.311	...	0.155	0.216	0.369	0.126	0.193	0.384
A4	0.153	0.198	0.287	0.154	0.211	0.311	...	0.116	0.216	0.276	0.158	0.193	0.479
A5	0.269	0.395	0.502	0.270	0.370	0.544	...	0.232	0.346	0.553	0.189	0.242	0.575
A6	0.153	0.263	0.287	0.193	0.317	0.389	...	0.194	0.260	0.461	0.189	0.242	0.575
A7	0.230	0.395	0.430	0.270	0.370	0.544	...	0.232	0.303	0.507	0.189	0.290	0.575
A8	0.230	0.329	0.430	0.231	0.317	0.466	...	0.194	0.303	0.461	0.189	0.242	0.575
A9	0.153	0.263	0.287	0.231	0.317	0.466	...	0.194	0.303	0.461	0.158	0.242	0.479
A10	0.153	0.198	0.287	0.154	0.211	0.311	...	0.155	0.216	0.369	0.095	0.145	0.288
A11	0.192	0.263	0.358	0.193	0.317	0.389	...	0.194	0.260	0.461	0.158	0.193	0.479
A12	0.192	0.263	0.358	0.231	0.317	0.466	...	0.194	0.303	0.461	0.158	0.242	0.479
A13	0.153	0.198	0.287	0.154	0.211	0.233	...	0.155	0.216	0.369	0.126	0.193	0.384
A14	0.192	0.263	0.358	0.193	0.264	0.389	...	0.155	0.260	0.369	0.158	0.242	0.479
A15	0.153	0.263	0.287	0.193	0.317	0.389	...	0.116	0.216	0.276	0.126	0.193	0.384
A16	0.192	0.329	0.358	0.193	0.317	0.389	...	0.155	0.260	0.369	0.126	0.193	0.384
A17	0.153	0.198	0.215	0.154	0.264	0.311	...	0.155	0.216	0.369	0.126	0.193	0.384
A18	0.192	0.263	0.358	0.231	0.317	0.466	...	0.155	0.216	0.369	0.095	0.145	0.288
A19	0.230	0.395	0.430	0.270	0.370	0.544	...	0.232	0.303	0.553	0.158	0.242	0.479
A20	0.230	0.395	0.430	0.270	0.423	0.544	...	0.232	0.303	0.553	0.189	0.242	0.575
A21	0.192	0.263	0.358	0.193	0.317	0.389	...	0.194	0.260	0.461	0.158	0.242	0.479
A22	0.153	0.263	0.287	0.193	0.317	0.389	...	0.116	0.216	0.276	0.126	0.193	0.384
A23	0.153	0.198	0.215	0.154	0.211	0.311	...	0.155	0.260	0.369	0.126	0.193	0.384
A24	0.153	0.263	0.287	0.193	0.264	0.389	...	0.155	0.216	0.369	0.126	0.193	0.384
A25	0.192	0.263	0.358	0.193	0.317	0.389	...	0.116	0.173	0.276	0.126	0.145	0.384
A26	0.192	0.329	0.358	0.231	0.317	0.466	...	0.232	0.303	0.553	0.189	0.242	0.575
A27	0.230	0.395	0.430	0.270	0.370	0.544	...	0.232	0.303	0.553	0.189	0.242	0.575

By completing the F-ROV algorithm, the final results presented in Table 6 are obtained. It is important to emphasize that Eqs. (11) and (12) are not applied in this case since all criteria are benefit.

Table 6. Results obtained by the F-ROV method

	T_i^+			Crisp value	EU country	Sorting
A1	1.175	1.767	2.947	1.865	Austria	6
A2	1.206	1.784	3.008	1.892	Belgium	5
A3	0.795	1.195	1.978	1.259	Bulgaria	23
A4	0.815	1.185	2.092	1.274	Czech Republic	22
A5	1.257	1.827	3.062	1.938	Denmark	3
A6	0.994	1.448	2.525	1.552	Estonia	13
A7	1.271	1.873	3.163	1.988	Finland	1
A8	1.136	1.598	2.855	1.730	France	9
A9	1.028	1.532	2.616	1.629	Greece	10
A10	0.790	1.110	1.992	1.204	Croatia	26
A11	0.969	1.441	2.425	1.526	Ireland	15
A12	1.039	1.491	2.578	1.597	Italy	11
A13	0.764	1.117	1.826	1.176	Cyprus	27
A14	0.935	1.395	2.299	1.469	Latvia	16
A15	0.822	1.356	2.073	1.387	Lithuania	17
A16	0.931	1.574	2.312	1.590	Luxembourg	12
A17	0.790	1.170	1.941	1.235	Hungary	25
A18	0.879	1.200	2.110	1.298	Malta	20
A19	1.213	1.784	3.004	1.892	The Netherlands	4
A20	1.245	1.837	3.100	1.949	Germany	2

A21	0.969	1.448	2.425	1.531	Poland	14
A22	0.795	1.356	1.964	1.364	Portugal	18
A23	0.822	1.161	2.016	1.247	Romania	24
A24	0.834	1.195	2.056	1.278	Slovakia	21
A25	0.860	1.197	2.145	1.299	Slovenia	19
A26	1.136	1.665	2.876	1.779	Spain	8
A27	1.218	1.743	2.991	1.864	Sweden	7

By completing the calculation procedure of the F-ROV method, which is shown in detail above, the final results are obtained. In general, compared to the World Bank report, there is some conformity, but there is no situation where several countries share the same position, which is the contribution of the research. Finland, Germany, Denmark, the Netherlands and Belgium represent the top five countries among the observed 27 within the EU network.

5. Verification tests

5.1. Sensitivity analysis

In a large number of studies ([Švadlenka et al. 2023](#); [Więckowski and Sałabun, 2023](#)), it has been proven that changing the initial values of input parameters plays an important role in the final ranking of alternative solutions. Accordingly, in this section, 60 scenarios that define new values of input indicators were created. This specifically means that the reduced values of all six parameters are in a range of 5-95%, depending on the scenario. The values of the first factor were modeled in S1-S10, the second in S11-S20 and so on until the last factor in S51-S60. The newly defined values of the input parameters are shown in Figure 1. This practically means that the first criterion in S10 has been reduced by 95% and its value is only (0.008,0.010,0.011) compared to its initial value (0.153,0.198,0.215). The values of other parameters increase proportionally.

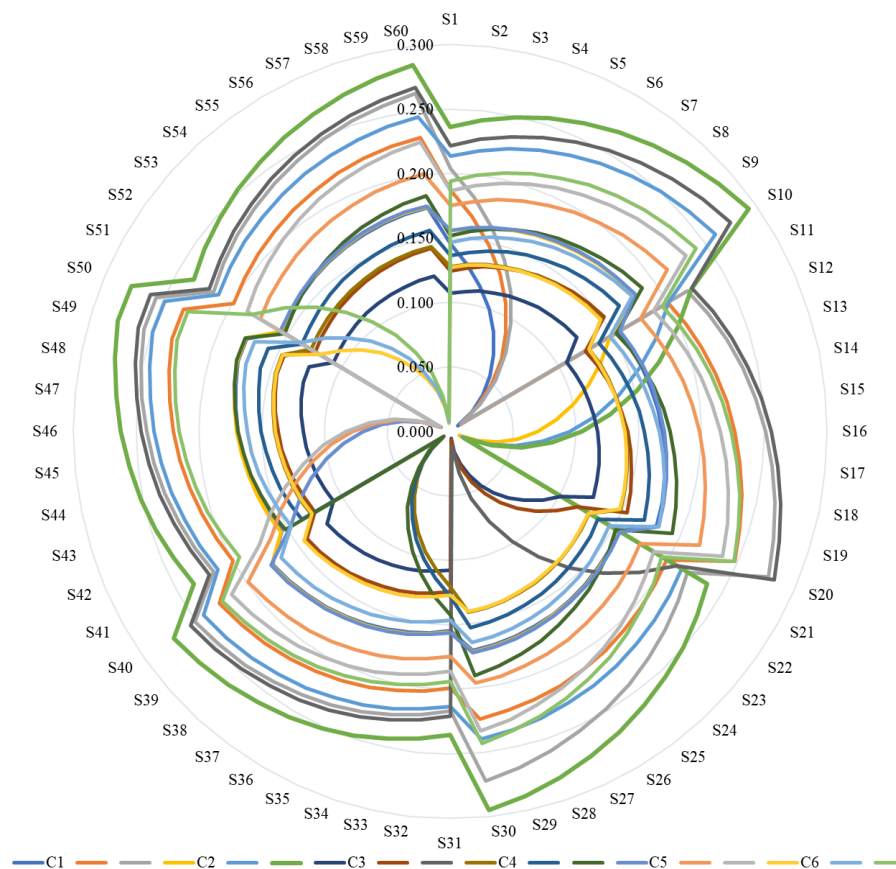


Figure 1. Newly defined factor weights

In accordance with the previously defined new values of the input indicators, it is necessary to re-apply the F-ROV method in all 60 scenarios in order to obtain new rankings of the EU countries on the basis of LPI assessment. As expected, the results are sensitive to changes in the initial values of the criteria, which is particularly expressed by a large set of potential solutions, as shown in Figure 2.

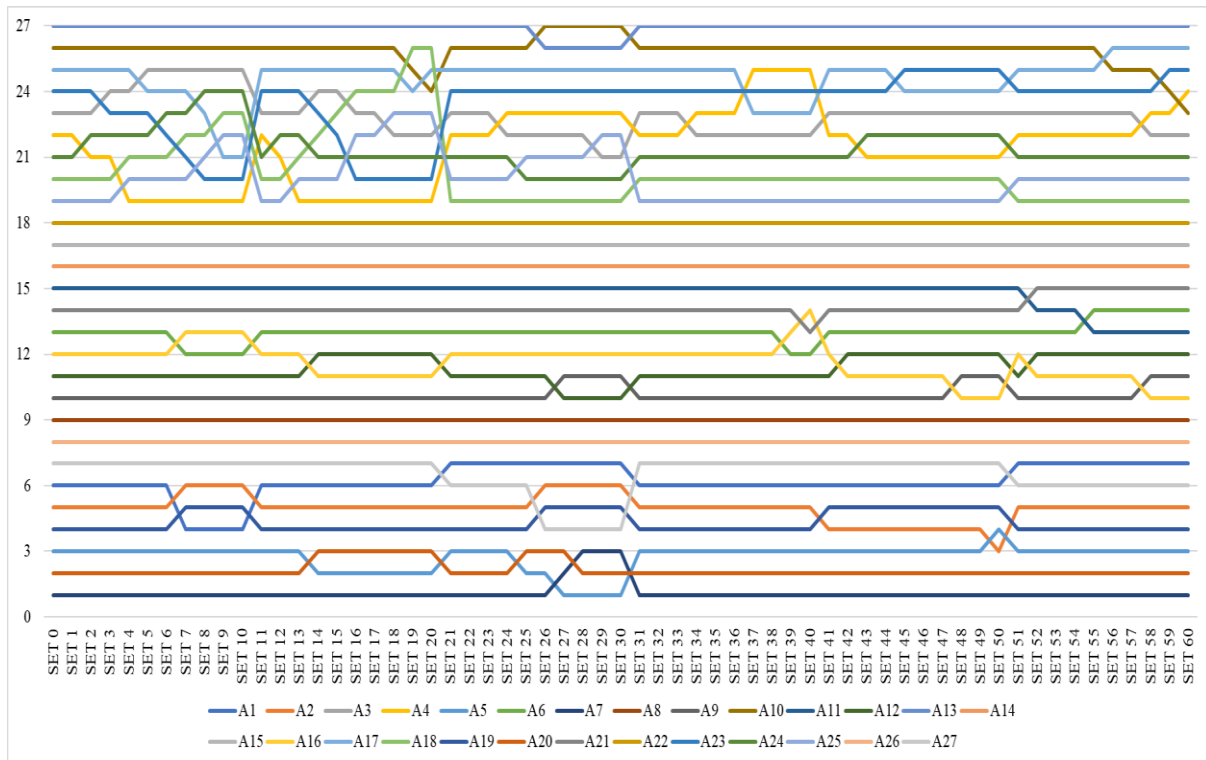


Figure 2. The influence of changing the initial criterion values on the ranking of alternative solutions

As it can be noticed, there is a large number of scenarios (55) in which there is a change in the ranking of the alternatives, at least to the smallest possible extent. In only five scenarios there is no change in ranks (S1, S11, S31, S32 and S33) since the smallest value reductions (5-25%) occur in them. It is important to emphasize that there are countries that do not change their original ranking in any scenario, which confirms that the weights of the criteria in their ranking does not play any role, namely A8, A14, A15, A22, A26, which are in ninth, 16th, 17th, 18th, and eighth place, respectively. When it comes to the best-ranked EU countries, depending on the decrease in the importance of the criteria, there are changes in the ranks. Finland maintains the first position in a total of 56 scenarios, which is about 93%. The only negative impact on its ranking is by the ease of arranging shipments as the third criterion. By drastically reducing the value of this criterion, Denmark takes the first position, because according to this criterion it has the lowest score and if the importance of this criterion is reduced to a minimum, the importance of this country, i.e. the rank, is increasing. In general, regardless of any changes in factor values, it can be found that Finland, Denmark and Germany are at the top of the list.

5.2. Comparison with other approaches

In this section of the paper, as recommended by a large number of researchers (Biswas et al. 2023; Ranjan et al. 2023), a comparison analysis with other methods in fuzzy form is performed. F-MARCOS, F-SAW and F-WASPAS are applied to verify the obtained results, which is shown in Figure 3.

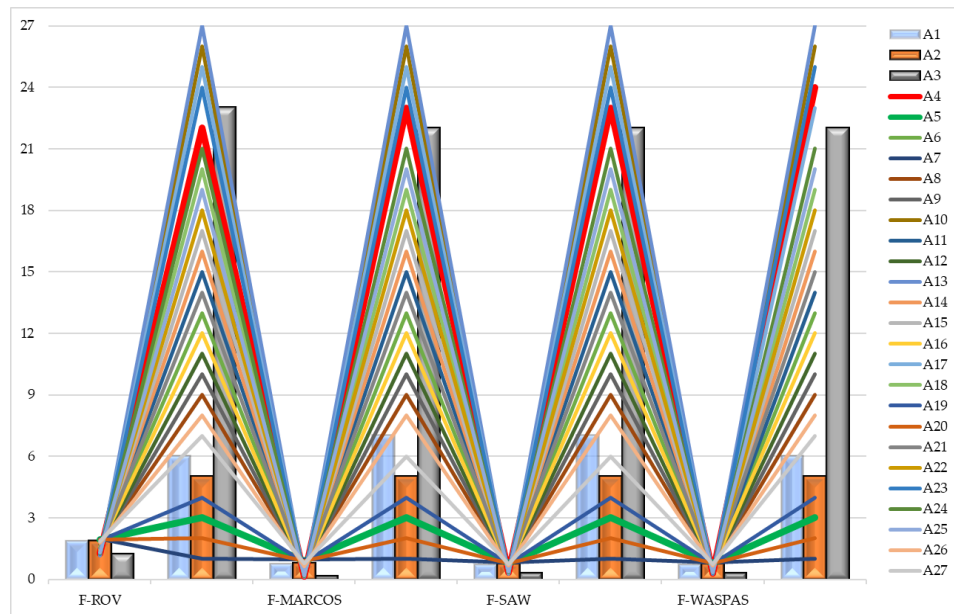


Figure 3. Comparison with other approaches

The results obtained with the F-ROV method provide excellent results, which is confirmed in this comparison analysis with three other MCDM methods in fuzzy form. This statement is manifested through the change of only six ranks out of a total of 27, which is negligible, because it is a change of only one position. Those are the alternatives: A1, A3, A4, A18, A25 and A27. It is also necessary to state that the top five countries do not change their position.

5.3. Matrix resizing

In such studies that involve a large set of potential solutions for evaluation, the stability of the proposed model is often tested with a reduction in the size of the initial matrix. A total of 25 were formed, whereby the weakest component or alternative was eliminated and the procedure was repeated. Figure 4 shows the results of the EU countries based on the LPI assessment when reducing the size of the initial fuzzy matrix.

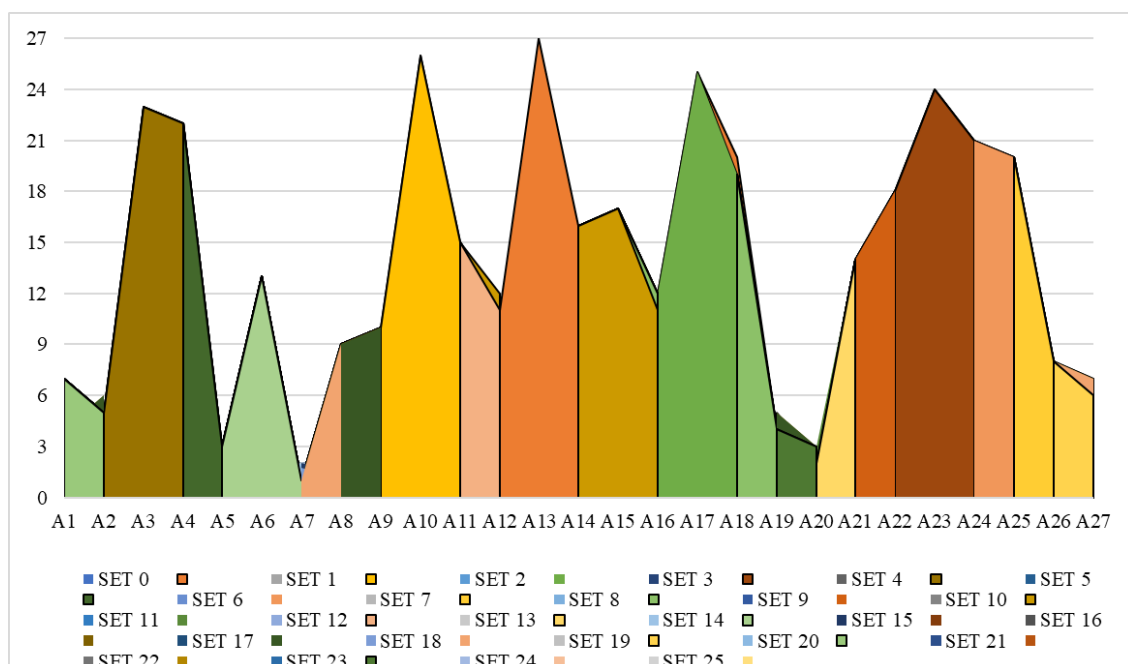


Figure 4. Influence of matrix size change on values and ranks

In general, it can be drawn a conclusion about the variability of the developed F-ROV method, since it is necessary to emphasize that there are changes in the final results when the size of the matrix is changed. In particular, most alternative solutions do not change position, but e.g. Germany and Denmark change their positions in some sets, while Finland is always ranked best. Other changes refer to the rise or fall of some alternatives for only one position, which may be negligible in relation to the total number of countries representing alternative solutions.

5.4. Calculation of correlation

Since there are changes in the ranks when the values of input factors change, and in the comparative analysis, the correlation of the ranks with the SCC (Božanić et al. 2023) and WS (Więckowski et al. 2023) coefficients was tested, which is shown in Figures 5 and 6, respectively.

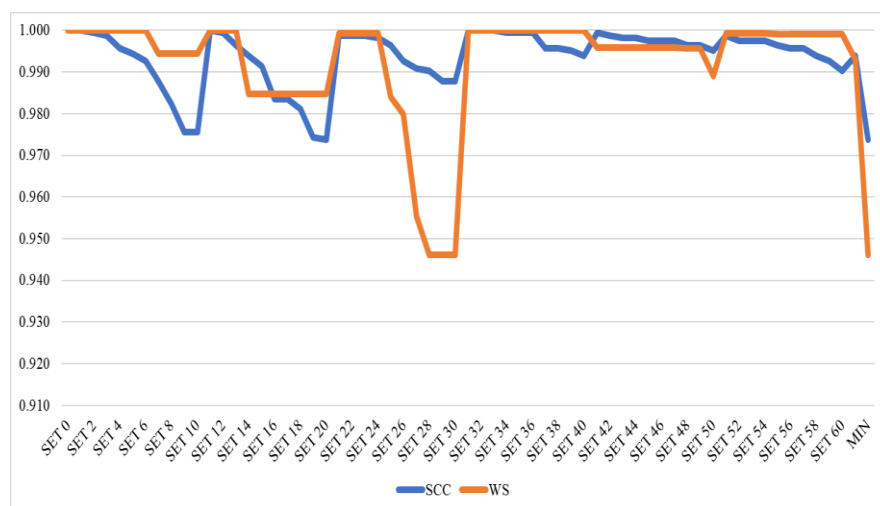


Figure 5. Correlation in sensitivity analysis

Previously, we have stated that there is variability in the ranks of alternatives when the weights of input indicators are changed. Considering that, it is necessary to determine to what extent there is a correlation compared to the initial solution. Both calculated coefficients show an extremely high degree of correlation since the average values are almost identical, $SCC=0.994$ and $WS=0.993$, while the minimum correlations are: $SCC=0.974$ and $WS=0.946$. Such coefficients show almost complete correlation.

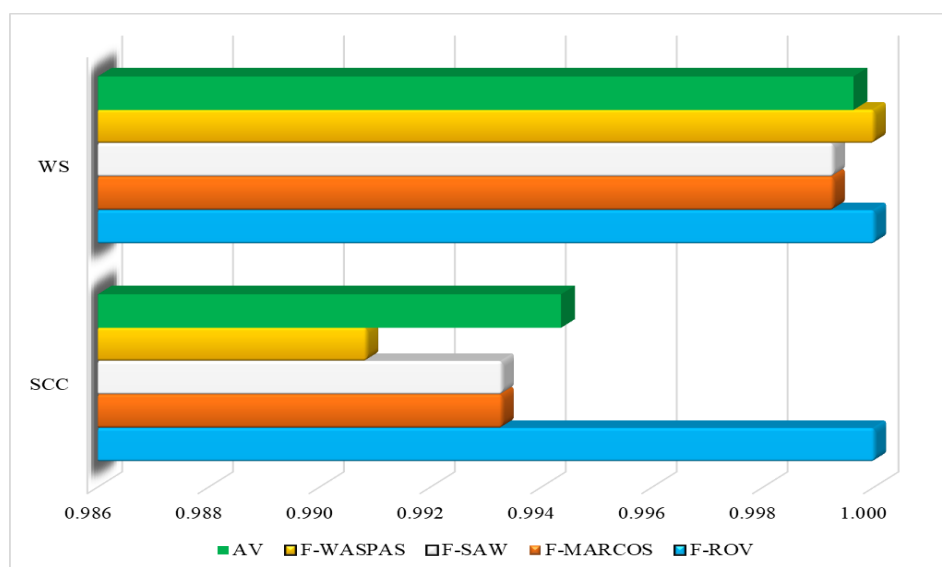


Figure 6. Correlation in comparative analysis

Correlation of initial results and comparative analysis show almost complete correlation on average. The complete correlation is as follows: F-ROV with F-MARCOS and F-SAW: $SCC=0.993$, $WS=0.999$, F-ROV with F-WASPAS: $SCC=0.991$ and $WS=1$.

6. Conclusion

In order to create an original fuzzy ROV algorithm, data from the latest World Bank report published in 2023 for EU countries and their LPI scores according to six influential factors were used. The last report underwent certain changes from the aspect of methodology, since domestic performance was eliminated, which is a novelty. One of the most important problems of LPI evaluation is the equal treatment of influential factors, which can lead to insufficiently precise rankings. The greatest contribution of this paper can be seen through creating a unique F-ROV approach to evaluate the logistics performance index of EU countries. From the social aspect, the contribution is manifested by indicating the need to define a methodology for treating the six factors on the basis of which the LPI is assessed and the World Bank report is formed. It is necessary to implement different weights that can be changed in real time and depending on different reports. The results show consistency with the current report when it comes to the top three countries, while other analyses show that there is a variation in the ranks and a deviation from the initial rank. The contribution of this research and the implementation of the defined model is reflected in a comparison with the World Bank report in which many countries share the same position, which is not the case in this paper. Thanks to the applied model, precise rankings are defined for each country and there is no division of the same position.

Future research is related to the estimation of LPI by applying one of the MCDM models for different regions and areas. Additionally, it is proposed to introduce the weights of LPI evaluation criteria, and this should be achieved through extensive research that would involve surveying all experts who evaluate LPI, and apply some of the averaging operators to determine the final weights.

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