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Review

A Systematic Review of the Applications of Multi-Criteria Decision Aid Methods (1977–2022)

Marcio Pereira Basílio [1,2,*], Valdecy Pereira [2], Helder Gomes Costa [2], Marcos Santos [3] and Amartya Ghosh [4]

1 Military Police of the Rio de Janeiro, Rio de Janeiro 21941-901, Brazil
2 Department of Production Engineering, Federal Fluminense University (UFF), Niteroi 24210-240, Brazil; valdecy.pereira@gmail.com (V.P.); heldergc@id.uff.br (H.G.C.)
3 Military Institute of Engineering (IME), Rio de Janeiro 21941-901, Brazil; marcosdossantos_doutorado_uff@yahoo.com.br
4 Symbiosis Institute of Business Management (SIBM), Hyderabad 509217, India; amartya.ghosh@sibmhyd.edu.in
* Correspondence: marcio_basilio@id.uff.br; Tel.: +55-21996379803

Abstract: Multicriteria methods have gained traction in academia and industry practices for effective decision-making. This systematic review investigates and presents an overview of multi-criteria approaches research conducted over forty-four years. The Web of Science (WoS) and Scopus databases were searched for papers on multi-criteria methods with titles, abstracts, keywords, and articles from January 1977 to 29 April 2022. Using the R Bibliometrix tool, the bibliographic data was evaluated. According to this bibliometric analysis, in 131 countries over the past forty-four years, 33,201 authors have written 23,494 documents on multi-criteria methods. This area's scientific output increases by 14.18 percent every year. China has the highest percentage of publications at 18.50 percent, followed by India at 10.62 percent and Iran at 7.75 percent. Islamic Azad University has the most publications with 504, followed by Vilnius Gediminas Technical University with 456 and the National Institute of Technology with 336. *Expert Systems with Applications*, *Sustainability*, and the *Journal of Cleaner Production* are the top journals, accounting for over 4.67 percent of all indexed works. In addition, E. Zavadskas and J. Wang have the most papers in the multi-criteria approaches sector. AHP, followed by TOPSIS, VIKOR, PROMETHEE, and ANP, is the most popular multi-criteria decision-making method among the ten nations with the most publications in this field. The bibliometric literature review method enables researchers to investigate the multi-criteria research area in greater depth than the conventional literature review method. It allows a vast dataset of bibliographic records to be statistically and systematically evaluated, producing insightful insights. This bibliometric study is helpful because it provides an overview of the issue of multi-criteria techniques from the past forty-four years, allowing other academics to use this research as a starting point for their studies.

Keywords: systematic review; multicriteria; MCDA; MCDM; MADM; MODM; AHP; TOPSIS; VIKOR; PROMETHEE; ANP

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1. Introduction

As the transmission of scientific knowledge in its most diverse fields of study expands, literature evaluation becomes a demanding work for the researcher [1]. The challenge is reflected in the volume of research published each month by thousands of academic publication outlets. According to [2]'s theory of limited rationality, a researcher's rationality is constrained by the knowledge available, the cognitive limitations of the individual mind, and the decision-making time availability.

Human activities require decision-making. All such decisions are based on an evaluation of individual decision options, typically based on the decision maker's preferences, experience, and other data [3]. Some decisions are simple, while others are complex [4].

According to Kahraman et al. [5] and Govindan and Jepsen [6], some decisions are relatively simple, especially if the consequences of making the wrong decision are minor, whereas others are highly complex and have significant effects. In most cases, real-life problem-solving involves several competing points of view that must be considered to reach a reasonable decision [7]. A decision can be defined formally as a choice made based on available information or a method of action aimed at solving a specific decision problem [8]. In practice, multiple-criteria decision analysis (MCDA) evaluates possible courses of action or options by selecting a preferred option or sorting the options from best to worst [9–12]. In everyday practice, the use of MCDA is critical in signaling the best rational alternative to the decision-maker so that he can allocate finite resources between competing and alternative interests. Whether in an organizational or domestic setting, the decision-maker is constantly confronted with multiple paths and limited resources. Researchers refer to multiple criteria methods in various ways. Some authors prefer the term multiple-criteria decision aid or aiding (MCDA), while others prefer to use the term multi-criteria decision-making or multiple-criteria decision-making (MCDM), multi-objective decision-making (MODM), or multi-attribute decision-making (MADM). Some authors prefer the term multiple-criteria decision aid or aiding (MCDA), while others prefer to use the term multiple-criteria decision analysis [13].

The most often used MCDA approaches, as opined by [3,14], are divided into two "schools": American and European. The American School of decision-support methods is based on a functional approach, namely the utilization of value or usability. These strategies typically do not account for data inconsistency, ambiguity, or decision-maker preferences. This collection of techniques is closely related to the operational approach based on a single synthesized criterion. MAUT, AHP, ANP, SMART, UTA, MACBETH, and TOPSIS are the critical methods used in the American School. The European School's techniques are based on a relational concept. As a result, they employ a synthesis of criteria based on outranking relations. Transgression between pairs of decision alternatives characterizes this relationship. Among the European School of decision support methods, the ELECTRE and PROMETHEE groups are the most prominent. NAIADE, ORESTE, REGIME, ARGUS, TACTIC, MELCHIOR, and PAMSSEM are other methodologies from the European MCDA sector. Many multi-criteria decision-making strategies integrate ideas from the American and European decision-making schools. EVAMIX, QUALIFLEX, PCCA, MAPPAC, PRAGMA, PACMAN, IDRA, COMET, and DRSA are a few examples.

Furthermore, as stated by [6,14–16], MCDA methods are used to solve decision-making problems in several areas, including the information and communication technology; business intelligence; environmental risk analysis; environmental impact assessment and environmental sciences; water-resource management; solid-waste management; remote sensing; flood-risk management; health-technology assessment; healthcare; transport; nanotechnology research; climate change; energy; international law and policy; human resources; financial management; performance and benchmarking; supplier selection; e-commerce and m-commerce; agriculture and horticulture; chemical and biochemical engineering; software evaluation; network selection; education and social policy; heating, ventilation, and air conditioning and small-scale energy management systems; and public security.

According to Sałabun et al. [3], despite the numerous MCDA approaches available, it is essential to note that no method is ideal and can be deemed acceptable for use in every decision-making context or for solving every choice problem [17]. As a result, different multi-criteria techniques may yield various choice suggestions [18]. However, if multiple multi-criteria methods produce inconsistent findings, the accuracy of each option is called into doubt [19]. In such a case, selecting a decision-support technique relevant to the given problem [20] becomes essential because only an appropriately chosen approach allows one to acquire the correct answer that reflects the decision maker's preferences [21].

Humans make decisions regularly, and decision-making is an inherent element of people's character. Some decisions are simple and have little impact on people's lives; others, on the other hand, directly impact people's lives, cities, and nations. In this regard, and given the importance of multi-criteria decision-making methods in assisting decision-makers in a variety of fields, the current study aims to answer the following research questions (RQ) and develop a reference framework on academic productivity regarding multi-criteria decision-making methods:

RQ1: Who are the most influential authors and researchers in their scientific productivity in multi-criteria decision-making methods?
RQ2:What is the annual scientific publication growth in multi-criteria decision-making methods?
RQ3: Which countries have the most significant production of articles on the multi-criteria methods of decision support?
RQ4: Which journals have the highest number of publications?
RQ5: What are the most used methods, and in which research areas?
RQ6: What are the conceptual structures of the multi-criteria decision-support methods?

Three hundred forty-two systematic literature studies on multi-criteria methods were discovered during the literature survey. The ten largest categories classified by Web of Science using multi-criteria methods were green sustainable science technology [22], energy fuels [23], environmental sciences [24], operations research and management science [25,26], computer science and artificial intelligence [27], management [28], economics [29], engineering environmental [30], computer science and interdisciplinary applications [31], and civil engineering [32].

This article is structured as follows: Section 2 briefly describes the methods and materials. Section 3 presents the preliminary bibliometric results and visualizes the collaborative relationships between countries and authors using R and the VOSviewer software. Keyword co-occurrences are analyzed, and strategic diagrams are constructed in the same section to reveal thematic trends on the multi-criteria decision support theme. The main discussions are summarized in Section 4.

2. Materials and Methods

This section presents the fundamental concepts that guided this study. The intention is not to cover all the subjects but rather to provide essential supporting information for understanding the research, the context, and the results.

The volume of academic publications is increasing at an accelerating rate. In this way, keeping up-to-date and knowing a given topic's state of the art is becoming increasingly difficult. As stated by Aria and Cuccurullo [33], the emphasis on empirical contributions has resulted in voluminous and fragmented research flows, which contributes to the heavy work of the researcher to keep up to date. Researchers affirm that literature reviews are prevalent in the state-of-the-art synthesis of various themes [33,34].

The structured literature review is a traditional way to analyze and review scientific literature. This type of review provides an in-depth analysis according to the content of the literature [35–39]. However, this method suffers from several limitations. For instance, it is very time-consuming, and the number of analyzed papers is limited. It is almost impossible to analyze hundreds of documents through the structured literature-review process. Although the authors carefully select the documents according to several criteria, it is challenging to eliminate subjective factors, and some essential studies may be omitted. With the digitization of scientific journals, the volume of published papers has increased dramatically. A bibliometric analysis effectively handles hundreds, even thousands, of documents and reviews the related literature from a macro perspective [37].

The term bibliometric refers to the quantitative study of bibliographic materials [40,41]. It can characterize the development in a research field or capture the changes in a specific journal. Various techniques have been developed to conduct bibliometric analysis, and the most-used methods are social network analysis and co-word analysis [37].

Social network analysis is based on the premise that the relationships between units can be interpreted as a graph [42]. It is an effective method to evaluate the importance of nodes and reveal the network structure. In the bibliometric networks, different types of networks, such as coauthorship networks [43,44], bibliographic coupling networks [45], and co-citation networks [46], are constructed by bibliometrics [47].

Co-word analysis is a content-analysis technique proposed by [48,49]. It is applied to map the strength of associations between information items in textual data [50]. It involves a co-occurrence analysis of keywords in a selected body of literature. Co-occurrence analysis, a central task of association analysis in data mining, is used to group keywords with high relevance in clusters [51]. Typically, each set corresponds to a search theme. Researchers use co-occurrence analysis to identify established and emerging research themes or tracking patterns [52–54].

Numerous software tools support bibliometric analysis; however, many do not assist scholars in a complete recommended workflow. The most relevant tools are CitNetExplorer [55], VOSviewer [56], SciMAT [50], BibExcel [57], Science of Science (Sci2) Tool [58], CiteSpace [59], HistCite, Pajek, Gephi, Bibliometrix [33], and VantagePoint (www.thevantagepoint.com (accessed on 24 April 2022)). In this study, VOSviewer and Bibliometrix were used to conduct a co-citation analysis.

In this study, a topical query on 29 April 2022, was conducted in the Web of Science (WoS) and Scopus database, using the following search query: ((“multi-attribute decision making” or “madm” or “mcda” or “modm” or “mcdm” or “multi-criteria” or “multi-criteria” or “multiplecriteria”) and (“ahp” or “todim” or “topsis” or “promethee” or “electre” or “vikor” or “maut” or “fitradeoff” or “dematel” or “copras” or “multimoora” or “swara” or “analytical network process” or “anp” or “simple multi-attribute rating technique” or “smart” or “goal programming” or “thor” or “cbr” or “saw” or “condorcet” or “drsa” or “macbeth” or “paprika” or “wpm” or “wsm” or “utadis” or “waspas”)). The search was only restricted to titles, abstracts, keywords, and articles published between 1977 and 2022. Additionally, the search in the WoS database was limited to the Core Collection. The search query yielded 35,643 entries from the WoS and Scopus databases. Following the download of the records, the RStudio bibliometrix package version 1.2.1335 was installed on a Win64 operating system. Bibliometric analysis was performed using the Bibliometrix R package. The Bibliometrix tool was used to build the descriptive and co-citation networks. The function convert2df embedded in the Bibliometrix package was used to extract and create a data frame corresponding to the unit of analysis within the exported files from WoS and Scopus databases. After making the data frames from the WoS and Scopus files, the mergeDbSources function merged the WoS and Scopus data frames and excluded duplicate records from both files. Twelve thousand one hundred forty-nine duplicate records were removed, resulting in a data frame with 23,494 records for the bibliometric analysis. The process of obtaining the bibliographic records file can be seen in Figure 1.

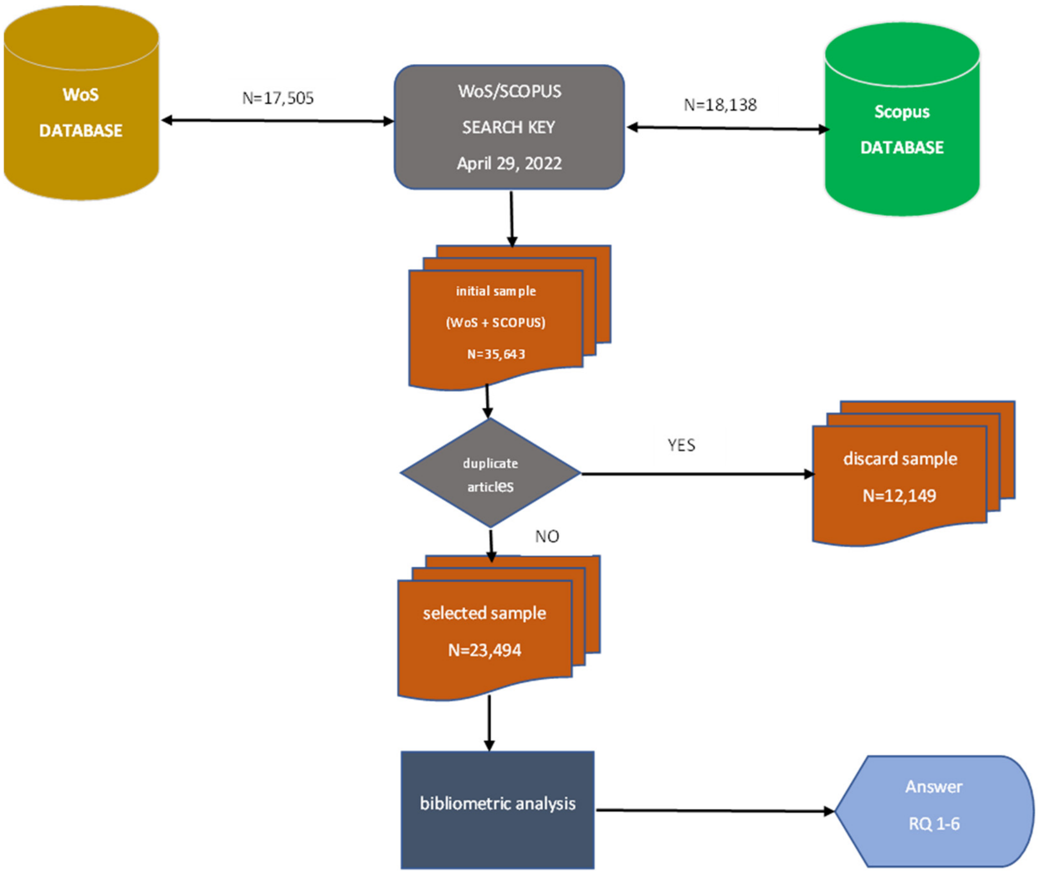

Figure 1. Search strategy and extraction of data. Source: Prepared by the authors based on Basilio et al. [60] and Ghosh and Prasad [61].

3. Results

The results from the bibliometric analysis show that 33,201 authors produced 23,494 documents in the period from 1 January 1977, to 29 April 2022. The types of documents identified in the sample, despite the limitations, are described in the methods and data section and further illustrated in Figure 2.

Regarding academic production, studies on multi-criteria decision-support methods had their genesis in 1977. Figure 3 depicts the publishing trajectory until April 2022. The graph shows that the upward trend began in 1986 with a modest inclination. During this time, the average number of publications each year was 7.3. From 1987 to 1996, the average number of papers per year climbed to 28.3 documents. This average increased to 123.2 records per year during the next ten years and finally reached 1265.73 from 2007 to 2021, indicating a strong level of interest in the topic among researchers. Taking the entire period into account, publications on multi-criteria decision-support methods grew at an annual percentage rate of 14.18. Figures 4 and 5 show the average total citations per year (16.06) and the average years from publication (6.36), respectively.

Five peaks are depicted in the graph shown in Figure 4. In 1983, the earliest and most important studies were conducted. In that year, six documents were published. The article by Van Laarhoven and Pedrycz [62], with a total citation count of 2158, had the most impact on citations in 1983. The authors presented a fuzzy variant of Saaty's pairwise comparison method for deciding between many options when there are competing choice criteria. Eleven publications were included in the sample in 1986. The article by Brans et al. [63] had a significant impact that year, increasing the yearly average of 1609 citations. Brans et al. [63] introduced the PROMETHEE approach in this study. Chen et al. [64] had the most-cited paper in 1994, with 967 citations. Chinese researchers provided novel methods for dealing with fuzzy multi-criteria decision-making based on the theory of fuzzy sets. There were

2454 citations to Chen's paper [64] in 2000, which affected the average of the 63 articles published that year. Chen [64] extended the TOPSIS model to the fuzzy environment. Furthermore, in 2004, two publications significantly impacted the average number of citations among the 128 papers published: Opricovic and Tzeng [65] had 2590 citations, while Pohekar and Ramachandran [66] had 1270 citations. The VIKOR and TOPSIS approaches were compared by Opricovic and Tzeng [65]. Pohekar and Ramachandran [66] conducted a systematic review of multi-criteria techniques for sustainable energy management. Table 1 provides a summary of the sample's most cited articles.

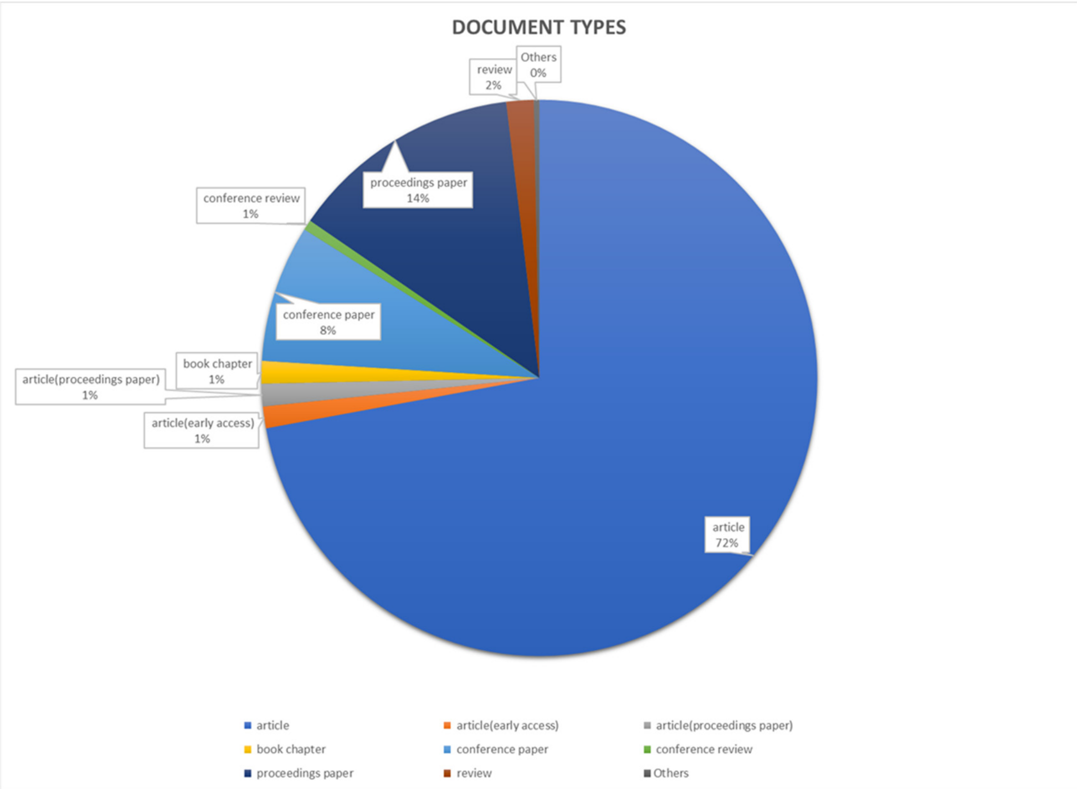

Figure 2. Graphical representation of the documents contained in the sample.

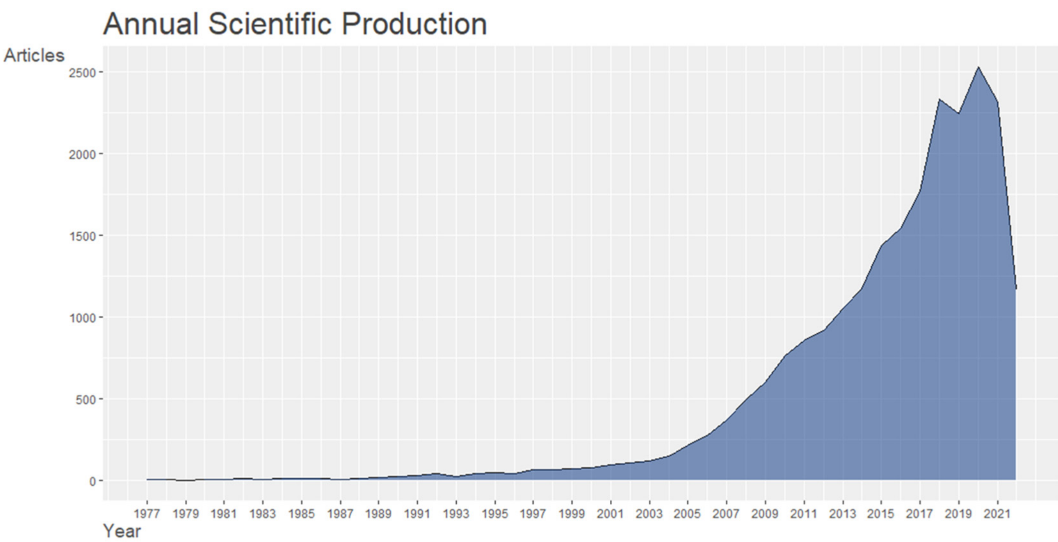

Figure 3. Graphical representation of the annual scientific production. Note: The data for 2022 corresponds to partial values quantified up to 29 April 2022.

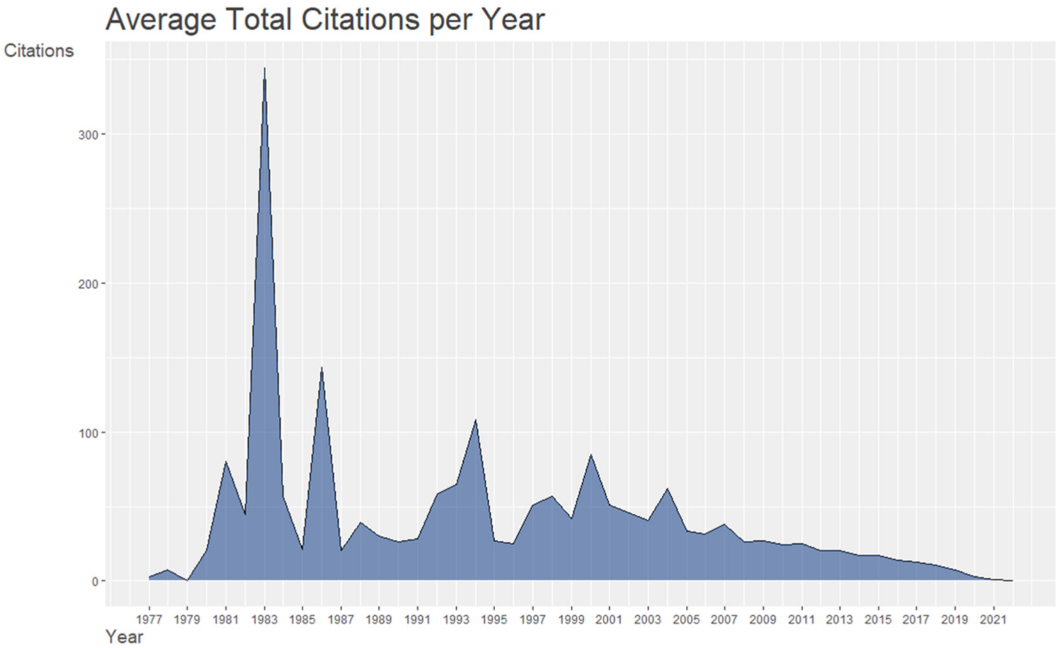

Figure 4. Graphical representation of the average total citations per year.

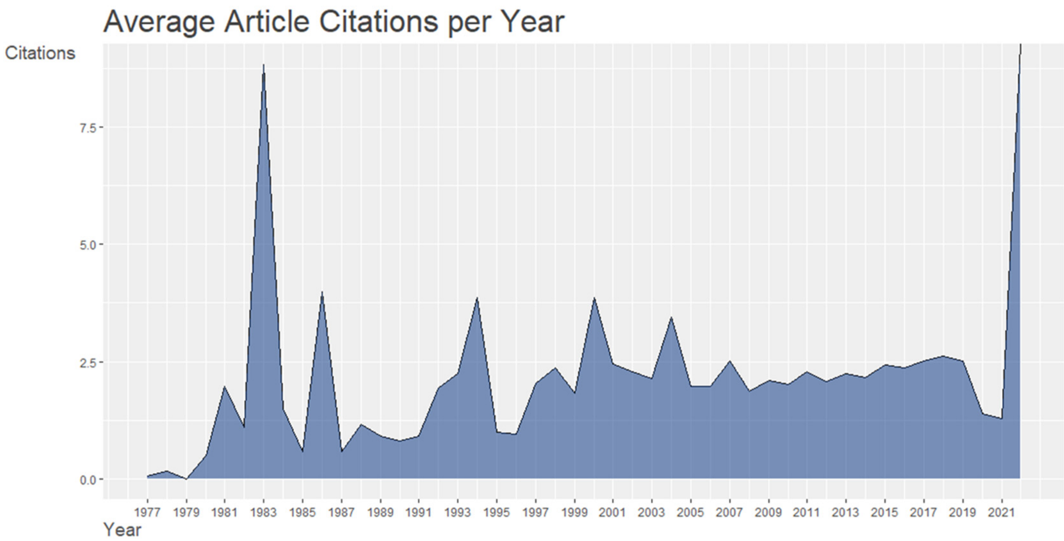

Figure 5. Graphical representation of the average article citations per year.

Table 1. Top 10 manuscripts per citations.

Rank	Title	Journal	First Author	Publication Year	Total Citations	TC per Year
1	A fuzzy extension of Saaty's priority theory	*Fuzzy Sets and Systems*	van Laarhoven, PJM	1983	1950	50.0
2	Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS	*European Journal of Operational Research*	Opricovic S	2004	1834	101.9
3	Extensions of the TOPSIS for group decision-making under fuzzy environment	*Fuzzy Sets and Systems*	Chen CT	2000	1815	82.5

Table 1. *Cont.*

Rank	Title	Journal	First Author	Publication Year	Total Citations	TC per Year
4	How to select and how to rank projects: The Promethee method	*European Journal of Operational Research*	Brans JP	1986	1422	39.5
5	Application of multi-criteria decision making to sustainable energy planning—A review	*Renewable and Sustainable Energy Reviews*	Pohekar SD	2004	960	53.3
6	Handling multicriteria fuzzy decision-making problems based on vague set theory	*Fuzzy Sets and Systems*	Chen SM	1994	888	31.8
7	A fuzzy approach for supplier evaluation and selection in supply chain management	*International Journal of Production Economics*	Chen CT	2006	854	53.4
8	A state-of the-art survey of TOPSIS applications	*Expert Systems with Applications*	Behzadian M	2012	742	74.2
9	A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method	*Expert Systems with Applications*	Boran FE	2009	732	56.3
10	Extended VIKOR method in comparison with outranking methods	*European Journal of Operational Research*	Opricovic S	2007	706	47.1

The year 2022 is shown as an outlier in Figure 5. The average number of papers cited every year was calculated using only the year of publication, which skews the results by overestimating this value. However, there are no distinguishing traits in this year's sample compared to earlier times. The volume of publications resulted in a total of 472,345 references.

3.1. Monitoring of Scientific Production around the World

Figure 6 shows that at least 120 countries or regions contributed to the research on multicriteria methods. China (n = 4327) is the largest contributor to multicriteria methods research, followed by India (n = 2485), Iran (n = 1812), Turkey (n = 1788), Taiwan (n = 1192), United States (n = 794), Brazil (n = 752), Spain (n = 608), Italy (n = 555), and Malaysia (n = 493). Regarding citations, Table 2 offers a slightly different order, but China continues to lead scientific production in terms of both knowledge generation and references to the scientific community: China (n = 82,615), Taiwan (n = 32,535), Turkey (n = 28,739), India (n = 23,643), Iran (n = 23,613), United States (n = 20,217), Lithuania (n = 12,292), United Kingdom (n = 10,917), Spain (n = 10,071), and Italy (n = 8601). As shown in Table 1, the top 10 research universities are Islamic Azad University (n = 504), Vilnius Gediminas Technical University (n = 456), National Institute of Technology (n = 336), University of Tehran (n = 334), Indian Institute of Technology (n = 265), and Istanbul Technical University (n = 243), as seen in Table 1.

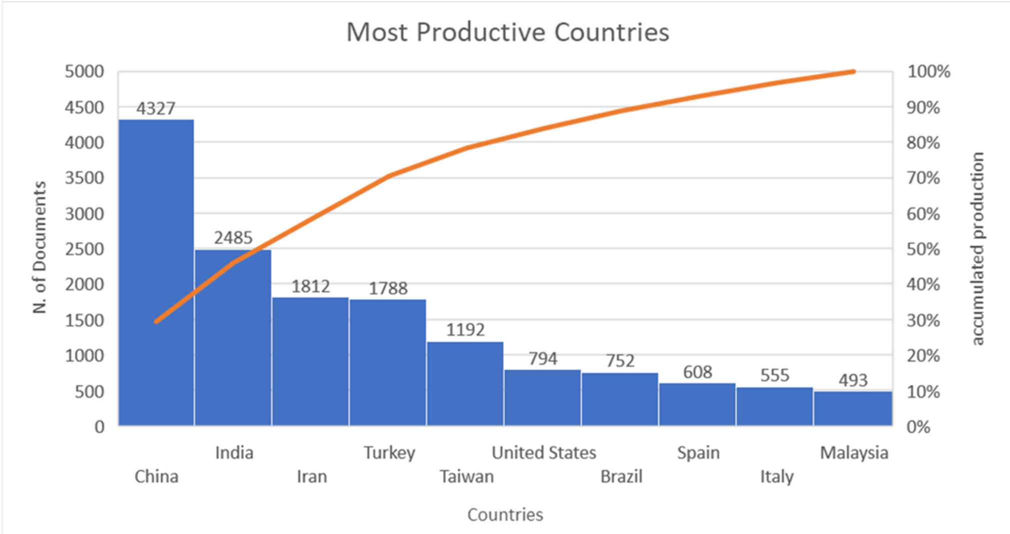

Figure 6. Graphical representation of the top 10 most productive countries.

Figure 7 illustrates the relationships between organizations through the coauthorship analysis, using universities as the unit of analysis. The research was based on the following criteria: (1) the minimum number of documents per organization ($n \geq 50$); (2) the minimum number of citations per organization ($n \geq 50$). With the established criteria, 50 organizations out of the 7619 analyzed were separated. The nodes represent the universities. The diameter of the nodes represents the number of citations, and the thickness of the connecting lines between the nodes represents the level of cooperation between the institutions. As a result, Islamic Azad University and Vilnius Gediminas Technical University stand out in this analysis.

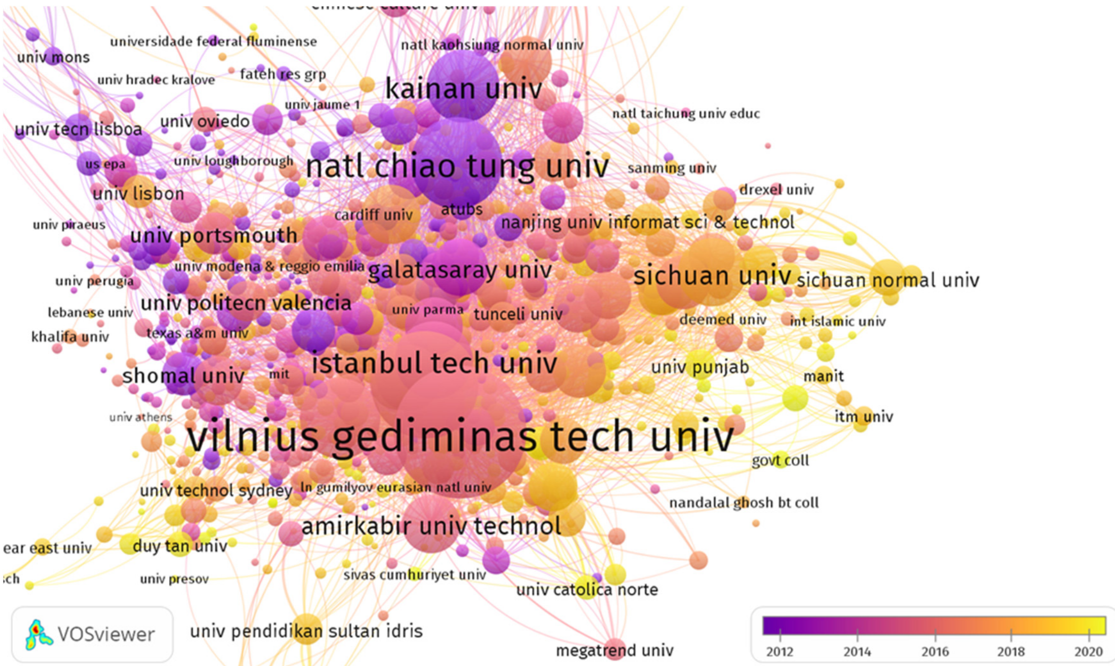

Figure 7. The network map of institutions involved in multi-criteria methods of decision-support research. Note: The colors of the circles are used to identify the clusters resulting from the analysis of the relations provided by the VOSviewer software.

Table 2. The top 10 countries/regions and institutions contributing to publications in multicriteria methods.

Rank	Country/ Region	Article Counts	Percentage (N/23,394), %	Total Citations	Percentage (TNC/373.732) %	Average Article Citations	Freq	SCP	MCP	MCP_Ratio	Institutions	Country	Article Counts	Percentage (N/23,394), %
1	China	4327	18.50	82,615	22.11	19.09	0.2035	3794	533	0.1232	Islamic Azad University	Iran	504	2.15
2	India	2485	10.62	23,643	6.33	9.51	0.1169	2338	147	0.0592	Vilnius Gediminas Technical University	Lithuania	456	1.95
3	Iran	1812	7.75	23,613	6.32	13.03	0.0852	1526	286	0.1578	National Institute of Technology	India	336	1.44
4	Turkey	1788	7.64	28,739	7.69	16.07	0.0841	1701	87	0.0487	University of Tehran	Iran	334	1.43
5	Taiwan	1192	5.10	32,535	8.71	27.29	0.0545	969	223	0.1126	Indian Institute of Technology System	India	265	1.13
6	USA	794	3.39	20,217	5.41	25.46	0.0380	633	161	0.2234	Istanbul Technical University	Turkey	243	1.04
7	Brazil	752	3.21	5584	1.49	7.43	0.0365	697	55	0.0861	University of Belgrade	Serbia	180	0.77
8	Spain	608	2.60	10,071	2.69	16.56	0.0294	496	112	0.2169	Yildiz Technical University	Turkey	176	0.75
9	Italy	555	2.37	8601	2.30	15.50	0.0272	463	92	0.1780	Sichuan University	China	157	0.67
10	Malaysia	493	2.11	6482	1.73	13.15	0.0244	389	104	0.2331	Central South University	China	150	0.64
	TOTAL	14,806	63.29	242,100	64.78								2801	11.97

Note: SCP: Single-country publications; MCP: Multiple-country publications.

This section provides a quick summary of the bibliometric findings. However, we chose to go beyond a typical bibliometric analysis by stratifying the investigation and providing the reader with specific information about the countries ranked in Figure 2. Table 3 lists the major research topics, universities, research funding organizations, notable authors, and the most relevant papers.

Table 3. Analytic picture of scientific production in the ten best-ranked countries.

Country	TOP 5				Studies
	Research Areas	Universities	Research Sponsors (%)	Authors	
China	Computer science, engineering, environmental sciences and ecology, operations research and management science, science technology, and other topics	Sichuan University, Central South University, North China Electric Power University, Hong Kong Polytechnic University, and Chinese Academy of Sciences	National Natural Science Foundation of China (48.75), Fundamental Research Funds For The Central Universities (7.77), China Postdoctoral Science Foundation (3.6), Ministry of Education China (2.68), and China Scholarship Council (1.9)	Jian-Qiang Wang, Zeshui Xu, Hu-chang Liao, Pei-De Liu, and Jing Wang	[67–76]
India	Engineering, computer science, environmental sciences and ecology, business economics, science technology, and other topics	National Institute of Technology, Indian Institute of Technology, Jadavpur University, Birla Institute of Technology Science Pilani, and National Institute of Technology Tiruchirappalli	Department of Science Technology India (2.097), University Grants Commission India (1.258), Council of Scientific Industrial Research India (0.779), National Natural Science Foundation of China (0.479), and Ministry of Human Resource Development Government of India (0.359).	Harish Garg, Ashwani Kumar, Sanjay Kumar, Shankar Chakraborty, and Samarjit Kar	[77–86]
Iran	Engineering, computer science, environmental sciences and ecology, business economics, science technology, and other topics	Islamic Azad University, University of Tehran, Amirkabir University of Technology, Tarbiat Modares University, and Iran University Science Technology	University of Tehran (0.925), National Natural Science Foundation of China (0.727), Austrian Science Fund (0.661), Islamic Azad University (0.528), and Iran National Science Foundation (0.462)	Seyed Meysam Mousavi, Maghsoud Amiri, Reza Tavakkoli-Moghaddam, Behnam Vahdani, and Abdolreza Yazdani-Chamzini	[87–96]
Turkey	Computer science; engineering, business economics, operations research and management science, and environmental sciences and ecology	Istanbul Technical University, Yildiz Technical University, Gazi University, Galatasaray University, and Karadeniz Technical University	Galatasaray University (3.628), Turkiye Bilimsel Ve Teknolojik Arastirma Kurumu Tubitak (2.243), Bagep Award of The Science Academy in Turkey (0.396), Erciyes University (0.396), and European Commission (0.396)	Cengiz Kahraman, Gulcin Buyukozkan, Basa Oztaysi, Ihsan Kaya, and Metin Dagdeviren	[97–106]
Taiwan	Computer science; engineering, operations research and management science, business economics, and environmental sciences and ecology	National Yang Ming Chiao Tung University, Nan Kai University Technology, National Taipei University, National Taipei University of Technology, and National Kaohsiung University of Science Technology	Ministry of Science and Technology Taiwan (18.635), Chang Gung Memorial Hospital (1.426), National Natural Science Foundation of China (1.426), Taiwan Ministry of Science and Technology (1.120), and Ministry Of Sciences And Technology In Taiwan (1.018)	Gwo-Hshiung Tzeng, James J. H. Liou, Chi-Yo Huang, Ming-Lang Tseng, and Ting-Yu Chen	[107–116]
United States	Engineering, computer science, operations research and management science, business economics, and environmental sciences and ecology	State University System of Florida, Pennsylvania Commonwealth System of Higher Education, University of California, University of Memphis, and La Salle University	National Natural Science Foundation of China (9.138), National Science Foundation (2.464), China Scholarship Council (1.437), Fundamental Research Funds for the Central Universities (1.335), and Portuguese Foundation for Science and Technology (1.027)	Madjid Tavana, Florentin Smarandache, Surendra M. Gupta, Joseph Sarkis, and Dursun Delen	[117–126]

Table 3. *Cont.*

Country	TOP 5				Studies
	Research Areas	Universities	Research Sponsors (%)	Authors	
Brazil	Engineering, computer science, business economics, operations research and management science, and environmental sciences and ecology	Universidade Federal de Pernambuco, Universidade Federal Fluminense, Universidade Federal do Rio De Janeiro, Universidade de São Paulo, and Universidade Tecnológica Federal do Paraná	National Council for Scientific and Technological Development (CNPQ) (22.18), Coordination for the Improvement of Higher Education Personnel (CAPES) (15.6), Foundation for Research Support of the State of São Paulo (FAPESP) (2.95), Foundation for the Support of Science and Technology of the State of Pernambuco (FACEPE) (1.39), and Foundation for Research Support of the State of Minas Gerais (FAPEMIG) (1.39)	Adiel Texeira de Almeida, Luiz Flavio Autran Monteiro Gomes, Danielle Costa Morais, Ana Paula Cabral Seixas Costa, and Helder Gomes Costa	[127–140]
Spain	Computer science, engineering, environmental sciences and ecology, operations research and management science, and business economics	The Polytechnic University of Valencia, Polytechnic University of Madrid, University of Granada, University of Oviedo, and Polytechnic University of Catalonia	European Commission (13.422), Spanish Government (8.555), National Natural Science Foundation of China (4.425), Spanish Ministry of Economy and Competitiveness (4.425), and Junta de Andalucia (2.507).	Morteza Yazdani, Juan Miguel Sanchez-Lozano, Monica Garcia-Melon, Maria Carmen Carnero, and Maria Teresa Lamata	[141–149]
Italy	Engineering, environmental sciences and ecology, computer science, science technology, other topics, and operations research and management science	University of Catania, University of Naples Federico II, University of Palermo, Polytechnic University of Turin, and University of Cassino	European Commission (3.303), Ministry of Education Universities and Research (2.385), National Natural Science Foundation of China (0.917), Ministry of Science and Higher Education Poland (0.734), and European Commission Joint Research Centre (0.550).	Salvatore Greco, Antonella Petrillo, Fabio De Felice, Fausto Cavallaro, and Silvia Carpitella	[150–159]
Malaysia	Engineering, computer science, science technology, other topics, environmental sciences and ecology, and operations research and management science	Universiti Teknologi Malaysia, Universiti Malaya, University Putra Malaysia, University Pendidikan Sultan Idris, and University Sains Malaysia	Ministry of Education Malaysia (4.48), University Teknologi Malaysia (2.83), University Sains Malaysia (2.12), University Kebangsaan Malaysia (1.18), and University Malaya (0.94).	Bilal Bahaa Zaidan, Aos Ala Zaidan, Lazim Abdullah, Osamah Shihab Albahri, and Mardini Abbas	[160–169]

3.2. Overview of the Leading Journals and Papers That Disseminate Research on Multi-Criteria Methods

Six thousand one hundred and five journals have published research on multi-criteria methods over the past forty-four years. As seen in Table 3, the top ten journals published 2180 of the total 20,861 studies on multi-criteria techniques (10.40%). *Expert Systems with Applications*, *Sustainability*, and *Journal of Cleaner Production* are the top three journals, accounting for over 4.67 percent of all indexed material. The journal with the highest impact factor (IF) is the *Journal of Cleaner Production* (7246), followed *by Applied Soft Computing* (5472), and *Expert Systems with Applications* (5041). (5.452). Five journals are classified as Q1 by the JCR 2019 standards, two as Q2, and three as Q3. In the eighth column of Table 4, the number of citations for each journal is displayed as an example.

Table 4. Top 10 most-active journals that published research articles on multicriteria methods (sorted by count).

Rank	Journal Title	Percentage (N/23,394), %	IF [2019]	Quartile in Category [2019]	H-Index	Article Counts	Total Number of Citations	Average Number of Citations	Percentage (TNC/373.732), %	Top 5 Countries by Source
1	*Expert Systems with Applications*	1.70	5.452	Q1	91	356	26,410	74.19	7.88	Taiwan, Turkey, China, USA, England
2	*Sustainability*	1.68	2.576	Q3	25	352	2978	8.46	0.89	China, Italy, Spain, Taiwan, Lithuania
3	*Journal of Cleaner Production*	1.29	7.246	Q1	43	270	7627	28.25	2.28	China, India, Iran, USA, Denmark
4	*European Journal of Operational Research*	1.26	4.213	Q1	76	264	22,144	83.88	6.61	France, England, USA, Belgium, Greece
5	*Journal of Intelligent & Fuzzy Systems*	1.07	1.851	Q3	26	225	2508	11.15	0.75	China, Turkey, Pakistan, Iran, India
6	*Applied Soft Computing*	0.79	5.472	Q1	48	166	6557	39.50	1.96	China, Iran, Turkey, Taiwan, India
7	*Computers & Industrial Engineering*	0.69	4.135	Q1	40	146	5165	35.38	1.54	China, Iran, Turkey, USA, Taiwan
8	*Soft Computing*	0.68	3.050	Q2	22	142	1402	9.87	0.42	China, Turkey, India, Iran, Taiwan
9	*Symmetry-Basel*	0.66	2.645	Q2	21	138	1407	10.20	0.42	China, Serbia, Lithuania, Pakistan, Taiwan
10	*International Journal of Information Technology & Decision Making*	0.58	1.894	Q3	24	121	2254	18.63	0.67	China, Taiwan, Turkey, USA, Iran
	Total	10.4				2180	78,452		23.42	

Figure 8 depicts the inter-relationship between the Journals, which was developed based on the researchers' preferences and referencing publications from sources with a high impact factor. The diameter of the circles is directly related to the number of citations, while the colors represent the identified clusters. In the eleventh column of Table 4, we can observe the five countries that published the most in each source. The maximum number of articles is from China, occupying the first position in eight out of the ten journals. The analysis of the highly cited papers shows that *Renewable and Sustainable Energy Reviews*, *Expert Systems with Applications*, and the *International Journal of Production Economics* have an incredible scientific impact on all scholars and have articles with more than 800 citations (Table 1).

3.3. Analysis of the Most Influential Authors Who Discuss the Topic of the Multi-Criteria Methods

Zavadskas E, Wang J, Tzeng G, Wang Y, and Kahraman C are among the top ten authors out of 29,050 who have published the most articles on this topic (Table 5). Edmundas Kazimieras Zavadskas is the first vice-rector of Vilnius Gediminas Technical University (VGTU). In addition, he is a member of the VGTU Senate, a professor, and the head of the Department of Construction Technology and Management. He has co-written over fifty novels in Lithuanian, Russian, German, and English. Corporations and academic institutions commissioned over forty research papers. The professor's primary research interests include building life cycles, decision-support systems, and multi-criteria optimization methods in construction technology and management.

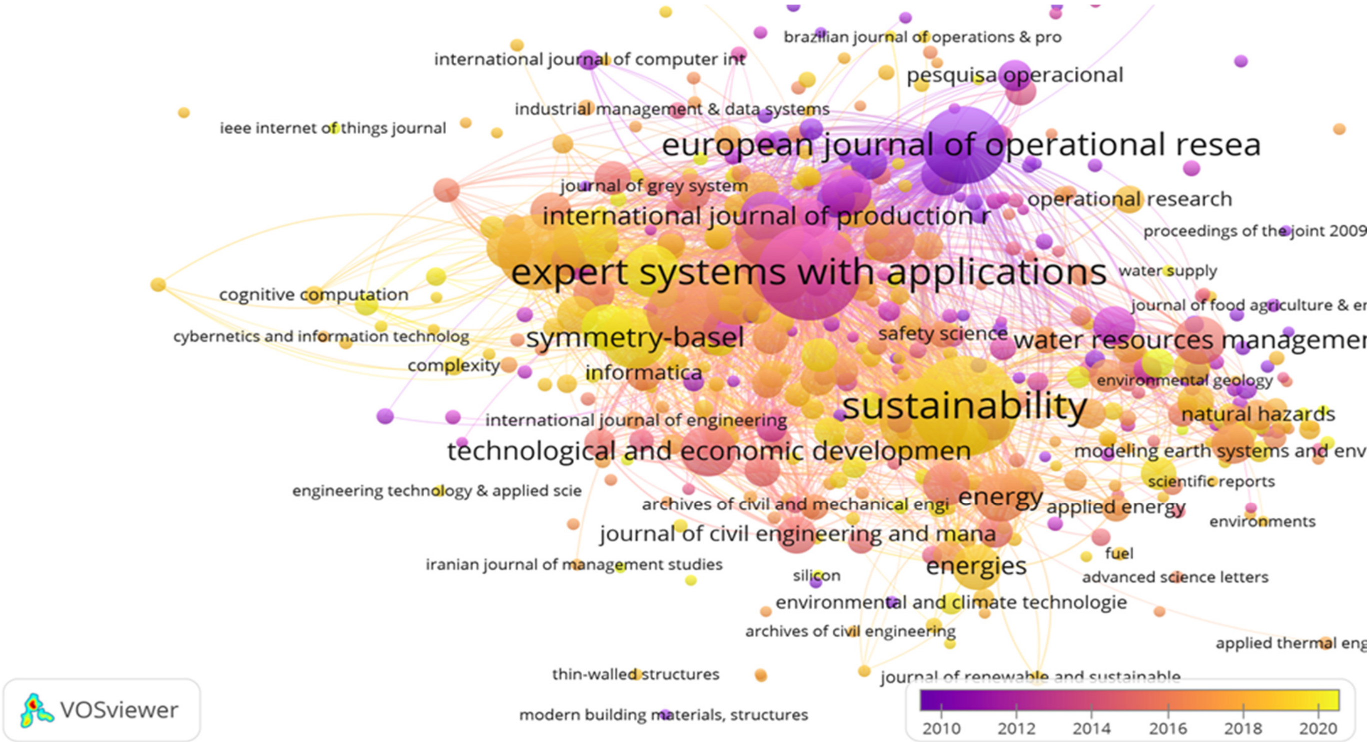

Figure 8. The network map of co-cited journals. Note: The colors of the circles are used to identify the clusters resulting from the analysis of the relations produced by the VOSviewer software.

Table 5. Ranking of authors with the highest scientific production on multicriteria methods.

Rank	Authors	Country	University	H_Index	G_Index	Article Counts	Total Number of Citations	Average Number of Citations	First Author Counts	First Author Citations Counts	Average First Author Citations Counts
1	ZAVADSKAS E	Lithuania	Vilnius Gediminas Technical University	57	87	240	9955	41.48	50	1806	36.12
2	WANG J	China	Central South University	46	68	211	5785	27.42	65	1946	29.93
3	TZENG G	Taiwan	National Taipei University	44	97	191	9814	51.38	5	1621	324.2
4	WANG Y	China	Qinghai Normal University	28	57	161	3419	21.24	75	2222	29.62
5	KAHRAMAN C	Turkey	Istanbul Technical University	34	68	145	4980	34.34	39	1939	49.71
6	CHEN Y	China	Chongqing University	29	53	124	3036	24.48	42	1173	27.92
7	ZHANG H	China	Central South University	37	59	104	3620	34.81	27	552	20.44
8	XU Z	China	Sichuan University	31	64	95	4178	43.98	12	832	69.33
9	WANG X	China	Central South University	20	33	94	1321	14.05	28	526	18.78

Table 5. *Cont.*

Rank	Authors	Country	University	H_Index	G_Index	Article Counts	Total Number of Citations	Average Number of Citations	First Author Counts	First Author Citations Counts	Average First Author Citations Counts
10	TURSKIS Z	Lithuania	Vilnius Gediminas Technical University	34	63	93	4264	45.85	10	273	27.3
Total						1458	50,372	34.54	353	12,890	36.51

Figure 9 depicts a group of 160 authors grouped into six clusters based on two essential criteria about the authors' academic output: the minimum number of citations (n $\geq$ 500) and the minimum number of documents (n $\geq$ 10). Each cluster, identified by a distinct color, indicates the authors' and co-authors' iterations. The number of links and the total links strength (TLS) are employed to determine the strength of the relationships. Each cluster's featured author is the author with the most links and the highest TLS. In this way, each cluster's information is presented: Cluster 1 (red) contains 37.5% of the sample, with an emphasis on authors Wang Y (Links = 112, TLS = 540) and Cheng Y (Links = 103, TLS = 394); Cluster 2 (green) contains 26.9% of the sample, with an emphasis on authors Wang J (Links = 140, TLS = 315), Xu Z (Links = 141, TLS = 2048), Zhang H (Links = 144, TLS = 1935), and Wang X (Links = 121, TLS = 658); Cluster 3 (blue) contains 10.6% of the sample, with an emphasis on author Kahraman C (Links = 143, TLS = 2548); Cluster 4 (yellow) contains 10% of the sample, with an emphasis on authors Zavadskas E (Links = 153, TLS = 9165) and Turskis Z (Links = 138, TLS = 4074); Cluster 5 (purple) contains 7.5% of the sample, and author Liu H stands out (Links = 122, TLS = 1395); Cluster 6 (light blue) has 7.5% of the sample, highlighting the author Tzeng G (Links = 139, TLS = 2167).

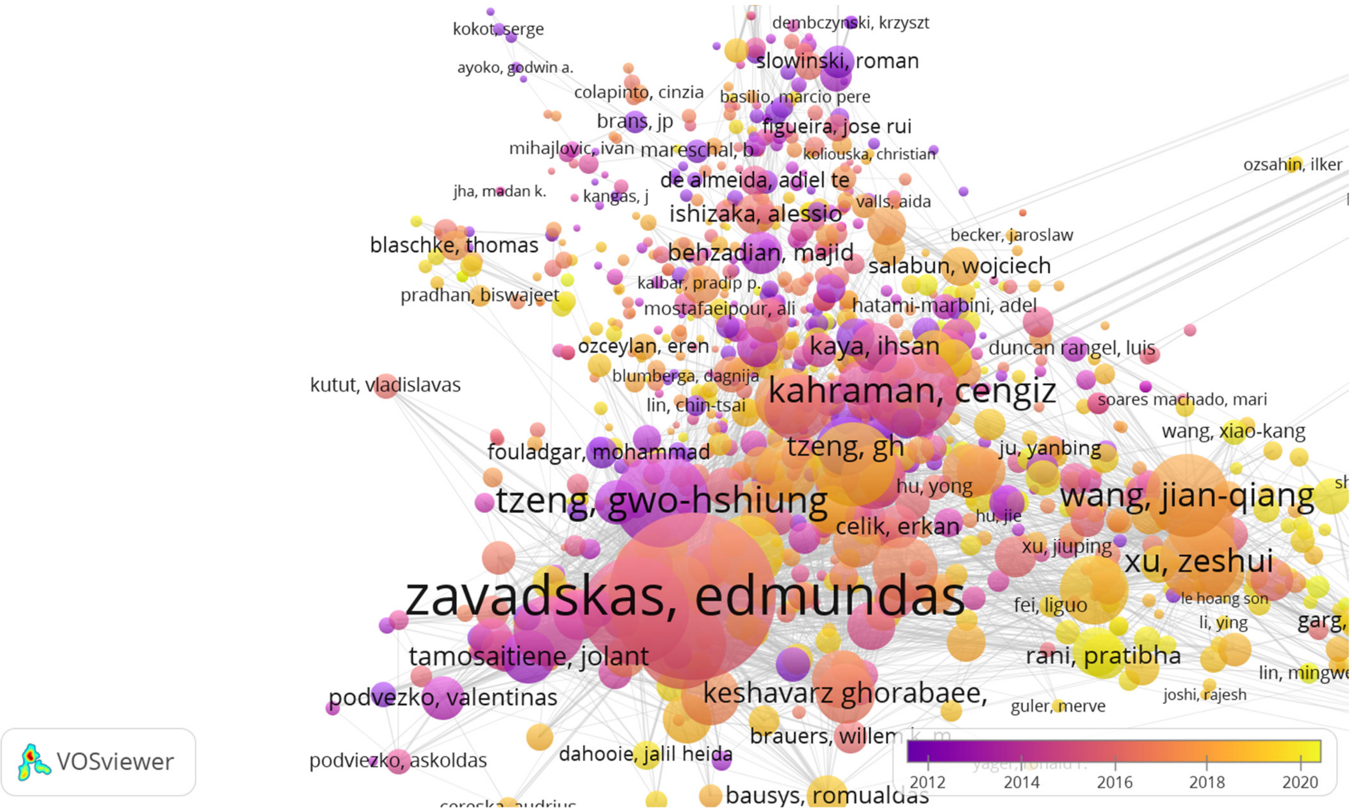

Figure 9. The network map of productive authors. Note: The colors of the circles are used to identify the clusters resulting from the analysis of the relations produced by the VOSviewer software.

3.4. Main Research Areas for the Application of Multi-Criteria Methods

The distribution of scientific production by research areas is depicted in Table 6. It is observed that there has been a shift in the preferences of academics in research fields over the past four decades. Table 7 displays the top five study areas by period. There was no change in the first five areas observed in the first two periods. From 1982 to 2002, research and applications of multi-criteria methods focused mainly on the following areas: operations research (1st), business economics (2nd), computer Science (3rd), engineering (4th), and mathematics (5th). With the increase in the volume of works published in the third decade under study, as shown in Figure 2, there was also a change in the research areas. From 2003 to 2012, the mathematics field was surpassed by environmental sciences ecology, which ranked fifth with 288 papers. Operations research, which held the number-one spot for two decades, was ranked third. The field of business economics lost its second place to computer science and fell to fourth place, followed by the ascent of engineering from fourth to first place. The most recent period analyzed was marked by a substantial increase in the number of published works. However, regarding the areas of interest of researchers, there has been a clear preference for engineering (1st) and computer science (2nd), followed by a change in preference as the traditional area of operations research has given way to environmental sciences ecology (3rd). In the fourth position, we find science technology, which has emerged with a greater level of interest from researchers due to the advancement of recent changes. The fifth place was occupied by business economics, a field in which scholars' interest has diminished over the past four decades.

Table 6. Distribution of scientific production by research areas.

Research Areas	Recorded Count	% of 26,376
Engineering	5101	19.34
Computer science	4706	17.84
Environmental sciences ecology	2133	8.09
Business economics	2122	8.05
Operations research	2010	7.62
Science technology	1635	6.20
Energy fuels	915	3.47
Mathematics	869	3.30
Water resources	579	2.20
Materials science	511	1.94
Total	20,581	78.02

Note: It is necessary to clarify the value indicated in the third column, "26,376" this is the total number of articles in the sample associated with the research areas. Each article can be related to more than one search area.

Table 7. Evolution of scientific production according to research areas in the analyzed periods.

Research Areas	Periods			
	1982 to 1992	1993 to 2002	2003 to 2012	2013 to 2022 (April 29)
	Ranking	Ranking	Ranking	Ranking
Engineering	4th	4th	1st	1st
Computer science	3rd	3rd	2nd	2nd
Environmental sciences ecology	-	-	5th	3rd
Science technology	-	-	-	4th
Business economics	2nd	2nd	4th	5th
Operations research	1st	1st	3rd	-
Mathematics	5th	5th	-	-

Note: Only data corresponding to the fifth position in each period were recorded.

In Section 3.1, a global overview of the scientific output on multi-criteria methods is provided, highlighting the significant countries and classifying each production. However, as seen in the case of research domains, the hegemony of the scientific output has also evolved differently between nations. The shift in emphasis in specific scientific fields and the consolidation of others directly impact the hegemony of nations. If we analyze Table 2, we can see the consolidation of engineering and computer science as prominent areas in the production of the ten countries explored and the emergence of interest in science and technology.

3.5. Most-Used Methods

Table 8 lists the 26 methods examined throughout the sample period. The publishing period in WoS/Scopus concerning the investigated method is recorded in column 3. The chronology was produced based on the evolution of multi-criteria approaches, as shown in Figure 10, using information from the starting period of each method's scientific output. The chronology depicts techniques that have been embedded in the literature and that continue to evolve, such as AHP, TOPSIS, PROMETHEE, ELECTRE, and others, such as SWARA, WASPAS, and FITRADEOFF, that have been published for up to ten years but are not yet well-known in academia. The publications of each studied technique are then noted in column 4. The AHP, TOPSIS, and VIKOR approaches have the most publications in the four decades studied. They are also the most commonly employed methods by professionals in solving multi-criteria related issues. Column 5 indicates the research areas wherein the specialists used the method the most. Computer science stands out among others because 47% of the researched methods address issues related to these areas, with the TOPSIS method being used the most. Engineering follows, with 35% of the methods, with the AHP method being the second most-used method. Business economics takes 11%, and operations research 8% respectively. In column 7, we build on the study to show a trend toward developing solutions that include one or more methodologies and the creation of hybrid models based on the data acquired. This section concludes by emphasizing that, despite the small number of applications, the scenario depicts the integration of multi-criteria methods with some machine learning techniques, which could be the beginning of a new trend in the coming years (see column 8).

Table 8. Characteristics of the methods most used by researchers.

N	Method	Publication Time	Recorded Count	Research Areas	Publication Time (Integrated/Hybrid Model)	Hybrid Model	New Technologies (Machine Learning)
1	AHP	1990–2021	6.835	Engineering (2.329)	1995–2021	1.388	38
2	TOPSIS	1991–2021	4.907	Computer science (1.797)	2003–2021	1.024	47
3	VIKOR	2002–2021	1.475	Computer science (519)	2009–2021	416	5
4	PROMETHEE	1989–2021	1.382	Engineering (445)	2001–2021	202	16
5	ANP	2000–2021	1.262	Engineering (428)	2006–2021	488	10
6	ELECTRE	1991–2021	1.005	Computer science (331)	2003–2021	120	6
7	DEMATEL	2007–2021	888	Computer science (289)	2007–2021	476	5
8	GOAL PRO-GRAMMING	1983–2021	553	Operations research (202)	1993–2021	147	3
9	SAW	1997–2021	403	Engineering (137)	2007–2021	67	5
10	TODIM	1999–2021	306	Computer science (171)	2013–2021	56	2
11	COPRAS	2006–2021	294	Business economics (83)	2011–2021	100	2
12	WASPAS	2012–2021	214	Engineering (68)	2013–2020	67	0
13	MULTIMOORA	2011–2021	198	Computer science (75)	2011–2021	43	0
14	SWARA	2011–2021	181	Business economics (46)	2011–2021	90	1
15	MAUT	1984–2021	164	Engineering (56)	2007–2021	19	0
16	MACBETH	1999–2021	162	Computer science (47)	1999–2021	27	0
17	WSM	1994–2021	87	Engineering (29)	2014–2021	17	2
18	DRSA	2002–2021	85	Computer science (51)	2012–2021	20	4
19	WPM	1997–2021	57	Computer science (23)	2014–2021	7	0
20	CBR	1996–2021	40	Computer science (25)	2006–2020	10	1

Table 8. *Cont.*

N	Method	Publication Time	Recorded Count	Research Areas	Publication Time (Integrated/Hybrid Model)	Hybrid Model	New Technologies (Machine Learning)
21	CONDORCET	1999–2021	35	Business economics (9)	-	0	1
22	FITRADEOFF	2016–2021	29	Computer science (14)	-	0	0
23	UTADIS	1998–2020	27	Operations research (14)	2005–2016	2	0
24	SMART	1996–2021	22	Engineering (9)	2021	2	0
25	PAPRIKA	2014–2021	12	Computer science (4)	2020	1	0
26	THOR	2008–2021	5	Engineering (2)	-	0	0

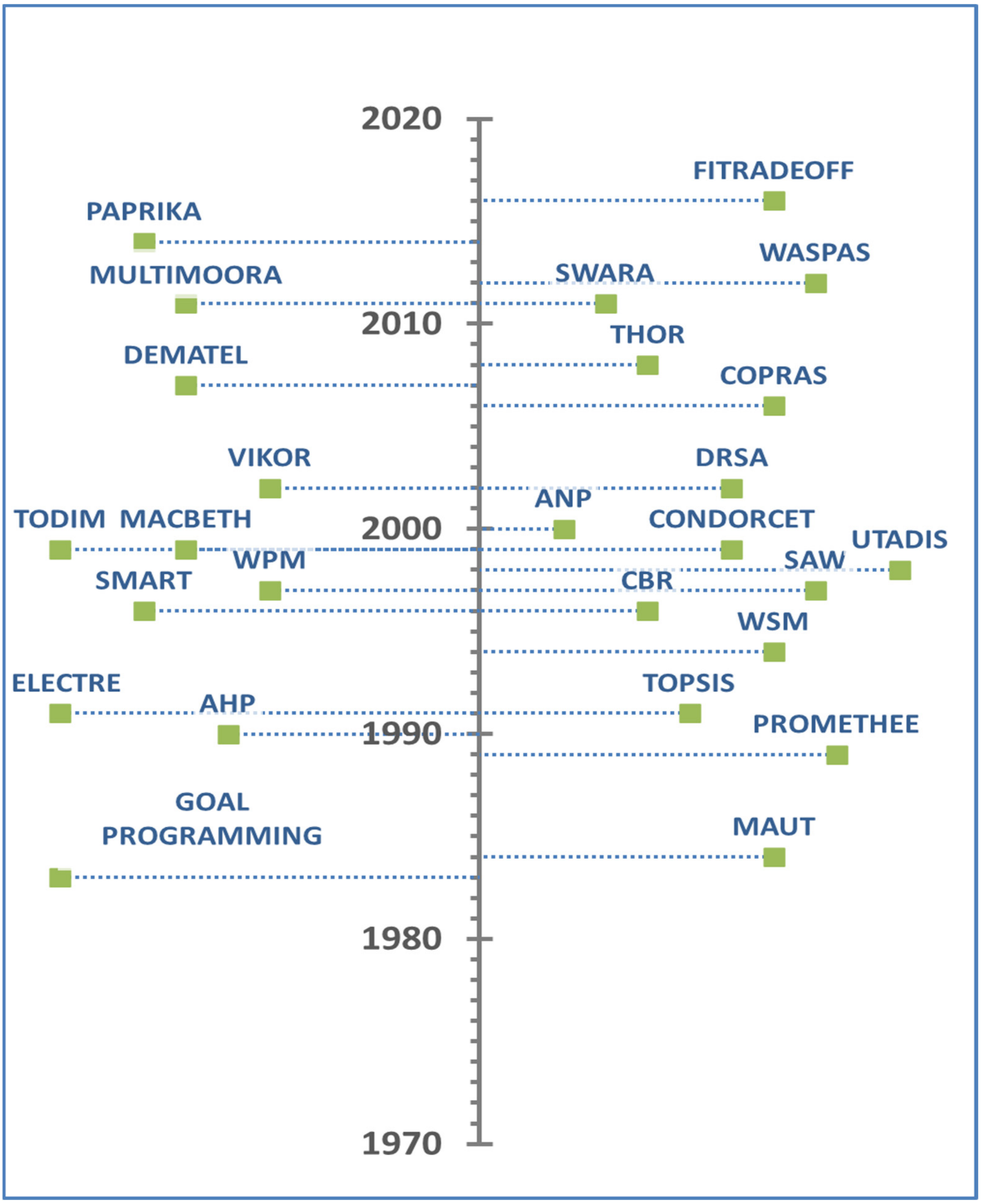

Figure 10. Evolution of scientific production classified by method over the period analyzed.

3.6. Mapping the Evolution of Themes

Cobo et al. [170] assert the set of identified themes of the subperiod t, with $U \in T\hat{}t$ representing each detected theme in the subperiod t. Let $V \in T\hat{}(t+1)$ represent each theme found in the subsequent subperiod t + 1. It is argued that there is a thematic progression from topic U to theme V if both related thematic networks contain the same keywords. Thus, V can be considered a development of U. Additionally, the keyword cluster $k \in U \cap V$ is regarded as a "thematic nexus" or "conceptual nexus".

Figure 11 was created using the "thematicEvolution" function of the Bibliometrix R package. The evolution of themes associated with multi-criteria methods is depicted in Figure 11 across the five time periods. In the first period, i.e., between 1977 to 1986, three themes are recorded. As the rectangles represented the same region during this period, it may be deduced that there was a balance in disseminating topics. In the second phase (1987–1995), there are twelve topics, of which eight had no foundation in the first period, such as "AHP", "TOPSIS", and "fuzzy set theory". These methods have their earliest publication record in 1990/1991 (Table 8). Still, researchers favor them, as in the case of TOPSIS, which has the same rectangular area as "GOAL PROGRAMMING", one of the three primary subjects of the program. During the third era (1996–2004), we recorded fourteen themes that originated in or branched from the preceding period. In this third period, the focus is on the AHP method, which is the most influential subject, as indicated by a distinct set of four keywords ("ahp", "analytic hierarchy process", and "analytical hierarchy process (ahp)"). It is important to note that the "GOAL PROGRAMMING" theme has become less popular and that the PROMETHEE and ELECTRE methods have become more popular. Despite being published for the first time in 1989/1991, they did not emerge as a topic until the third period. The themes decreased from fourteen to nine for the fourth phase (2005–2013). Two AHP-related concepts continue to hold the apex of importance. In addition to the PROMETHEE method, the TOPSIS methods, which did not emerge in the third era, reappeared distinctly. The final period evaluated between 2014–2022 continues with a reduction from nine to six themes presented in a balanced way, reflecting the preference for topics associated with the AHP and TOPSIS methods. The use of the theme-evolution map allowed us to graphically confirm the choice of specialists in solving multi-criteria problems using original tools in the AHP and TOPSIS methods during the study period.

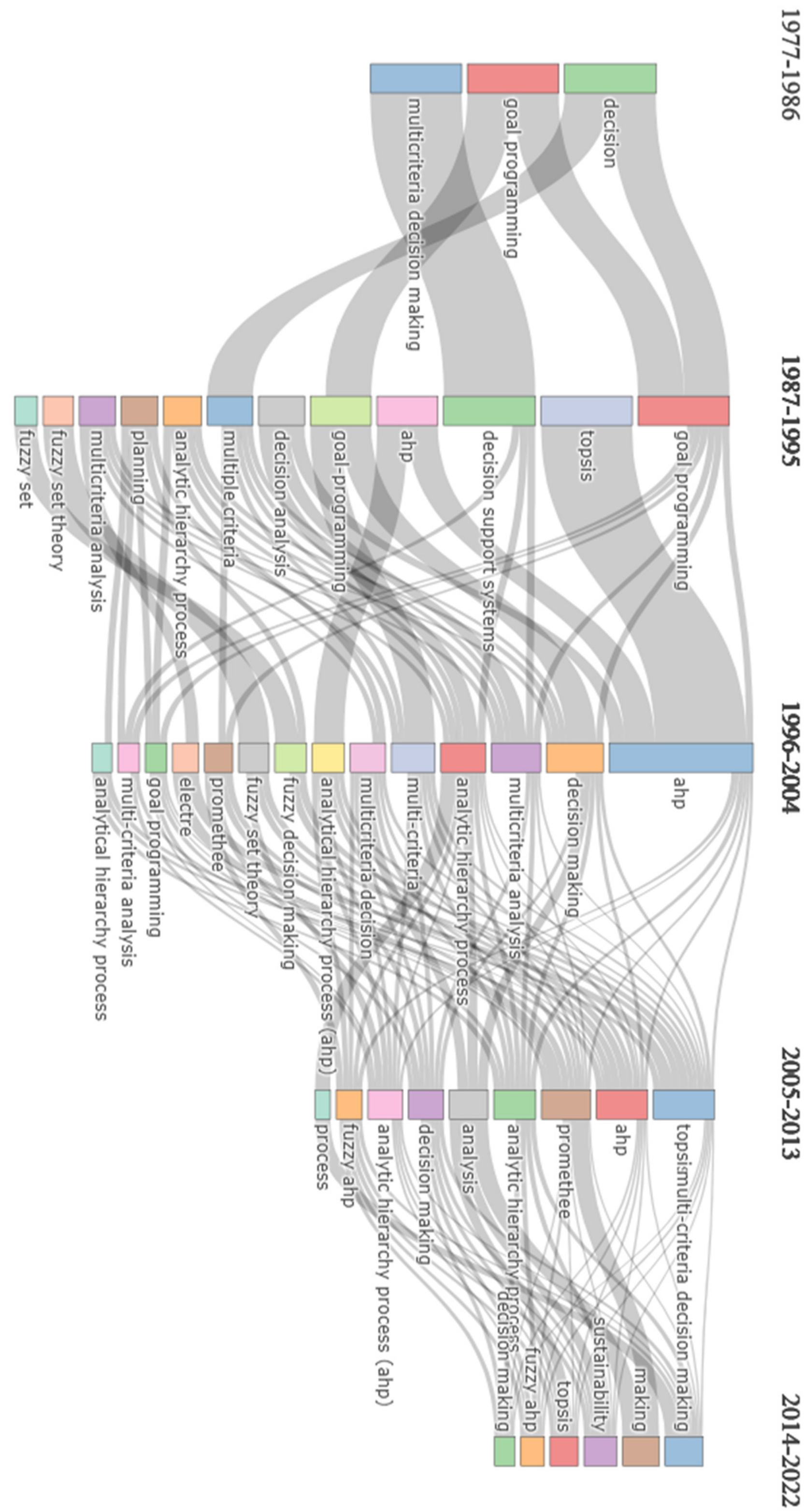

Figure 11. The evolution of themes built with the authors' keywords.

4. Discussion

This research article presents a bibliometric analysis of the multi-criteria methods from 1977 to 29 April 2022. The bibliographic data was obtained from the Scopus and Web of Science (WoS) databases. The bibliometric analysis was conducted using the Bibliometrix R tool and the VOSviewer software to investigate the essential characteristics of the studies done so far, including publications; citations, citation structure; influential authors; co-citation contributors and burst detection analysis; author-keywords; co-occurrence analyses; and timeline-view analysis. The ability to make judgments is a distinguishing characteristic of a person. Man makes spontaneous and intuitive decisions based on his brain's information-processing skills. We judge the color of our ties for a business meeting as to whether or not to invest millions of dollars in a specific project. We realize that we face two distinct types of decisions: simple and complex. We can make straightforward decisions with few variables and little trouble. However, when the problem involves a matrix (n $\times$ m) variable, we require methodologies and computer capabilities to systematize, arrange, and rank the best options to aid decision-making. Accordingly, the objective of this study was to comprehend the global evolution of research on the creation and use of multi-criteria decision methods.

With a scientific production growth rate of 14.18% each year, it is clear that the academic community is interested in researching and publishing publications on multi-criteria decision-making approaches. Moreover, 60.93% of all publications were concentrated in only ten nations, with China leading the way with 18.50%, India coming in second with 10.62%, and Iran coming in third with 7.75%. In addition, the remaining 39% of publications have an average production rate of less than 1%, suggesting that the dissemination of multi-criteria approach research in such nations could enhance academic output. The top 10 countries in terms of citations follow a consistent pattern, accounting for 62.48% of all citations made during the research period. Among the top 10 countries in terms of multi-country collaboration (MCP) in publications, Turkey has the lowest MCP ratio with 0.0487, indicating a limited partnership with researchers from other nations, followed by India (0.0592) and Brazil (0.0861). Malaysia leads multi-country collaboration, with an MCP ratio of 0.2331, followed by the United States (0.2234) and Spain (0.2169).

Regarding sites that publish articles on multi-criteria techniques, the study reveals the top ten journals that have published approximately 10.4% of the subject's total publications. China, India, Iran, and Turkey, the four nations with the most publications on multi-criteria techniques, account for around 80% of the university-based publications on multi-criteria methods. These universities account for 11.79% of academic output, with the Islamic Azad University of Iran contributing 2.14% and Vilnius Gediminas Technical University of Lithuania accounting for 2.18%. Surprisingly, Lithuania is not among the top ten nations regarding scientific output. However, among the other authors in this survey, Prof. Edmundas Kazimieras Zavadskas of Lithuania ranks first with 240 articles on multi-criteria approaches.

The journal *Expert Systems with Applications* has published 1.70% of all articles to date, followed by *Sustainability* with 1.68 percent and the *Journal of Cleaner Production* with 1.30%. The leading journals in terms of citations are *Expert Systems with Applications*, with an average of 7.88 citations per paper, followed by the *European Journal of Operational Research*, with 6.61 citations per article. Regarding the origin of publications, eight of the top ten countries publish most of their articles in the ten highest-ranked journals. In contrast, the *European Journal of Operational Research* ratio is 2 out of 10.

Regarding the most influential authors in this field, approximately 0.034% of 33,201 authors are responsible for 6.98% of publications over the past forty-four years, with ZAVADSKAS E having the most publications, with 240, followed by WANG J with 211 articles and TZENG G with 191 articles. This bibliometric analysis reveals that six of the top ten authors are Chinese, with the Central South University author affiliation standing out.

In addition to identifying writers with higher academic production, this study includes a comprehensive summary of the countries, funding sources, and the five multi-criteria approaches, i.e., AHP, TOPSIS, VIKOR PROMETHEE, and ANP, most frequently utilized by the authors in their respective studies. Engineering and computer science are the most prominent subjects in terms of research fields. One trend identified was the expansion of multi-criteria technique integration and the formation of hybrid models.

This paper gives a complete overview of multi-criteria methods through a bibliometric study, enabling scholars to comprehend the current state and future development patterns of multi-criteria decision-making methods research. As an indication for prospective research, we can emphasize the need to understand the emergence and regionalization of specific techniques and their variations, expand research within the identified countries to gain a deeper understanding of their scientific production on the issue investigated, apply topic modeling to find latent themes in the researched database, and systematize method variants and their interfaces with other research areas, such as machine learning.

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
ANP	Analytical Network Process
COMET	Characteristic Objects Method
COPRAS	Complex Proportional Assessment
DRSA	Dominance-based Rough Set Approach
ELECTRE	ÉLimination et Choix Traduisant la REalité (French)
MACBETH	Measuring Attractiveness by a Categorical Based Evaluation Technique
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
MODM	MultiObjective Decision Making
MOORA	Multi-Objective Optimization by Ratio Analysis
MULTIMOORA	MOORA plus the full Multiplicative Form
NAIADE	Novel Approach to Imprecise Assessment and Decision Environment
PCCA	Pairwise Criterion Comparison Approach
PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluation
WASPAS	Weighted Aggregated Sum Product Assessment
TODIM	Tomada de Decisão Interativa Multicritério (Portuguese)
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	VlseKriterijumska Optimizacija I Kompromisno Resenje (Serbian)

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