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# Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) Method: A Comprehensive Bibliometric Analysis

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**ABSTRACT**

This paper explores the evolution, applications, and prospective developments of a very popular multi-criteria decision-making (MCDM) method called Measurement of Alternatives and Ranking according to COmpromise Solution Method (MARCOS). Employing an extensive bibliometric analysis, the study examines 115 pertinent papers sourced from the Scopus database spanning over the years from 2020 to 2024. This study also provides an evaluation of the methodological significance and outlines potential future directions of MARCOS method. The outcomes indicate "Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS)" by Stević et al. (2020) as the most cited paper. Journals such as "Sustainability (Switzerland)", "Mathematics" and "Expert Systems with Applications" stand out among the most cited journals. "University of East Sarajevo" is an institution distinguished for its prolific research in this field. "Stević Ž." Has been identified as the most cited and published author. The most frequently used keywords are "MARCOS", "MARCOS method", and "MCDM". CRiteria Importance Through Intercriteria. Correlation (CRITIC) method is a weighting model often integrated with MARCOS method. The results of the study provide researchers and practitioners in the field of MCDM with an important insight into the current state of the MARCOS methodology, highlighted studies and potential future developments. It also provides a comprehensive overview of the importance of this method in the multi-criteria decision-making literature, shedding light on future research directions.

## 1. Introduction

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Multi-criteria decision-making (MCDM) is a process where several criteria are considered in making a decision. MCDM is used to address the complexity of any decision-making process and to balance various factors.

MCDM encompasses several fundamental stages as described below:

i. Problem definition: The initial step involves the identification of the problem that needs addressing at the outset of the decision-making process. This step involves decision-makers identifying the goals, objectives and key stakeholders involved in the decision-making process.

ii. Criteria identification: A fundamental step in the decision-making process is the identification of criteria (factors). This process involves the identification and selection of relevant criteria to evaluate and compare alternatives. The objective is to ensure that the selected criteria are comprehensive, pertinent and reflective of the decision-making framework.

iii. Criteria weight estimation: Criteria weights represent the relative importance or significance of each criterion in the decision-making process. Criteria weights ensure consistency and objectivity in decision-making. By using a systematic approach to estimate weights, MCDM methods reduces the influence of subjective biases and personal preferences in the decision process. Weighting methods can often be objective (based on mathematical models) or subjective (based on expert opinion). The method chosen may vary depending on the complexity of the problem, data availability and the preferences of the decision maker. A good weighting method can help decision makers make fair and consistent decisions by taking into account important factors. Therefore, the choice of weighting method should be carefully planned and supported by problem context-specific analysis. Situations that influence the choice of weighting methods:
   - ✓ Decision maker's preferences: The preferences of the decision maker are an important factor to consider when determining the weighting method. A detailed analysis is carried out on how to interact with the decision maker, identify preferences and how to integrate these preferences into the mathematical model.
   - ✓ Data availability and problem complexity: The complexity of the problem and the available data are other factors that influence the weighting method to be used. Especially in the case of uncertain or incomplete data, an analysis is made as to which method is more appropriate.

iv. Identification of alternatives: Alternative solutions, options or decisions available on the issue to be decided are identified. These alternatives represent a variety of options that are appropriate to the decision-makers' objectives.

v. Selection of method for comparison and ranking: The selection of a method for comparison and ranking of alternatives is a crucial phase in decision-making process. During this stage, performance of the selected alternatives is assessed and ranked. Each alternative undergoes evaluation based on the weighted sum of its overall performance. The ranking of alternatives is then achieved by employing a ranking method suitable for the specific decision problem. However, it is important to note that each ranking method possesses distinct characteristics, and the decision on which method to use depends on various factors like:
   - ✓ Nature and complexity of the problem: The problem to be analyzed should be evaluated in terms of the number of criteria, the priorities of the decision maker and

the problem structure. Some ranking methods can cope better with complex and large-sized problems, while others may be effective for smaller and simpler problems.

- ✓ Data status: Data availability is important in the choice of ranking method. If the data is clear and precise, parametric ranking methods may be more appropriate. However, in the case of uncertain or incomplete data, non-parametric methods may make more sense.
- ✓ Decision maker's preferences: The preferences of the decision maker are a determining factor in the choice of ranking method. Some ranking methods may better reflect the subjective assessments and preferences of the decision maker. Therefore, the decision maker's involvement and priorities should be taken into account.

vi. Analysis of results and iteration: The results obtained are evaluated and analyzed. Decision makers review their decisions based on the results and repeat the process if necessary. As an iterative process, multi-criteria decision making can be repeated whenever necessary, taking into account new information or changing circumstances.

vii. Implementation of the decision: After selecting the best alternative, the decision is implemented. In this phase, the selected alternative is put into practice and the necessary steps are taken.

MCDM is a methodology that helps decision makers make informed and systematic decisions in complex situations, taking into account information and priorities. The method combines analytical tools, mathematical modeling and subjective assessments of decision makers. Fuzzy MCDM extends MCDM framework by incorporating fuzzy set theory to deal with uncertainty and imprecision in decision-making [1]. Fuzzy set theory allows the representation of vague and subjective information by assigning degrees of membership to elements in a set [2]. Fuzzy MCDM models capture the uncertainty associated with criteria weights, decision matrix entries, and decision preferences.

Bibliometric analysis is research carried out by systematically examining papers in the scientific literature on a given topic and their various characteristics in order to understand the trends, popularity and level of progress in the topic. This analysis usually involves large data sets and is based on data from scientific databases. Various metrics such as citation analysis, publication frequency, geographical distribution, authors' influence, institutions' contribution, and frequency of use of key concepts are the measurement tools used in bibliometric analysis [3]. These metrics are used to understand the interactions, relationships and importance of publications on a topic. Bibliometric analyses are used to track developments in a particular research field, identify prominent research trends, identify influential publications or researchers, and predict future research directions. These analyses provide important information to the academic community, researchers, institutions and decision-makers about which topics are priorities, which areas should be allocated more resources and which research groups can collaborate [4]. In this context, bibliometric analyses offer a comprehensive methodology for understanding the evolution of scientific knowledge, exploring dynamics in the research field and identifying future research directions. The integration of various metrics and analyses helps the academic community to better understand the interactions of scientific publications and make strategic decisions. Bibliometric analysis has found extensive application in various research fields. Among these areas, especially in decision-making research, studies related to MCDM have been screened with bibliometric analysis. For example, Zaliluddin [5], conducted a bibliometric study focusing on the study of fuzzy logic and MCDM. They analyzed papers published in Scopus between 1984 and 2022. Vatankhah *et al.,* [6], conducted a bibliometric study in Travel and tourism, MCDM studies. They analyzed papers published in Web of Science and Scopus

between 1997 and 2022. Liao *et al.,* [7] conducted a bibliometric study on Fuzzy MCDM, hospitality, tourism studies. They analyzed papers published in Web of Science between 1997 and 2022. Herawan *et al.,* [8] completed a bibliometric study with MCDM and tourism study. They analyzed papers published in Scopus between 2013 and 2023. Nirmal *et al.,* [9] conducted a bibliometric study focusing on Fuzzy MCDM and green supply chain study. They analyzed papers published in Scopus between 2010 and 2023. There are also bibliometric analyses specific to MCDM methods in the literature. Table 1 summarizes the bibliometric analysis studies specific to MCDM methods.

**Table 1**
Bibliometric analyses specific to MCDM methods

| Authors | Year | Keyword | Time Span | Number of Publications Reviewed | Database | Software used |
|---|---|---|---|---|---|---|
| Zyoud and Fuchs-Hanusch [10] | 2017 | AHP and TOPSIS | 1976-2015 | AHP:10188; TOPSIS: 2412 | Scopus | VOSviewer |
| Chen *et al.,* [11] | 2019 | ANP | 1997-2018 | 1485 | Web of Science | VOSviewer |
| Ferreira and Santos [12] | 2021 | MACBETH | 1994-2016 | 192 | Scopus | VOSviewer |
| Koca and Yıldırım [13] | 2021 | DEMATEL | 1999-2020 | 1963 | Web of Science | Biblioshiny |
| Ayan and Abacıoğlu [14] | 2022 | WASPAS, MABAC, EDAS, CODAS, COCOSO, and MARCOS | 2012-2022 | 1215 | Web of Science and Scopus | Biblioshiny |
| Demir *et al.*, [4] | 2024 | MABAC | 2015-2023 | 264 | Scopus | VOSviewer and Biblioshiny |
| Present study | 2024 | MARCOS | 2020-2024 | 115 | Scopus | VOSviewer and Biblioshiny |

Table 1 shows the bibliometric analyses performed at different time intervals specific to MCDM approaches. This is the first study that provides a comprehensive analysis of the contents for the MARCOS method, which is one of the MCDM methods.

MARCOS method serves as a valuable approach in decision-making processes, aiming to assess and prioritize alternatives according to multiple criteria. MARCOS method is widely recognized as a powerful MCDM method and has been adopted for diverse range of applications. The important findings and trends of previous studies on MARCOS method can be summarized as follows: Badi *et al.,* [15] proposed a hybrid BWM-AHP-MARCOS model for wind farm site selection in Libya, emphasizing its application in the energy sector. Wang *et al.,* [16] examined the potential of MARCOS method in the field of transportation using fuzzy rough SWARA and fuzzy rough MARCOS model for the selection of electric vehicles. Stević *et al.*, [17] highlighted the applicability of MARCOS in the context of logistics management by proposing the FUCOM-MARCOS model for the selection of logistics distribution channels for final product delivery. Xu *et al.,* [18] developed the application of trapezoidal interval type-2 fuzzy PIPRECIA and trapezoidal interval type-2 fuzzy MARCOS, emphasizing the advantages of combining MARCOS with fuzzy logic-based models. Miškić *et al.,* [19] applied MEREC and MARCOS method to determine the quality of logistics system and emphasized the role of MARCOS in the evaluation of logistics processes. Işık *et al.,* [20] investigated the potential of MARCOS in financial analysis by proposing LOPCOW, SWARA II and MARCOS model to evaluate the financial performance of non-life insurance companies. These examples show that the MARCOS method has been successfully applied in various sectors and disciplines. These studies show that

MARCOS offers a flexible and effective solution for multi-criteria decision-making processes and inspire future researchers about the potential of the method. Tešić *et al.,* [21] used fuzzy LMAW and fuzzy MARCOS method for dump truck selection.

This bibliometric analysis provides a comprehensive review to understand the evolution, impact and future potential of MARCOS method in the field of multi-criteria decision making. MARCOS is characterized by its ability to evaluate multiple factors in decision-making processes. MARCOS method shows better stability compared to other MCDM methods, especially when criteria weights are changed. This stability in maintaining ranking orders is particularly valuable in ensuring the reliability and robustness of the decision-making process, even amidst changes in criteria or other variables [22-24]. In recent years, MARCOS method has attracted much attention and has become an important research topic in multi-criteria decision making. This analysis presents a comprehensive bibliometric analysis to understand the position, development and impact of MARCOS method in the literature. Given the multidimensional impact of the method in decision-making processes, this analysis examines the geographical distribution of papers published on MARCOS, the number of citations, preferred journals, leading institutions and authors. This paper not only presents the prominent trends in research on MARCOS method, key stakeholders and developments in this field, but also highlights potential future applications and research areas of this method. The aim of the study is to provide an important resource not only for academics and researchers interested in MARCOS method, but also for decision makers and industry professionals considering applying this method to real-world problems. By emphasizing the importance of MARCOS method in multi-criteria decision-making processes, this analysis aims to guide future research directions by deepening the existing knowledge in the field.

### *1.1. Basic Principles of MARCOS Method*

The main objective of the MARCOS method is to make comparisons between different clusters or alternatives using a large number of criteria. MARCOS method is based on the definition of the relationship between alternatives and reference values. A detailed explanation of the basic principles of MARCOS method and how it works is as follows [25-26]:

Step 1: Constructing the initial decision matrix

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \; i = 1,2,\ldots..,m \text{ and } j = 1,2,\ldots..,n \tag{1}$$

Step 2: Obtaining the extended decision matrix

The ideal $(AI)$ and anti-ideal $(AAI)$ of the initial decision matrix are indicated in the form of the expanded decision matrix $(X^G)$ obtained by the adding of the solution.

$$X^G = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \\ AAI \\ AI \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \\ x_{aa1} & x_{aa2} & \cdots & x_{aan} \\ x_{ai1} & x_{ai2} & \cdots & x_{ain} \end{bmatrix} \tag{2}$$

In determining the $AI$ and $AAI$ values, Eq. (3) is used for the criteria that have benefits, and Eq. (4) is used for criteria that have cost characteristics.

$$In\ the\ benefit-enabled\ criteria=\begin{cases}AAI=\min\limits_{i}x_{ij}\\ AI=\max\limits_{i}x_{ij}\end{cases} \quad (3)$$

$$In\ cost-enabled\ criteria=\begin{cases}AAI=\max\limits_{i}x_{ij}\\ AI=\min\limits_{i}x_{ij}\end{cases} \quad (4)$$

Step 3: Standardizing extended decision matrix

In the standardized decision matrix $(N)$, Eq. (5) is employed for cost criteria, and Eq. (6) is used for beneficial criteria.

$$n_{ij}=\frac{x_{ai}}{x_{ij}} \quad (5)$$

$$n_{ij}=\frac{x_{ij}}{x_{ai}} \quad (6)$$

Step 4: Obtaining a weighted standardized matrix

As a result of the criterion weights of the elements of the standardized decision matrix ($\omega_j$), the weighted standardized decision matrix ($V$) elements are obtained via Eq. (7).

$$v_{ij}=n_{ij}.\omega_j \quad (7)$$

Step 5: Calculation of benefits of alternatives

According to the anti-ideal and ideal solution, the benefit ratings of alternatives are found using Eqs. (8) and (9), respectively.

$$K_i^-=\frac{S_i}{S_{aai}} \quad (8)$$

$$K_i^+=\frac{S_i}{S_{ai}} \quad (9)$$

The $S_i$ value used in equations indicates the sum of the weighted normalized decision matrix elements and is found using Eq. (10).

$$S_i=\sum_{i=1}^{n}v_{ij} \quad (10)$$

Step 6: Calculation of benefit functions of alternatives

The benefit function refers to the reconciled solution of the relevant alternative within the ideal and anti-ideal solution and is found by Eq. (11). The final benefit function sorts alternatives. The alternative with the highest final benefit function is determined as the best.

$$f(K_i)=\frac{K_i^++K_i^-}{1+\frac{1-f(K_i^+)}{f(K_i^+)}+\frac{1-f(K_i^-)}{f(K_i^-)}} \quad (11)$$

$f(K_i^-)$ anti-ideal solution according to the ideal solution, $f(K_i^+)$ means the benefit function according to the ideal solution and is found to be used by Eqs. (12) and (13), respectively.

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad (12)$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \quad (13)$$

Step 7: Ranking of Alternatives

Decision alternatives are ranked in descending order according to the calculated utility function values. This ranking is the result of comparing the values obtained by each alternative. The alternative with the highest value is characterized as the alternative with the highest preferability value, which allows decision makers to determine the preferred alternative. On the other hand, the alternative with the smallest value is identified as the alternative with the lowest preferability value. This approach allows for a clear identification of the best and worst alternatives in the decision-making process, allowing decision makers to participate in a more informed choice process.

### *1.2. Evolution of MARCOS Method*

MARCOS method, developed in 2020 by Stević *et al.,* [25], is one of the most recent approaches introduced to the MCDM literature. It has undergone various extensions using fuzzy theories, gray theories, D numbers, Z numbers. A literature review focusing on the evolution of the method and how it has developed is given in Table 2.

**Table 2**
Extended versions of MARCOS method

| Extended version of the MARCOS method | Reference |
|---|---|
| Trapezoidal interval type-2 fuzzy MARCOS method | Xu *et al.,* [18] |
| Fuzzy MARCOS method | Stanković *et al.*, [24] |
| Grey MARCOS method | Badi and Pamucar [27] |
| D- MARCOS method | Chattopadhyay *et al.,* [28] |
| Picture fuzzy MARCOS method | Simić *et al.*, [29] |
| Single-Valued Neutrosophic fuzzy MACROS Method | Tang *et al.*,[30] |
| Interval type-2 fuzzy MARCOS method | Boral *et al.,* [31] |
| Spherical fuzzy MARCOS method | Ali [32] |
| Interval rough Dombi MARCOS method | Iordache *et al.,* [33] |
| Interval-Valued Intuitionistic Fuzzy MARCOS method | Salimian *et al.,* [34] |
| q-rung orthopair fuzzy MARCOS method | Ali [35] |
| Fermatean fuzzy MARCOS method | Wang *et al.,* [36] |
| Hesitant fuzzy MARCOS method | Liu *et al.,* [37] |
| Z- MARCOS method | Jiskani *et al.,* [38] |
| Pythagorean Fuzzy MARCOS method | Chaurasiya and Jain [39] |
| Rough fuzzy MARCOS method | Du *et al.,* [40] |

These extensions have contributed to enhance the effectiveness, flexibility, and comprehensiveness of MARCOS method and allow the method to be successfully applied in different fields of varying complexity.

### *1.3. Application Areas of MARCOS Method*

Case studies evaluating the application of MARCOS method in various sectors reveal prominent success stories and real-world application scenarios. The number of studies examining how the MARCOS method has been effectively used in complex decision-making processes in different fields is given in Figure 1.

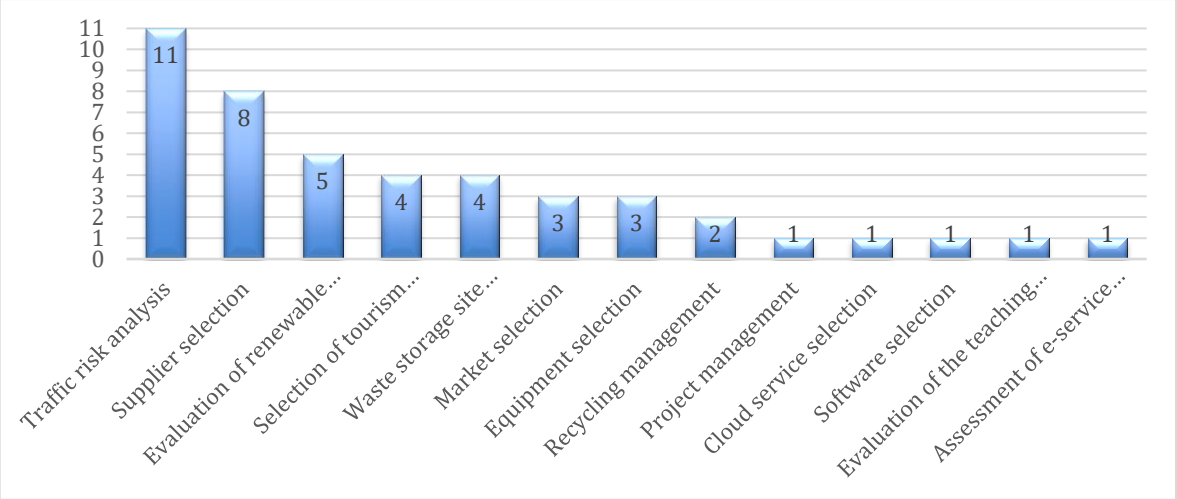


**Fig. 1.** Topics studied with the MARCOS method

MARCOS method has been applied in 11 papers for solving problems in traffic risk analysis. These applications show how MARCOS method can be used as an effective tool in various decision-making processes in the field of traffic safety. Then, MARCOS method was applied to solve problems in 8 papers on supplier selection and 5 papers on renewable energy sources. These applications highlight how MARCOS method can be successfully applied to problems of varying complexity in different industries, especially in areas such as traffic safety, supply chain management and the energy sector.

### *1.4. Methods Used in Combination with MARCOS Method*

"Step 4" of MARCOS method uses various weighting methods to determine the weighting coefficient. These methods not only calculate the weight vector of the criteria but also contribute to obtain integrated ranking results. Figure 2 shows the frequency of various MCDM weighting methods used to calculate the weight coefficient of MARCOS method in different problems.

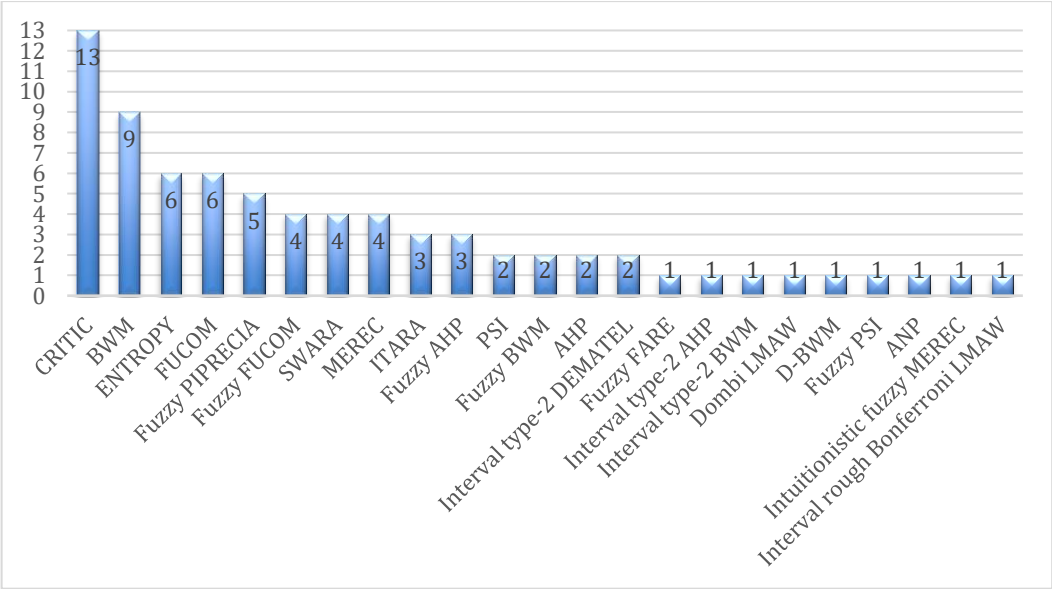


**Fig. 2.** Preferred methods for calculating the weight coefficients of the MARCOS method

CRITIC weighting method is frequently applied together with MARCOS method in 13 papers. In addition, BWM method, ENTROPY and FUCOM methods stand out as the preferred methods to calculate the weights of MARCOS method in 9 papers and 6 papers, respectively. These preferences indicate that various weighting methods are used for the effective application of MARCOS method in MCDM processes.

### *1.5. Research gaps and research questions*

A comprehensive review of existing academic work in the field of MCDM reveals two critical research gaps for MARCOS method.

viii. Bibliometric analysis for MARCOS, one of the MCDM methods, has not been done before.
ix. The need for a widely accepted model that enables the evaluation of research using MCDM methods.

This study is the first of its kind bibliometric research evaluating the MARCOS method. The main objective of this study is to solve the accompanying questions:

i. What is the growth trend and citation status of papers related to MARCOS method?
x. Who are the most cited leading authors in the field?
xi. Which are the most cited documents, journals, organizations and countries?
xii. Which are the most cited documents, journals, organizations and countries?
xiii. What are the main research points and thematic research in MARCOS applications?
xiv. Which publication is the most cited?
xv. Which MCDM methods are most commonly integrated with MARCOS method?
xvi. What are the evolution and improved versions of MARCOS method?

By revealing the conceptual richness of MARCOS studies, this study can help MCDM researchers understand current and future research trends and thus design more innovative and creative research.

The study is organized as follows. Section 2 introduces the research methodology. Section 3 discusses and analyzes the research results, identifies and summarizes research topics and research trends related to MARCOS method. Section 4 presents the discussion, while Section 5 concludes with future research directions.

## 2. Materials and Methods

### *2.1. Search Strategy*

Literature on "Measurement of Alternatives and Ranking according to COmpromise Solution Method" or "MARCOS method" was searched in Scopus. The publication period of the literatures is limited to 2020. In the end, 146 types of literature were found.

### *2.2. Inclusion and Exclusion Criteria*

Relevant literature on MARCOS method published in different academic journals was included. The language of the papers was English, the type of literature was limited to "paper", and there was no restriction on the types included in the study. Letters, conference abstracts, editorials, theses, dissertations, biographies, book reviews, conference presentations, news reports, duplicate publications, publications withdrawn by the authors, etc. were excluded, and literature on topics not related to MCDM was also excluded.

### *2.3. Literature Review Process*

Based on the screening results and inclusion and exclusion criteria, the literature was screened, resulting in the inclusion of 115 papers. The specific screening process is shown in Figure 3.

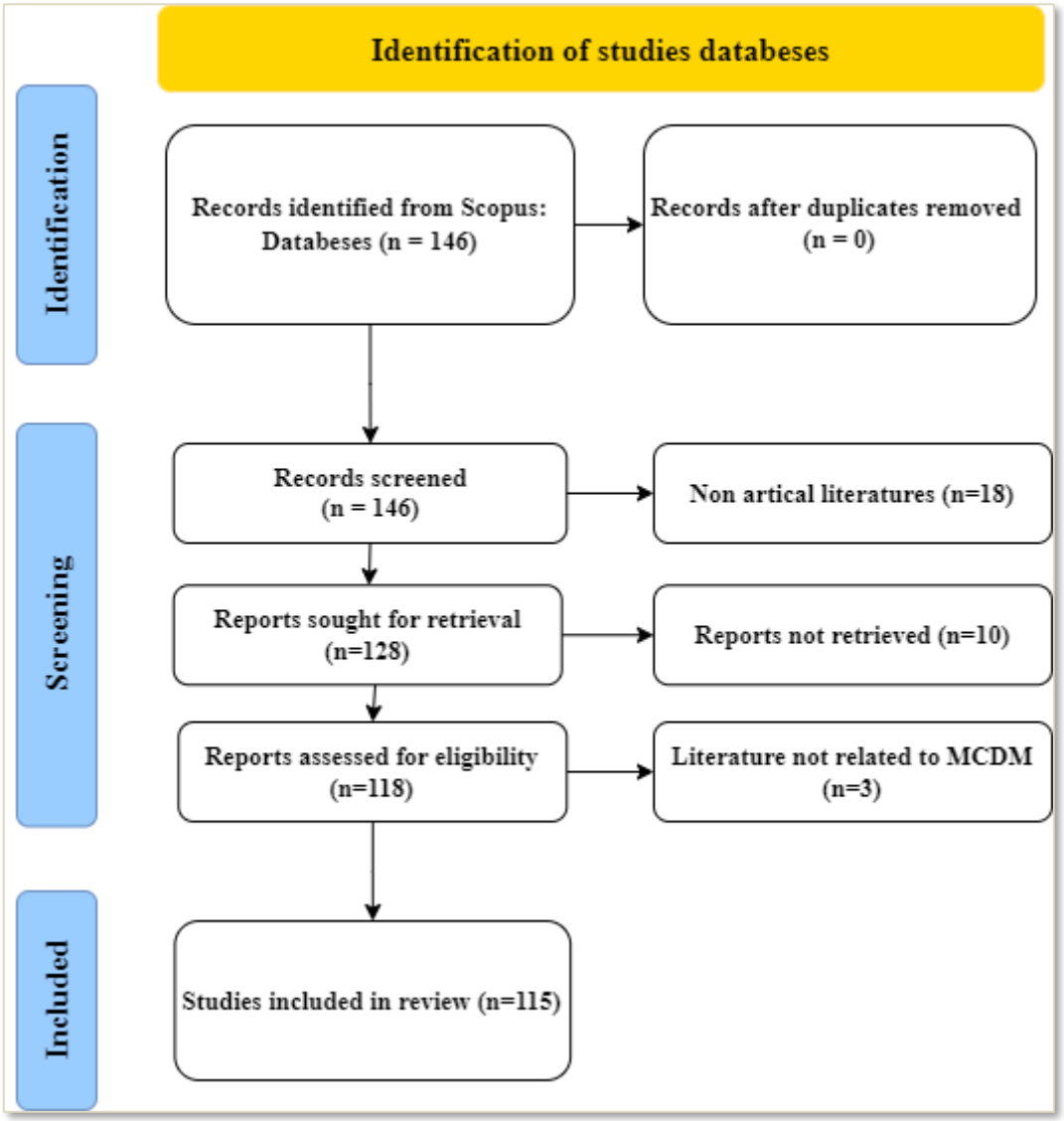


**Fig. 3.** Data collection PRISMA flow diagram of the MARCOS method

The identification, screening and inclusion criteria were the three stages of the data search followed in Figure 3. In the first stage, 146 records were screened. Of the screened records, 31 were deleted in the second step. In the final stage, 115 studies were included in the review.

### *2.4. Bibliometric Analysis Software*

In the study, R software was used to perform bibliometric analysis of papers related to MARCOS method in the Scopus database. This software is an application designed for bibliometric analysis that does not require any code and whose interface works on the internet [41]. VOSviewer software was also used for keyword network mapping [42]. The study presented a conceptual framework of papers published on MARCOS and identified the most influential papers and prolific authors in the field. The study findings can help MCDM researchers understand current and future research trends. A

comprehensive bibliometric analysis was performed on MARCOS papers listed in the Scopus database using quantitative techniques such as Bibliometrix, Biblioshiny, R package with a web-based interface, VOSviewer.

## 3. Bibliometric analysis results of MARCOS method

### *3.1. Performance Analysis*

The study includes examining the annual publication growth rate of publications, determining the most published author and cited journal, as well as the most published and cited organization and document. The study also identifies the authors and countries with the highest productivity in terms of the number of publications and citations, and evaluates the performance analysis of the data with keyword analysis.

#### *3.1.1. Publication trends*

Figure 4 shows the growth in documents over time in the bibliometric analysis of MCDM studies using MARCOS method.

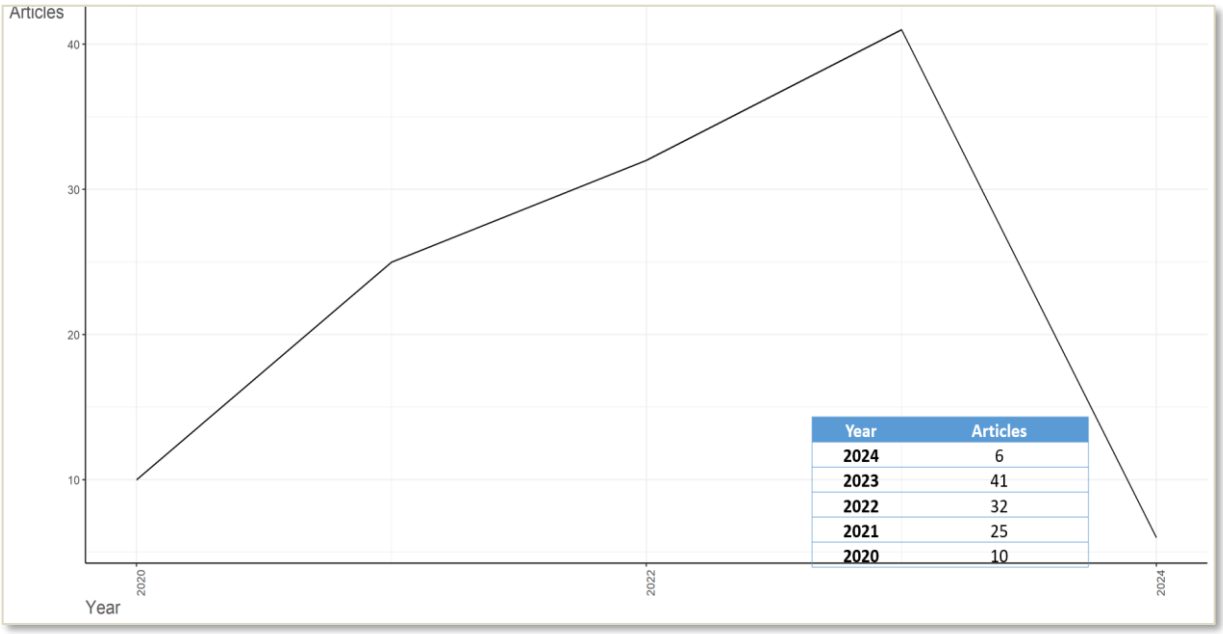


**Fig. 4.** Distribution of MARCOS studies used in the researches according to years

According to Figure 4, there is a growing interest among scientists worldwide for analyses with MARCOS method. The number of publications has increased over time, with 6 publications in 2024, 41 in 2023, 32 in 2022, 25 in 2021 and 10 in 2020. In particular, 2023 was the year with the highest increase in MCDM research on analyses with the MARCOS method.

#### *3.1.2. Country or area analysis*

The world density map for the studies conducted with MARCOS method is shown in Figure 5.

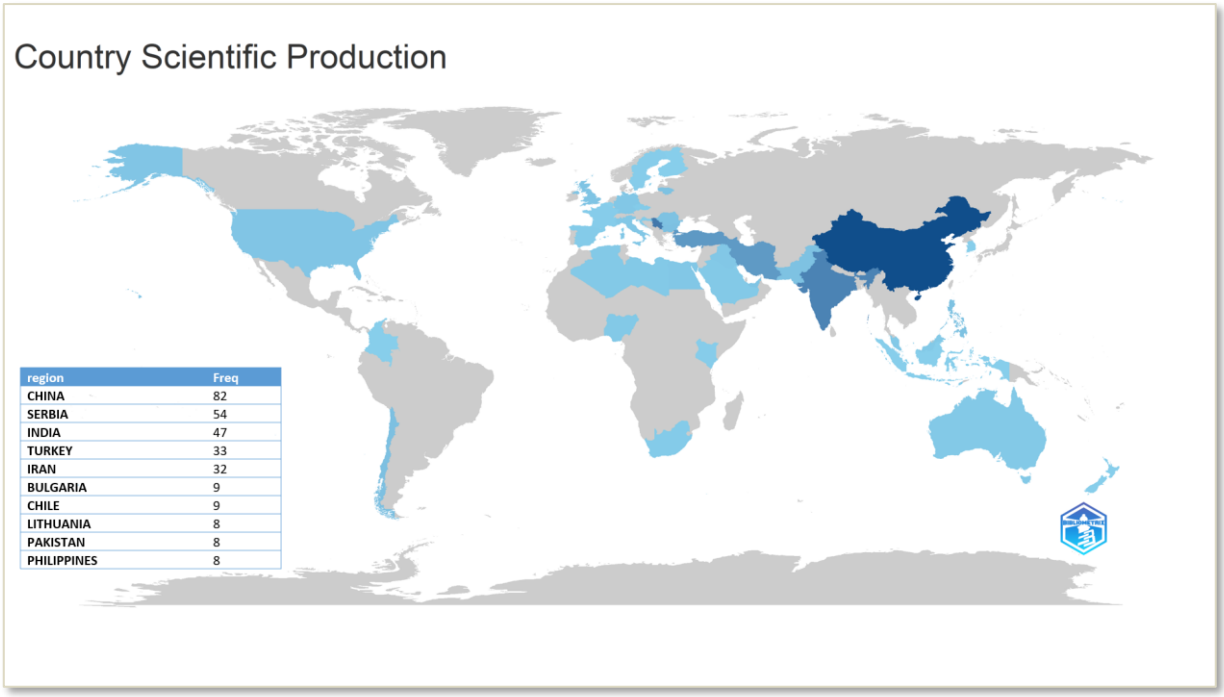


**Fig.5.** Country scientific production

In the map, dark blue, blue and grey colours indicate the country with the most broadcasting, the country with less broadcasting and the country with no broadcasting respectively. According to the table in Figure 5, it shows the 10 most efficient countries broadcasting with the MARCOS method. According to the table, the most efficient country is China (82). China is followed by Serbia (54), India (47) and Turkey (33). The co-operation map of the countries that use the largest number of documents in co-operation is shown in Figure 6.

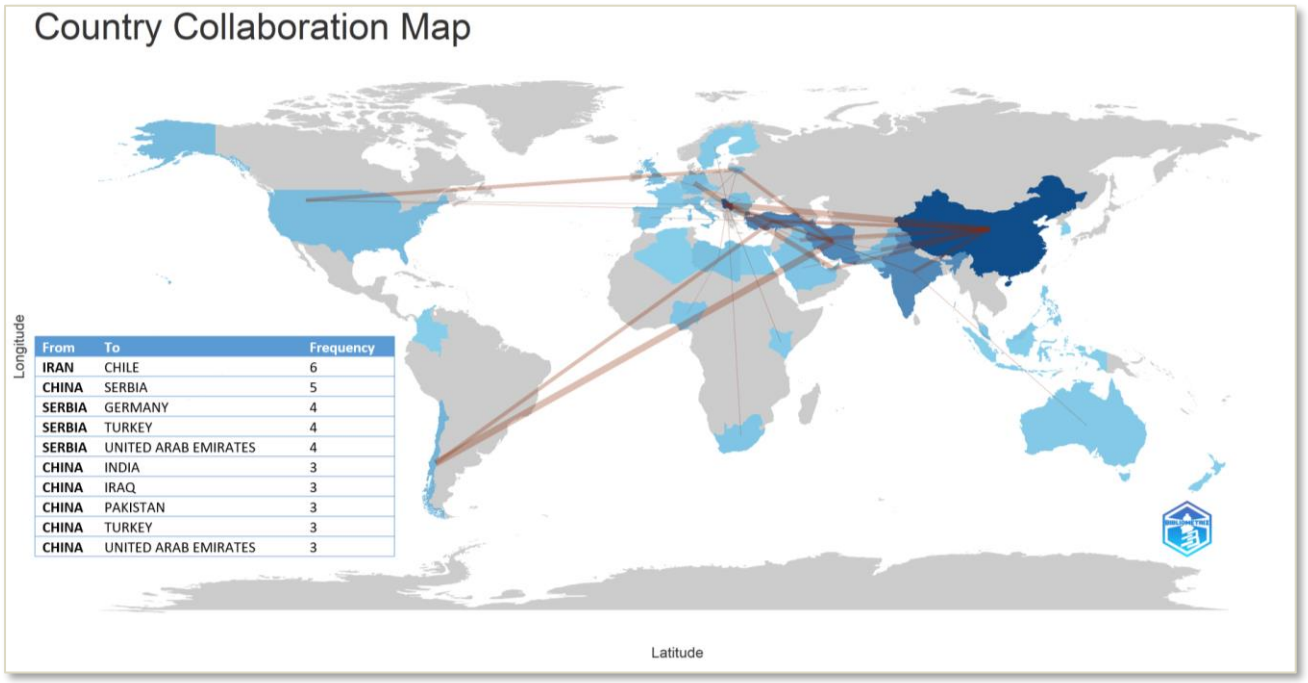


**Fig. 6.** Country collaboration map

Countries with high linkages are defined as countries that cooperate with others the most. In the studies using MARCOS method, it is seen that China co-operates with Serbia, India, Iraq, Pakistan, Turkey, and the United Arab Emirates. Serbia is in co-operation with Germany, Turkey, and the United Arab Emirates. It can be said that China is the country with the most cooperation.

### *3.1.3. Institutional analysis*

The publication outputs of the institutions or affiliates of the authors who contributed to the research based on MARCOS method are given in Table 3.

**Table 3**
Relevant organizations that have contributed to research with the MARCOS method

| Affiliation | No. of papers |
|---|---|
| University of East Sarajevo | 36 |
| University of Belgrade | 17 |
| Shanxi University | 12 |
| University of Novi Sad | 10 |
| Cebu Technological University | 9 |
| Hanoi University of Industry | 8 |
| Southeast University | 7 |
| University of Defence in Belgrade | 7 |
| National Institute of Technology | 6 |
| Shanghai University | 6 |

Between 2020 and 2024, “University of East Sarajevo” ranks first with 36 publications, “University of Belgrade” ranks second with 17 publications and “Shanxi University” ranks third with 12 publications.

### *3.1.4. Author analysis*

A total of 115 research papers on the MARCOS method have appeared in different publications, written by a total of 330 people. Table 4 highlights the most relevant authors in terms of citations received and various publications worldwide.

**Table 4**
The most relevant authors

| Author | No. of papers | Total citations |
|---|---|---|
| Stević Ž. | 15 | 819 |
| Puška A. | 9 | 743 |
| Pamucar D. | 6 | 783 |
| Subotić M. | 6 | 255 |
| Tanackov I. | 5 | 82 |
| Badi I. | 4 | 141 |
| Deveci M. | 4 | 68 |
| Fan J. | 4 | 12 |
| Krstić M. | 4 | 37 |
| Mardani A. | 4 | 108 |

In terms of the number of publications, Stević Ž (Stević Željko) ranks first with 15 papers, Puška A (Puška Adis) ranks second with 9 papers Pamucar D (Pamucar Dragan) and Subotić M (Subotić Marko) ranks third with 6 papers. Stević Ž (Stević Željko) ranks first with 819 citations, Pamucar D (Pamucar Dragan) ranks second with 843 citations, and Puška A (Puška Adis) ranks third with 743 citations.

### *3.1.5. Journal analysis*

The ranking of the sources of the publications made with MARCOS according to the number of publications is given in Table 5.

**Table 5**
The most published and cited journals for the MARCOS method

| Source | Total citation | No. of publications |
|---|---|---|
| Mathematics | 88 | 8 |
| Sustainability (Switzerland) | 104 | 8 |
| Engineering Applications of Artificial Intelligence | 7 | 5 |
| Journal of Intelligent and Fuzzy Systems | 6 | 5 |
| Decision Making: Applications in Management and Engineering | 57 | 4 |
| Expert Systems with Applications | 75 | 4 |
| Facta Universitatis, Series: Mechanical Engineering | 24 | 4 |
| Operational Research in Engineering Sciences: Theory and Applications | 52 | 4 |
| Journal of Cleaner Production | 57 | 3 |
| Information Sciences | 17 | 2 |

According to Table 5, Sustainability (Switzerland) ranks first with 104 citations. Mathematics ranks second with 88 citations and Expert Systems with Applications ranks third with 75 citations. Mathematics and Sustainability (Switzerland) rank first with 8 papers, Engineering Applications of Artificial Intelligence and Journal of Intelligent and Fuzzy Systems rank second with 5 papers.

### *3.1.6. Analysis of references*

The most productive paper is the one with the highest cumulative number of citations. Accordingly, the ten most productive papers are presented in Table 6.

**Table 6**
The most efficient documents

| Document with reference | Total citations |
|---|---|
| Stević *et al.,* [25] | 586 |
| Stanković *et al.,* [24] | 174 |
| Bakır and Atalık [43] | 114 |
| Torkayesh [44] | 107 |
| Badi and Pamucar [27] | 103 |
| Chattopadhyay *et al.,* 28] | 80 |
| Puška *et al.,* [26] | 56 |
| Ulutaş *et al.,* [45] | 52 |
| Sımıć *et al.,* [46] | 51 |
| Gong *et al.,* [47] | 41 |

The paper titled "Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS)" by Stević *et al.,* [25] published in Computers & Industrial Engineering ranks first with 586 citations. This paper is followed by the paper titled "A New Fuzzy MARCOS Method for Road Traffic Risk Analysis" published in Mathematics by Stanković *et al.,* [24] with 174 citations. The paper titled "Application of Fuzzy AHP and Fuzzy MARCOS Approach for the Evaluation of e-Service Quality in the Airline Industry" published in Decision Making: Applications in Management and Engineering by Bakır and Atalık [43] with 114 citations.

### *3.1.7. Keyword analysis*

A keyword is a description of the paper as a word or phrase. The widespread use of any term depends on the presence of the keyword in the paper. VOSviewer was used to reveal the joint effects

of working with keywords and the research knowledge base. Based on the indexed keywords of the paper, 394 keywords were discovered. 24 keywords were considered for analysis by setting the threshold to 3 in VOSviewer software, as shown in Figure 7.

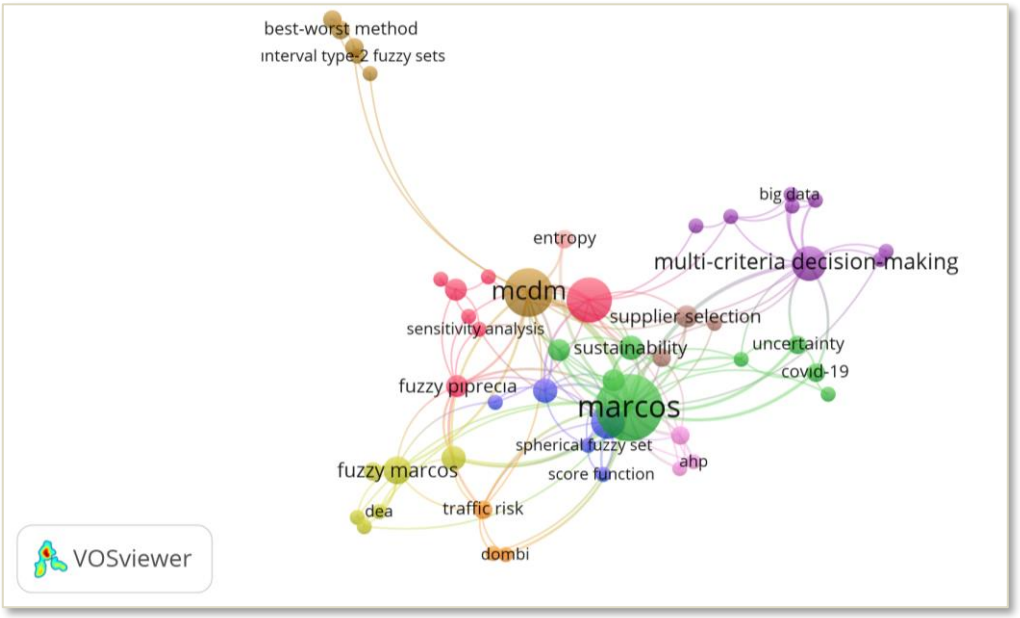


**Fig. 7.** Co-occurrence keywords

A different set of keywords is created with each color. In Figure 7, each circle indicates the presence of a particular keyword and the sub-domain of MARCOS method network theme. A circle with a similar color represents the distribution in a comparison region. The largest cluster by number of elements is named "MARCOS". This cluster contains keywords such as "big data, blockchain, digital transformation". The second largest cluster is named "MCDM". It contains keywords such as "BWM, interval type-2 fuzzy set, it2f-marcos". The third largest cluster is named "MARCOS method". It contains keywords such as "fuzzy PIPRECIA, fuzzy FUCOM, sensitivity analysis".

With the VOSviewer software, the keywords "Overlay visualization" were colored differently according to the year of publication and the time intervals in which they appeared in the literature were determined. In our case, the average (yellow) publication year for newly introduced terms is 2023. The colors of the items were determined by the time elapsed since their publication. The time period from 2021 to 2023 (Blue-Green-Yellow Color) is shown in Figure 8.

While previously used keywords such as "big data, DEA, traffic risk" are keywords that have been intensively studied in the 2021-2022 period, it can be said that keywords such as "MEREC, BWM, healthcare waste" have also been used in the literature recently.

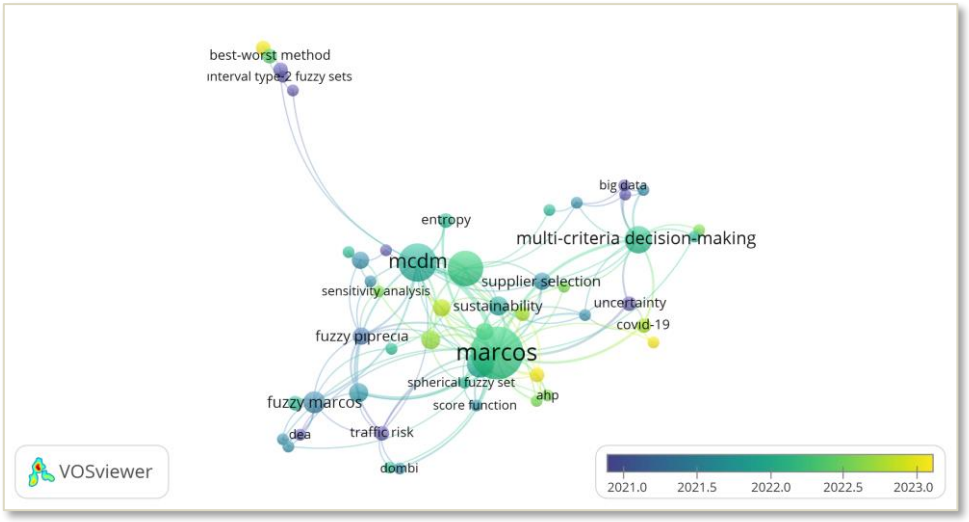


**Fig. 8.** Keyword timeline

### *3.2. Scientific Mapping Analysis*

Scientific mapping is the application of computational techniques as a whole to visualize, analyze and model various scientific and technical activities [3,4].

#### *3.2.1. Three field plot*

The use of "three field plots" can often be a preferred visualization method during a literature review to show relationships between topics, keywords or papers. This is used to visually compare or analyze data representing different areas of research. In this so-called "Sankey diagram", the three parameters to be associated (keyword, author name and country) are set in the program and the leading ones for each parameter are given in Figure 9.

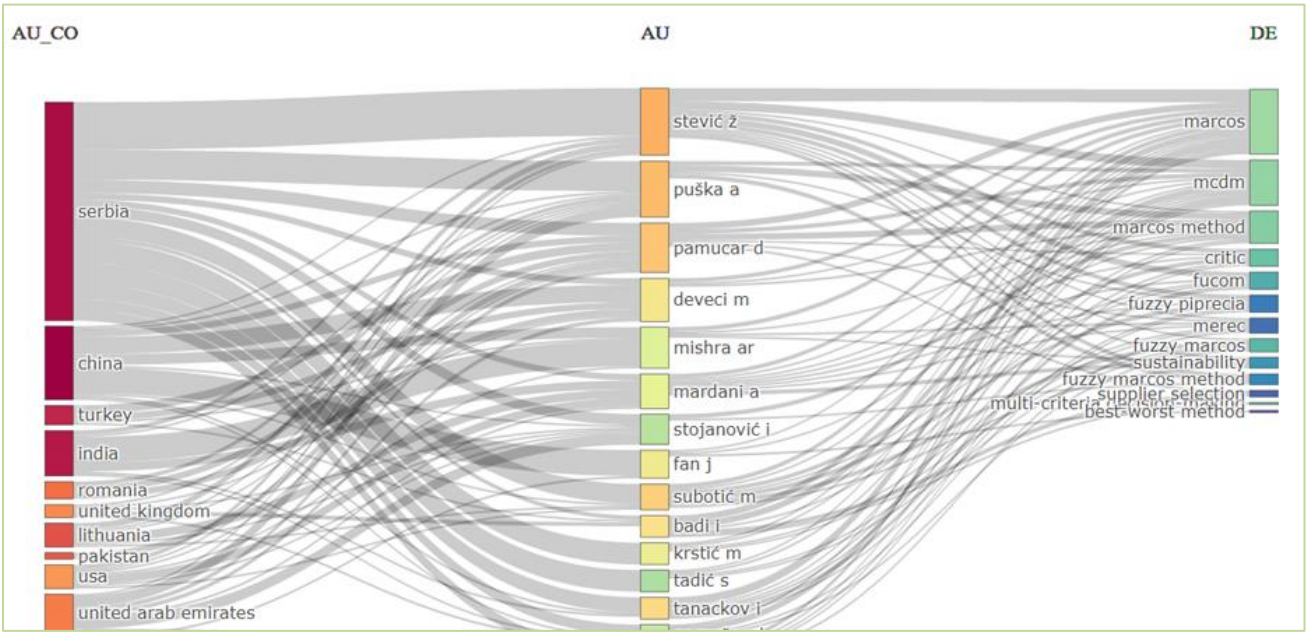


**Fig. 9.** Three field plot

The size of the boxes in Figure 9 shows the magnitude of the relationship between the parameters. In this diagram, the size of the boxes refers to influential parameters in the literature. The leading country is "Serbia", the lead author is "Stević Ž" and the most used keyword is "MARCOS".

### *3.2.2. Factor analysis*

Factor analysis is a statistical technique within such tools and is often used to reduce complexity and reveal hidden structures in multivariate data sets. It is a method used to understand the relationships between variables in a data set and to make the data set more understandable and manageable. This analysis is usually expressed in coefficients called factor loadings. These loadings indicate which factors the variables are related to or which factors explain the commonality between certain variables. The factor analysis of the keywords is given in Figure 10.

Upon conducting factor analysis on the keywords pertaining to MARCOS method in various papers, it becomes evident that keywords like "fuzzy MARCOS," "fuzzy PIPRECIA," "MARCOS," "CRITIC," "score function," "spherical fuzzy set," "machine learning," "supply chain management," and "sustainable development" are prominently grouped together in the red cluster due to their high factor loads. Additionally, within this cluster, other keywords including "FUCOM," "traffic risk," "sensitivity analysis," "fuzzy AHP," "healthcare waste," "SWARA," "site selection," "entropy," "BWM," and "MEREC" are represented by dots on the graph. Meanwhile, keywords such as "COVID-19," "supply chain," and "multi-criteria decision-making" form the blue cluster, while "blockchain" and "digital transformation" are grouped in the purple cluster. The keywords "IMF SWARA" and "DEA" are found within the orange cluster, while "big data" stands alone in the green cluster.

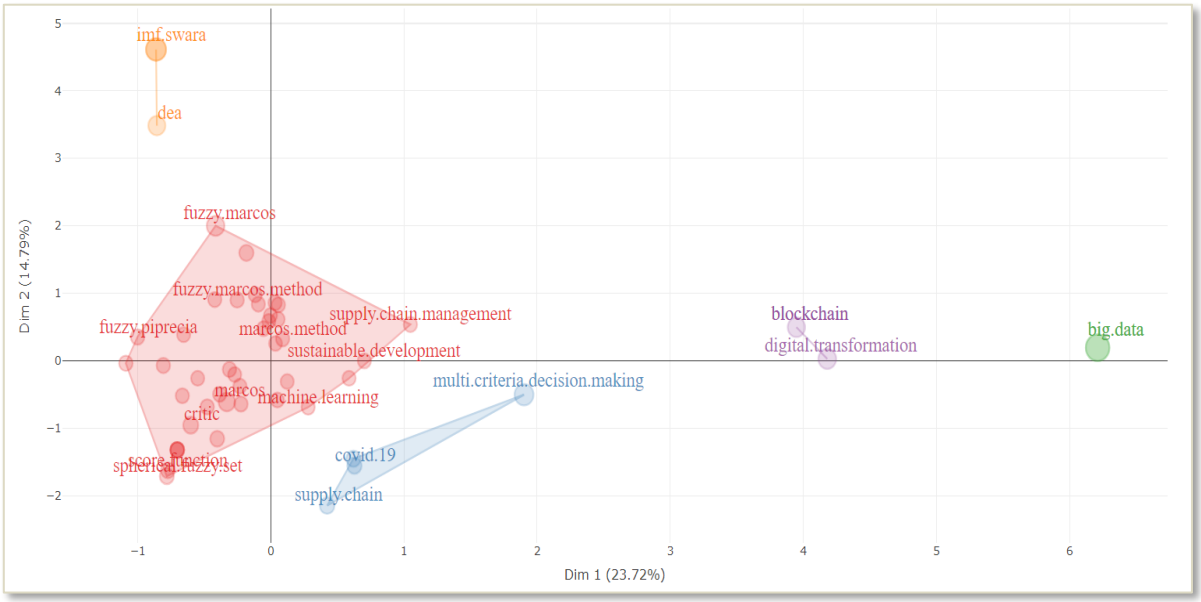


**Fig. 10.** Factor analysis of author-keywords

### *3.2.3. Topic dendrogram*

Dendrograms are tree-like graphs showing the structural relationships obtained as a result of hierarchical cluster analysis. "Topic dendrograms" are used especially in bibliometric analyses to understand which topics the papers are closely related or similar to. A topic dendrogram is given in Figure 11 to show the hierarchical relationship between keywords.

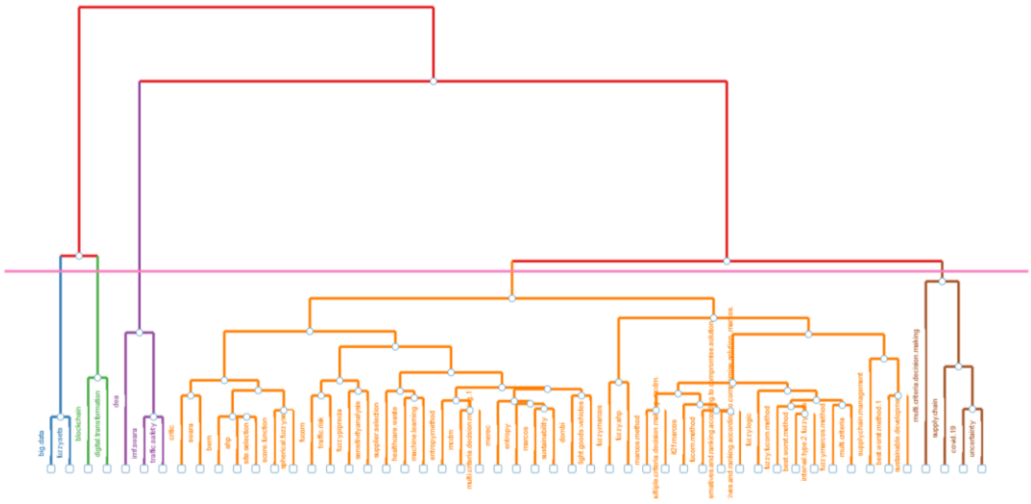

**Fig. 11.** Topic dendrogram of keywords

Below the horizontal pink line along the topic dendrogram in Figure 11, the keywords are divided into 4 clusters (blue, green, purple, and orange). These clusters describe how the topics are related to each other. In the blue cluster, the related topics are “big data-fuzzy sets”. In the green cluster, which intersects the central cluster at this level, the relevant topics are “blockchain-digital transformation”. In the purple cluster, also intersecting the central cluster at this level, the related topics are “DEA-IMF SWARA-traffic safety”. In the orange cluster, which intersects the central cluster at this level, the related topics are “CRITIC-SWARA” and “BWM-AHP-site selection”. In the brown cluster, intersecting the central cluster, the related topics are “multi-criteria decision-making-supply chain-covid 19-uncertainty”.

### *3.2.4. Thematic Map*

A "thematic map" is a graph created to visually represent the relationships between words, topics or keywords used in the research literature. In order to identify the main review topics of the field, a thematic review of papers related to MARCOS method was conducted using author's keywords. Figure 12 shows that the related studies are grouped under four themes, albeit with different intensities.

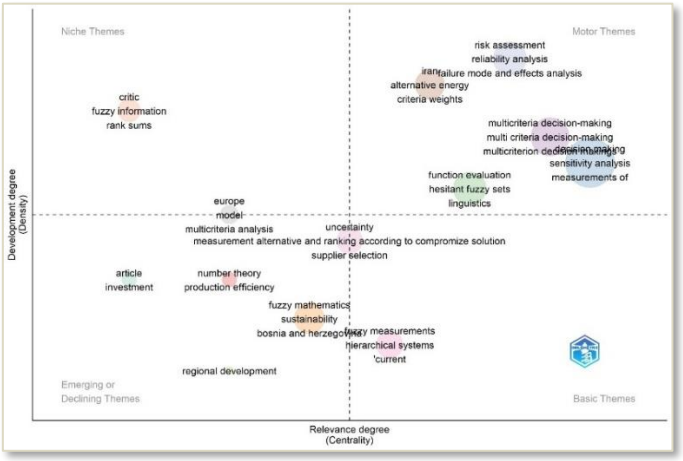


**Fig. 12.** Thematic map based on keywords

Considering author's keywords, "risk assessment", "reliability analysis", "hesitant fuzzy set" keywords are at the forefront of scientific studies.

### *3.2.5. Trend topics*

The topics trending in the literature of MARCOS method by years from 2020 to 2024 are given in Table 7.

**Table 7**
Trending Topics by Year

| Item | freq | year_q1 | year_med | year_q3 |
|---|---|---|---|---|
| Decision making | 52 | 2021 | 2022 | 2023 |
| Sensitivity analysis | 23 | 2021 | 2022 | 2022 |
| Measurements of | 22 | 2022 | 2022 | 2023 |
| Fuzzy sets | 18 | 2022 | 2023 | 2023 |
| Measurement of alternative and ranking according to compromize solution | 9 | 2022 | 2023 | 2024 |
| Multicriteria decision-making | 9 | 2022 | 2023 | 2023 |
| Bosnia and Herzegovina | 5 | 2020 | 2021 | 2021 |
| Health care | 5 | 2021 | 2021 | 2022 |
| Reliability analysis | 5 | 2021 | 2021 | 2021 |

The top trending topic in the first quarter of 2021, the second quarter of 2022 and the third quarter of 2023 was "decision making". The keyword "sensitivity analysis" was the trending topic in the first quarter of 2021, the second quarter of 2022 and the third quarter of 2022. Currently, "measurement of alternative and ranking according to to compromize solution" is the most trending topic in this area.

### *3.2.6. TreeMap*

A treemap is a type of chart used to visualize hierarchical data structures. Data is represented using areas of rectangles. These rectangles represent categories or subcategories in the hierarchical structure. Large rectangles usually represent broader categories, while small rectangles represent subcategories or subdivisions. Colors and the size of the rectangles can be used to indicate the value or size of each category or subcategory. The TreeMap showing the frequency of use of keywords is given in Figure 13.

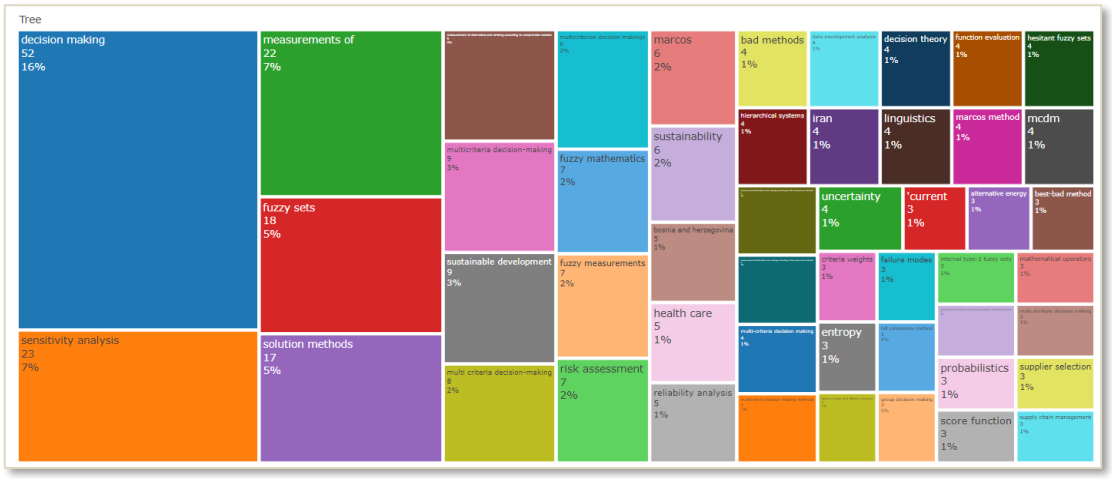


**Fig. 13.** Keywords of TreeMap

The keyword "decision making" has the highest usage rate, as shown by the blue rectangle in Figure 13, accounting for 16% of the total keywords. Additionally, "sensitivity analysis" has a good usage rate of 7%.

## 4. Discussions

The growth in scientific output on topics related to MCDM is occurring at a tremendous pace. There are relatively few studies analyzing bibliometric data of research papers in different fields. In this context, a search of the Scopus database yielded 115 English-language papers produced using MARCOS method within the time frame specified at the outset. This data is an important source to understand the growing interest in MCDM research and the place of MARCOS method in the literature.

This study is the first bibliometric analysis using MARCOS method and aims to assess the scientific productivity that has evolved around this method. In this context, a review was carried out to identify the most prolific authors, reference works, organizations, countries and academic disciplines. Thanks to the majority of open access papers, it was observed that many authors emerged as the topic progressed and that contributions spread rapidly and widely. The review reveals that China, Serbia and India are the countries that produce the most academic work in this field, results that are in line with previous research. The most productive document was the study published in Computers & Industrial Engineering by Stević *et al.,* [25] under the title "Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS)". In addition, it was determined that the most cited journal was "Sustainability (Switzerland)". According to the results of the research, the institution or the organization to which the authors are affiliated that has the most studies in this field is "University of East Sarajevo", and "Stević Ž." stands out as the author who has published the most publications and at the same time the most cited author. This information provides an important source for understanding the global distribution and important stakeholders of the studies conducted within the framework of the MARCOS method.

According to the results of the study, the keywords "MARCOS", "MARCOS method" and "MCDM" are among the top three most frequently used clusters. For information on the top three clusters by number of components; Cluster 1 consists of keywords such as big data, blockchain, digital transformation. Cluster 2 includes keywords such as BWM, interval type-2 fuzzy set, it2f-marcos. Cluster 3 consists of keywords such as fuzzy PIPRECIA, fuzzy FUCOM, sensitivity analysis. These results identify the groupings of keywords that are prominent in the literature around the MARCOS method and reflect the different focal points in this topic.

This study uses scientific maps to provide a detailed overview of the main trends and results in research linked to the MARCOS method, using conceptual structures that identify the main themes, topics and intellectual constructs that classify the impact of an author's work. According to the results of the factor analysis, the keywords of the papers related to the MARCOS method form two separate clusters in terms of factor loadings. In the first cluster, keywords with high factor loadings include terms such as "IMF SWARA", "DEA", "FUZZY MARCOS", "BWM", "FUZZY PIPRECIA". The other cluster includes keywords such as "blockchain", "big data" and "digital transformation". While "big data" and "fuzzy set" and "blockchain" and "digital transformation" are related to each other, keywords such as "DEA", "IMF SWARA" and "traffic safety" stand out as related topics. Keywords such as risk assessment, reliability analysis, hesitant fuzzy set still have an important place in the literature on the MARCOS method. In the first quarter of 2021, the second quarter of 2022 and the third quarter of 2023, the most trending topic was "decision making". The keyword "sensitivity analysis" was the

trending topic in the first quarter of 2021, the second quarter of 2022 and the third quarter of 2022. Currently, "measurement of alternative and ranking according to to compromize solution" is the top trending topic in this area.

This study is the first bibliometric analysis of the literature on MARCOS method published between 2020 and 2024. This analysis focuses on publications indexed in the Scopus database related to MARCOS method used in MCDM studies. As a review of the literature during this period, the study aims to understand the scientific productivity, keywords, publication trends, and important factors related to MARCOS method.

## 5. Conclusions

This study investigated and assessed worldwide scientific achievements in MARCOS method research using data from the Scopus database. The current top researchers were identified and regional distributions and publications were mapped. China was identified as the most productive country in terms of the number of papers. "Stević Ž." was identified as the most prolific author in the bibliometric review of MARCOS method used in MCDM publications. The most cited journal for MARCOS related publications is "Sustainability (Switzerland)". “MARCOS”, “MARCOS method” and “MCDM” are the most important keywords used by the authors. Furthermore, CRITIC is a weighting model that is often integrated with the MARCOS method.

By summarizing research with MARCOS method in depth, we hope that the findings will provide guidance for additional research directions and perspectives in the rapidly expanding field of MCDM. Administrative implications for future work can be listed as follows:

i. This research provides valuable data on the evaluation of MARCOS method in relation to the most influential sources, most influential authors, most influential links, most influential countries and most influential studies in the existing literature. This provides researchers and practitioners with guidance on which papers they should reference, which papers are most relevant, and which papers have had the most impact on MARCOS method.
ii. This bibliometric review of MARCOS method in studies in the field of MCDM can help to provide a comprehensive overview of past and current research and identify future research directions for MARCOS method. This can guide researchers to understand and further contribute to the existing knowledge in this field.
iii. The findings of the study reflect the state of research on MARCOS method. Moreover, as a reference point, this study provides researchers with a comprehensive understanding of the MARCOS method. This allows researchers to study the topic in more depth.
iv. By making use of the analysis of citations and co-citations, researchers can identify the different research streams or fields that make up their intellectual structure, allowing them to identify themes and insights. This in turn can guide how researchers can relate their work to existing literature.
v. Depending on the research area, it is possible to identify gaps in the literature and potential research directions. This provides researchers with up-to-date information on MARCOS method and its variants.
vi. As a paradigm, this research can provide with valuable insights to study MARCOS method in the field of MCDM and at the same time highlight areas of research that require further attention to provide theoretical and practical implications.

While the Scopus database was the main focus of this study, other sources such as Dimensions, Web of Science, Cochrane Library and PubMed were also considered. A potential next step is to

design and build graphical tools that offer more data and cover a wider area. This would broaden the scope of the research and provide a more comprehensive assessment.

## Author Contributions

Conceptualization, G.D. and P.C.; Methodology, P.C. and D.P; Software, G.D., P.C., S.K., and D.P; Formal analysis, G.D. and P.C; Writing- original draft preparation - G.D., P.C., A.A., S.K., and D.P, Writing- review and editing - G.D., P.C., A.A., S.K., and D.P. All authors have read and agreed to the published version of the manuscript.

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## Data availability statement

The datasets used for the current study can be obtained from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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