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The Synergy of Fuzzy Logic and Multi-Criteria Decision-Making: Application Areas and Global Trends

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ABSTRACT

This study conducts a bibliometric analysis to understand the evolution and application of Multi-Criteria Decision Making (MCDM)/Fuzzy MCDM methods in scientific literature. The literature review process, utilizing the Scopus database, analyzed 13278 articles out of 30144 published between 2014-2024. The analysis reveals substantial academic output in MCDM/Fuzzy MCDM fields with an annual growth rate of 13.38%. However, the declining citation-per-paper ratio suggests that increasing publication volume may negatively impact individual studies' visibility. Journals like Sustainability, PLOS One, and IEEE Access emerge as top publishers, highlighting the rise of open-access platforms while cautioning that rapid acceptance processes may introduce methodological weaknesses. Leading authors such as Zeshui Xu and Dragan Pamučar have made significant theoretical and practical contributions. Xu's operators for intuitionistic fuzzy sets and Pamučar's novel MCDM methods for healthcare supplier selection represent key milestones. The University of California System demonstrates strong research infrastructure as the most prolific institution. China dominates as the most productive country (14545 articles, 122430 citations), followed by India, Pakistan, and Turkey, whose collaborations enhance scientific interaction. Yager's (2013) IEEE Transactions on Fuzzy Systems paper, "Pythagorean Membership Grades in Multicriteria Decision Making," remains the most cited (2433 citations). Science mapping identifies key trends: fuzzy logic's role in decision model evolution and integration with machine learning. Applications in energy efficiency, maritime safety, and sustainability are growing. Future integration with AI/ML is projected to enhance decision-making efficiency.

1. Introduction

Contemporary decision-making processes increasingly require the evaluation of complex, multi-criteria structures. In this context, MCDM/Fuzzy MCDM methods enable decision-makers to make rational choices by considering multiple—often conflicting—criteria. However, classical MCDM approaches may prove inadequate for real-world problems characterized by high uncertainty. This is where MCDM methods integrated with fuzzy logic stand out, owing to their capacity to model both quantitative and qualitative information.

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Fuzzy MCDM has found broad applications across disciplines due to its flexible framework that accommodates decision-makers' subjective judgments, linguistic variables, and uncertainties. Recent years have witnessed a significant surge in academic studies within this field. Fuzzy MCDM techniques are now effectively employed in diverse sectors—including energy, environment, finance, healthcare, transportation, and supply chain management—to address complex decision problems such as sustainability assessments, risk analysis, alternative selection, and resource allocation.

This study conducts a bibliometric analysis of scientific publications on MCDM/Fuzzy MCDM indexed in the Scopus database between 2014–2024. It aims to:

- Identify publication trends,
- Map contributions by leading authors, institutions, countries, and journals,
- Analyze keyword distributions, and
- Reveal the field's developmental dynamics.

By doing so, we provide researchers and practitioners with a comprehensive roadmap of the current landscape and potential future research directions in this domain.

1.1 Multi-Criteria Decision Making and Fuzzy Logic

MCDM is a decision-making approach where decision-makers attempt to find an optimal solution by considering multiple, sometimes conflicting criteria. In this process, the weight and importance of each criterion are determined based on the decision-maker's objectives and the nature of the problem. MCDM is particularly effective in complex scenarios involving the evaluation of numerous alternatives. Today, MCDM methods enable businesses to make strategic decisions, policymakers to establish critical policies, and technical fields such as engineering to achieve optimization.

Fuzzy Logic, unlike classical logic, is a logical system capable of modelling uncertainty and approximate truths. Developed by Lotfi Zadeh [1], fuzzy logic serves as a tool to better simulate human thought processes. In traditional logic, an element is either true or false (0 or 1). However, in fuzzy logic, a gradient exists between elements—meaning an element can take any value between true and false. This characteristic makes fuzzy logic an ideal method for solving many real-world problems involving uncertainty.

The integration of fuzzy logic with MCDM has made decision-making processes more flexible and realistic by accounting for decision-makers' subjective judgments and uncertainties. Fuzzy MCDM methods allow decision-makers to convert uncertainties and linguistic expressions into numerical data, leading to more reliable results. For example, decision-makers may use linguistic terms such as "very good," "average," or "poor" to describe alternatives; such expressions are then transformed into numerical values using fuzzy logic, enabling further analysis.

Fuzzy logic not only enhances the applicability of MCDM methods but also provides decision-makers with more flexible and powerful tools. Techniques such as Fuzzy AHP (Analytic Hierarchy Process), Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), and Fuzzy VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) are just a few examples of the advantages derived from combining these two fields. These methods assist decision-makers in comparing alternatives and determining which options are more suitable.

In conclusion, Fuzzy MCDM methods enable more robust and flexible management of decision-making processes, particularly in scenarios involving uncertainty and subjective evaluations. As a result, more accurate and reliable decisions can be made, and complex problems can be resolved more efficiently.

2. Bibliometric Analyses of MCDM/Fuzzy MCDM

The widespread use of MCDM methods across various fields, particularly in disciplines such as transportation, supplier selection, software engineering, energy engineering, and environmental engineering, has become an important area of research. These methods provide the necessary tools for making effective decisions in complex decision-making processes.

Kriswardhana *et al.* [2], in their study examining the use of the Analytic Hierarchy Process (AHP) for transportation decisions, highlighted how this method has been applied over the last two decades in key areas such as transportation infrastructure, location selection, and accident prevention. They noted that AHP has addressed challenges related to transportation decisions based on environmental impacts while also being integrated with fuzzy and TOPSIS methods to create hybrid models.

Iskandar *et al.* [3], in their review of the literature on supplier selection, found that the Fuzzy AHP method is an effective tool for evaluating sustainability factors. Their analysis of 78 peer-reviewed articles revealed that only 17% of FAHP was used independently, with most studies combining it with other methods to create more robust decision models. They emphasized the need for future research to focus on green and sustainable applications. Magabaleh *et al.* [4] reviewed the use of MCDM methods in software engineering. They explored how methods such as AHP, TOPSIS, and DEMATEL are applied at various stages of the software development life cycle. Their findings demonstrated the importance of these methods in improving software quality and optimizing software processes. Kut and Pietrucha-Urbanik [5] analyzed the use of MCDM methods in environmental and energy engineering, employing CiteSpace software to identify international collaborations and key research topics. Their work underscored the critical role of MCDM in addressing global challenges such as environmental sustainability and energy security. Rezk *et al.* [6] researched the importance of meta-heuristic algorithms and MCDM in the management of renewable energy systems. They found that these methods optimize resource allocation and reduce environmental impacts in the integration and management of renewable energy systems, thus contributing to the achievement of sustainable development goals. Ecer [7] conducted a review of the Best-Worst Method (BWM), demonstrating its successful application across various fields in recent years. The study emphasized that BWM provides high reliability with a limited number of pairwise comparisons, which makes it a preferred tool in numerous research areas. Ćesić *et al.* [8] examined the use of fuzzy decision support systems and MCDM analyses in managing urban heat island phenomena. They pointed out the limited number of methods used for managing this phenomenon and highlighted the significant potential of fuzzy theory in this field. Sorooshian *et al.* [9] reviewed research on clean production and environmental sustainability in Southeast Asia. They evaluated the leadership and research collaborations of ASEAN countries, revealing the need for greater cooperation in environmental sustainability research through the combination of MCDM and bibliometric analysis techniques. Kiani Mavi *et al.* [10] focused on success criteria in construction projects and emphasized that MCDM methods such as AHP are frequently used in this area. They pointed out that these methods offer effective tools for defining success criteria and improving project success rates in the construction industry. Srivastava *et al.* [11] investigated the use of MCDM in education, examining how these methods have transformed decision-making processes in the education sector. They specifically noted the widespread use of fuzzy analysis techniques.

Khulud *et al.* [12] conducted a bibliometric analysis showing that research on sustainable supplier selection has experienced the greatest growth since 2019. This analysis emphasized how MCDM methods in the supplier selection process offer decision-makers the opportunity to evaluate environmental and social factors. Sohail *et al.* [13] reviewed waste management, demonstrating the effectiveness of MCDM methods in optimizing waste management decisions at various stages. They noted that Asian countries are leading in this field and that research collaborations have been

increasing. Norouzi Khatiri *et al.* [14] explored the use of MCDM methods in groundwater management, highlighting the need to develop models that improve decision-making processes in water resource management. They emphasized that studies in this field can be enhanced by integrating uncertainty analysis and optimization methods. Liao *et al.* [15] reviewed the application of fuzzy MCDM methods in tourism and hospitality, noting that AHP and TOPSIS are the most commonly used techniques. They suggested that these areas require further investigation in future studies.

Boix-Cots *et al.* [16] examined the MIVES method, a decision-making approach focused on sustainability, and highlighted its potential for evaluating environmental and social indicators in construction engineering. They also pointed out research opportunities for the broader application of the MIVES method in the future. Basílio *et al.* [17] conducted another systematic review on the historical development of MCDM methods over four decades, revealing that China has the highest number of publications in this field. Li *et al.* [18] reviewed the evolution of MCDM, discussing its development in four stages and noting that today's most prominent research areas are energy, environment, and supplier selection. Their analysis showed that MCDM is a dynamic field with global impact.

Owojori *et al.* [19] reviewed research on adaptive reuse, indicating its significance in sustainable construction practices. The study presented key findings on how factors such as environmental impact, life cycle assessment, and MCDM are integrated into the adaptive reuse process. de Souza *et al.* [20] systematically reviewed MCDM methods used in research and development project portfolio selection (PPS). Their study, covering 66 articles published since 1970, provided an in-depth analysis of the methods and criteria used in this field, as well as the development of solution algorithms. Tian *et al.* [21] investigated the integration of the TODIM (Interactive Multi-Criteria Decision-Making) method with various types of fuzzy set theories. They discussed how MCDM methods are used in uncertain and complex decision-making situations and highlighted the potential of this approach for future research. Bortoluzzi *et al.* [22] reviewed the literature on key performance indicators (KPIs) and MCDM models used in the analysis of renewable energy technologies (RET). The study identified the current state of research in renewable energy and future research opportunities.

Nadkarni and Puthuvayi [23] reviewed the application of MCDM methods in cultural heritage buildings. They explored how these methods are used in adaptive reuse strategies, renovation project prioritization, and the assessment of building significance, presenting opportunities for future research. Chowdhury and Paul [24] conducted a systematic review of MCDM methods in corporate sustainability. The study examined how standalone and integrated MCDM methods are used to assess various dimensions of corporate sustainability. They identified gaps in the literature regarding the integration of MCDM methods and comparisons across different economic contexts.

These studies demonstrate how MCDM methods can be integrated into decision processes across different sectors and contribute to fundamental issues such as sustainability, environmental impact, and efficiency. They also highlight how hybrid models combining different MCDM methods lead to more reliable and effective results.

3. Materials and Methods

This study is based on bibliometric analysis methods to allow for a wide-ranging analysis of the literature. Bibliometric analysis is a powerful method used to quantitatively assess scientific outputs and identify research trends, collaborations, and key works.

3.1. Database Selection

In bibliometric analyses, choosing an accurate and reliable database is of paramount importance. For this study, the comprehensive academic database Scopus was selected. Scopus is a broad

database that covers scientific journals, conference papers, and books across different disciplines, and it provides tools for scientific impact analysis with indicators such as citation counts, the h-index, and co-citation networks. Additionally, it serves as an important tool for identifying research trends across fields, institutions, and nations. The reliability of the database is supported by Scopus' rigorous data validation processes [25].

3.2. Search Strategy

The analysis was conducted using the following search strategy keywords: "mcdm OR 'Multi-Criteria Decision Making' OR madm OR 'Multi-Attribute Decision Making' OR modm OR 'Multi-Objective Decision Making' OR 'Decision Making' OR 'Multi-Criteria Analysis' OR 'Fuzzy Optimization' AND (('Fuzzy Set' OR 'Fuzzy Sets' OR 'Fuzzy Logic'))". The search was conducted in the Scopus database and limited to publications from 2014-2024. A total of 30144 unique documents were identified. The search strategy ensured a comprehensive collection of the literature and helped uncover the current trends in the research area.

3.3. Inclusion and Exclusion Criteria

To clean and classify the data before analysis, inclusion and exclusion criteria were established. These criteria are as follows:

- Inclusion Criteria

The literature directly related to the search strategy was preferred. The publication type was limited to "articles." The preferred language for the articles was English.

- Exclusion Criteria

Letters, conference abstracts, editorials, theses, biographies, book reviews, news reports, duplicate publications, retracted articles, and other non-academic content were excluded from the analysis.

Based on these criteria, a literature search was conducted, and publications outside the scope were excluded from the study.

3.4. Literature Screening Process

The screening process included the following steps:

- Searching for the keywords in the Scopus database within the specified time frame.
- Filtering the data according to the inclusion and exclusion criteria.
- Detailed examination of the relevant articles and inclusion in the analysis.

As a result, a total of 13278 articles were included in the analysis based on the specified criteria. The literature screening process is shown in detail in Figure 1. Figure 1 presents the filtering stages from the initial total article count to the final included articles, step by step [26].

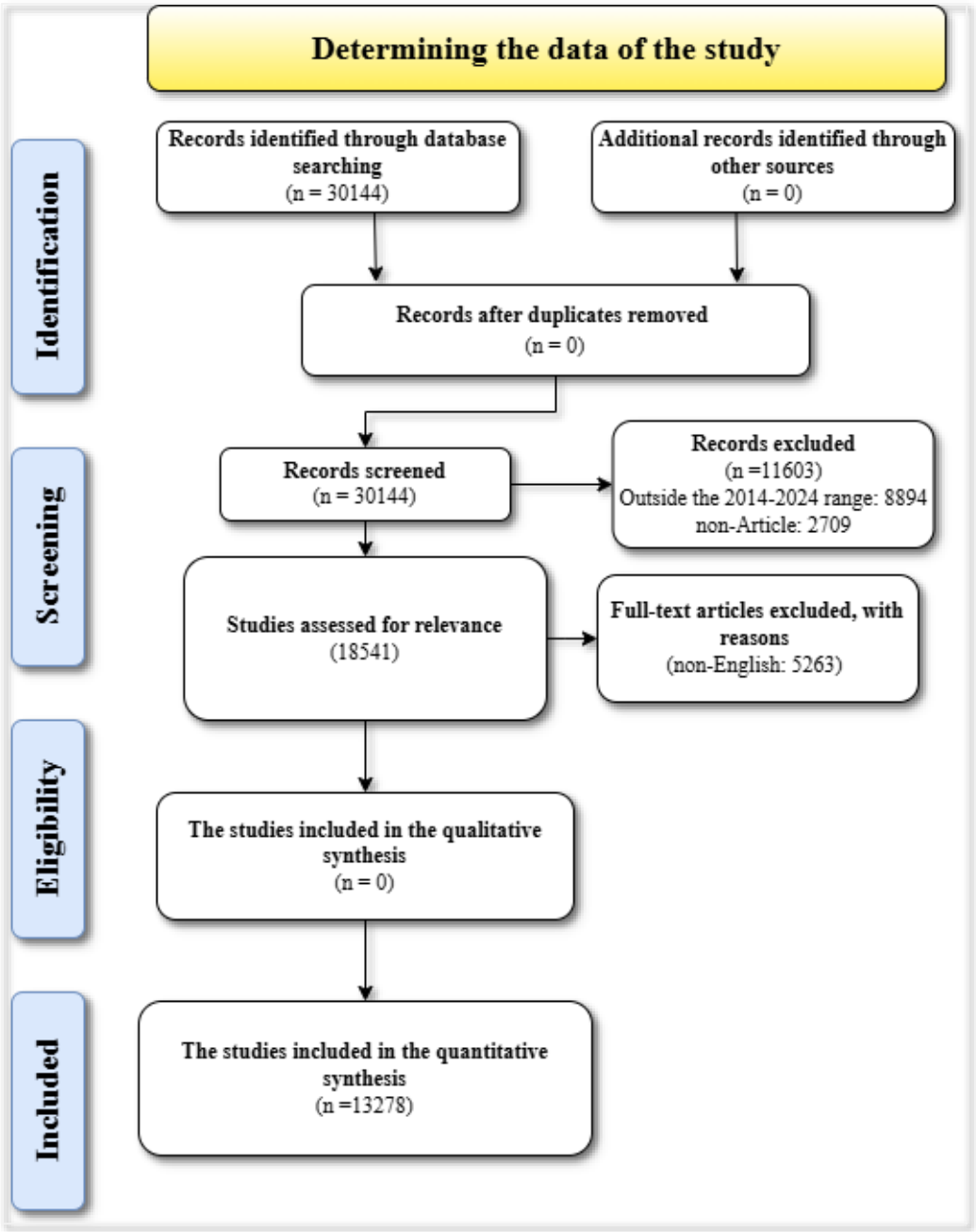

Fig. 1. Data collection PRISMA flow diagram

The definition, screening, and inclusion criteria were the three stages of data search followed, as shown in Figure 1. In the first stage, 30144 records were screened. Of these screened records, 11603 were removed in the second step. In the final stage, 13278 articles were included in the study for review.

3.5. Data Analysis

The included literature was analyzed using bibliometric analysis software. The analysis tools used in the research are as follows:

- VOSviewer: Used for visualization tasks such as co-citation networks, author collaborations, and keyword analysis [27].

- R Bibliometrix Package: Preferred for citation analysis, author performance, and publication trend evaluation [28].
- Python Programming Language: Used for graphic and data visualization. The findings obtained through libraries such as Matplotlib and Seaborn were visually supported, making trends, distributions, and relationships more comprehensible. Python's open-source nature and flexible data processing capabilities allowed the analysis process to be conducted in a more dynamic and reproducible manner.

The obtained data were analyzed to reveal key research areas, highly impactful publications, and author collaborations.

4. Overview of MCDM/Fuzzy MCDM Studies

The data obtained through the bibliometric analysis indicate that MCDM studies have an interdisciplinary nature and find applications in various fields. Figure 2 shows the areas in which MCDM studies have concentrated.

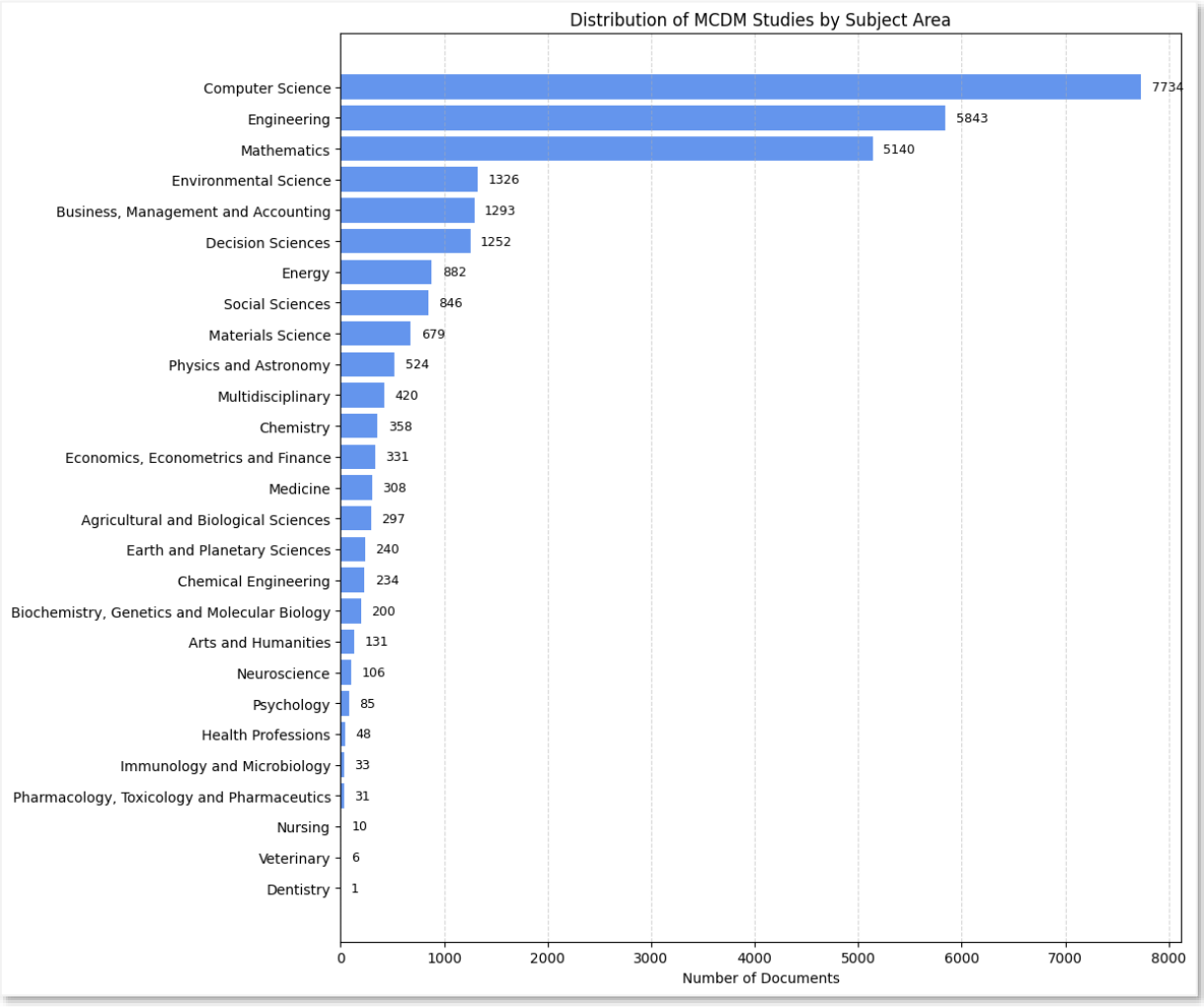

Fig. 2. Distribution of MCDM/Fuzzy MCDM Studies by Subject Area

Figure 2 shows the distribution of MCDM/Fuzzy MCDM studies across different categories. The highest number of studies has been conducted in the field of Computer Science (7734 papers),

followed by Engineering (5843 papers) and Mathematics (5140 papers). Notable numbers of studies can also be found in fields such as Environmental Science, Business, Management and Accounting, and Decision Sciences.

The presence of MCDM research in disciplines such as Medicine, Psychology, and Health Sciences indicates that this method has a multidisciplinary approach. However, it is observed that there are very few studies in areas like Nursing, Veterinary, and Dentistry, suggesting that MCDM methods are less used in these fields.

MCDM is applied not only in technical fields like Engineering and Computer Science but also in a wide range of areas such as Environmental Science, Health Management, Business, Economics, and Sustainable Development. This highlights the multidisciplinary nature of the method and its growing importance in decision-making processes.

4.1. Performance Analysis

In this study, relevant publications were summarized within a detailed descriptive analysis framework; the current status of institutions, countries, and journals, as well as collaborations between countries, were systematically evaluated. In the first stage of the analysis process, descriptive statistics were generated using Biblioshiny software, and key bibliometric indicators were identified. The main findings and statistical results for the dataset are presented in Table 1. This comprehensive approach allowed for the quantitative presentation of current trends in the research field and an understanding of the structural characteristics of scientific production in the literature.

Table 1.
Main information

Description	**Results**
MAIN INFORMATION ABOUT DATA	
Timespan	2014:2024
Sources (Journals, Books, etc)	1938
Documents	13278
Annual Growth Rate %	13,38
Document Average Age	4,78
Average citations per doc	25,83
References	487966
DOCUMENT CONTENTS	
Keywords Plus (ID)	32582
Author's Keywords (DE)	26971
AUTHORS	
Authors	18094
Authors of single-authored docs	734
AUTHORS COLLABORATION	
Single-authored docs	1187
Co-Authors per Doc	3,36
International co-authorships %	30,4
DOCUMENT TYPES	
article	13278

Table 1 shows the general characteristics of the bibliometric study, the content of the documents, author contributions, and collaboration rates.

- Basic Data Characteristics

A total of 13,278 documents published in 1,938 different sources during the time period of the study (2014-2024) were analysed. The annual growth rate of 13.38% indicates a steady increase in research production in the field. The average number of citations per document is 25.83, and the average document age is 4.78 years, suggesting a high level of academic impact.

- Content and Author Characteristics

Keyword distribution: The 32,582 Keywords Plus and 26,971 author-defined keywords reflect the conceptual diversity of the works. Author statistics: A total of 18,094 different authors participated in the studies, with only 734 authors producing single-author papers. Collaboration models: The average number of authors per document is 3.36, and the international co-authorship rate is 30.4%, indicating a strong culture of collaboration in the field.

- Document Types and Source Diversity

The fact that all analysed documents are in the form of peer-reviewed journal articles (13,278 articles) indicates that the study is based on a reliable dataset in terms of academic quality standards. The number of references, 487,966, highlights the richness of the literature in the field.

- Key Results and Comments

The high growth rate and citation counts indicate that the fuzzy MCDM field continues to develop as a dynamic research area. The relatively high rate of international collaboration (30.4%) shows that the field has become global in nature. The low proportion of single-author papers (1,187 documents) reveals that researchers tend to work with interdisciplinary teams.

These findings show that the fuzzy MCDM field has achieved significant academic accumulation both methodologically and applicative and has become a field increasingly adopted by researchers.

4.1.1. Status of Publications and Citations

Figure 3 shows the status of documents and their citations over time in the bibliometric analysis of research using MCDM/Fuzzy MCDM.

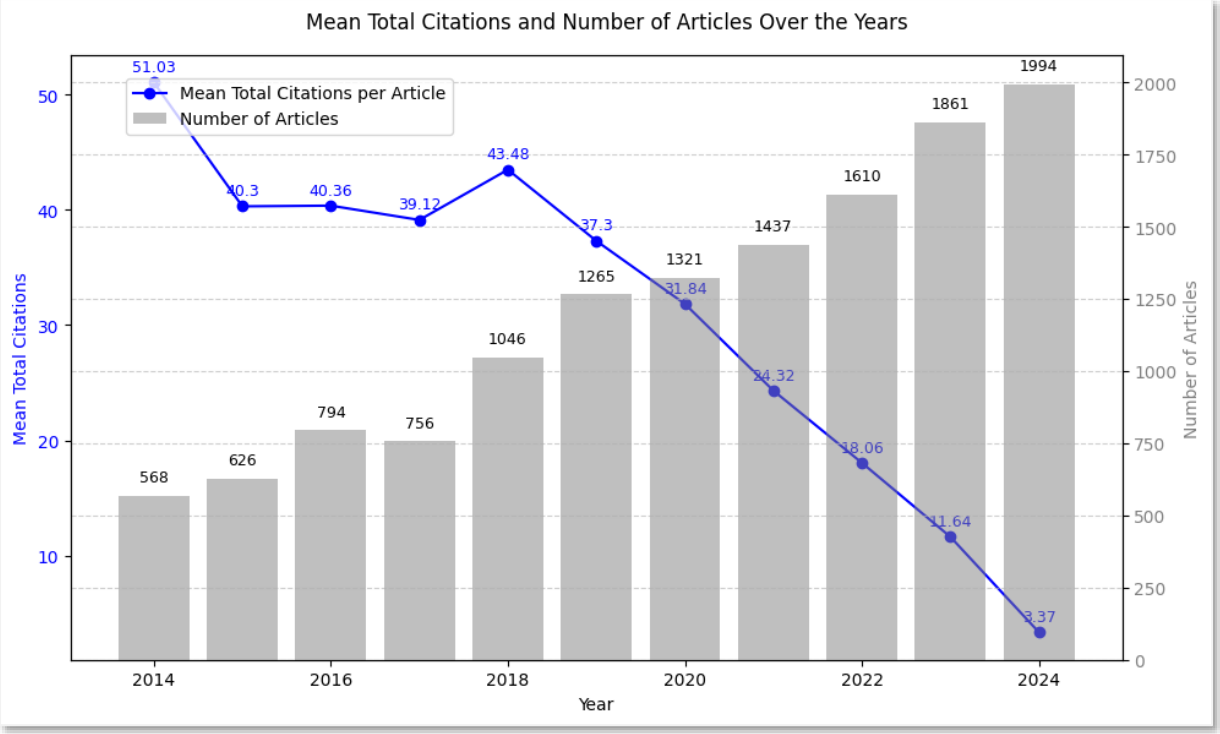

Fig. 3. Mean total citations and number of articles over the years

According to Figure 3, it can be said that interest in the MCDM/Fuzzy MCDM field has rapidly increased, with a large number of new studies being conducted. However, it can also be interpreted that these new studies receive fewer citations, or are expected to receive more citations over time.

- General Trends

Decrease in Average Citations: The average number of citations per article was 51.03 in 2014, but decreased to 39.12 in 2017. This decline could be the result of increased competition due to the growing number of articles in the field or the fact that newer publications have not yet accumulated sufficient citations. After 2020, this declining trend continued, and a lower value of 3.37 was observed in 2024. This can be attributed to the quantitative increase in research.

Increase in the Number of Articles: Academic studies related to MCDM/Fuzzy MCDM are steadily increasing, with rapid growth observed particularly after 2020. This trend appears to be continuing and may expand further with applications in disciplines such as artificial intelligence, sustainability, finance, and engineering.

Continuous Increase: From 2014 to 2024, the number of publications in the MCDM field has shown a consistent increase, indicating a growing academic interest in the topic.

Acceleration Trend: Since 2018, particularly between 2019-2024, a clear acceleration is evident. For example: 2018: 1,046 articles, 2019: 1,265 articles, 2020: 1,321 articles, 2021: 1,437 articles, 2022: 1,610 articles, 2023: 1,861 articles, 2024: 1,994 articles. These data suggest that MCDM is becoming increasingly critical in modern decision-making processes.

Post-2020 Growth: Following the COVID-19 pandemic (2020 and beyond), there may have been an increased interest in data-driven decision support systems that manage uncertainties. MCDM is a highly suitable method for such uncertain environments.

Record Level in 2024: With 1,994 articles published in 2024, the field has reached its highest level. This indicates that the popularity of the field is at its peak.

- Critical Comments

Citation-Article Relationship: Despite the increase in the number of articles, the decrease in average citations may indicate that the visibility of individual studies has diminished due to an "information overload" in the literature. The rapid increase in publications after 2020 may signal the weakening of quality control mechanisms or a "publication bombardment."

Time Effect: The higher citations of publications between 2014 and 2018 suggest that these studies have become key references in the literature. The lower citation counts after 2020 may be due to new publications not yet fully entering the citation cycle.

4.1.2. Most Relevant Sources

The ranking of sources (journals) with the highest number of published articles on MCDM/Fuzzy MCDM and the number of articles published in each source are presented in Table 2.

Table 2.
The most published journals

Sources	**Articles**
Sustainability	5434
PLOS One	3716
IEEE Access	2805
BMC Medical Informatics and Decision Making	2646
Journal Of Cleaner Production	2335
Scientific Reports	2310
Journal of Intelligent Fuzzy Systems	2088
Frontiers in Psychology	1665
Expert Systems with Applications	1571
BMJ Open	1409

According to Table 2, the journal Sustainability stands out as the most prolific source with 5434 articles, significantly ahead of others. It is followed by PLOS One (3716), IEEE Access (2805), and BMC Medical Informatics and Decision Making (2646). Together, these four journals account for a total of 14601 articles, representing approximately 60% of the publications listed.

- Focus Areas and Trends of the Journals

Sustainability: Covers multidisciplinary research related to sustainable development, environmental management, and climate change. Its high publication count reflects the global surge in research in these fields. PLOS One: With its broad scope and open-access policy, the journal accepts articles from all disciplines as long as methodological rigor is maintained. This flexibility explains the high number of publications. IEEE Access: An open-access journal focused on engineering and technology. Its fast publication processes and relatively low publication fees have made it popular among researchers. BMC Medical Informatics and Decision Making: Specializes in medical decision support systems, data analytics, and health informatics. The post-pandemic interest in digital health solutions likely contributed to its increased publication volume.

- Quantity-Quality Balance and Critical Reflections

Drivers Behind High Publication Counts: Open-access policies (e.g., PLOS One, IEEE Access) and low publication fees are key factors contributing to high article counts. The high output of Sustainability is directly linked to funding and policy priorities in sustainability research. Quality Concerns: A high number of publications does not necessarily correlate with journal impact factor (IF) or citation performance. For instance, while Sustainability had a 2023 IF of 3.9, Journal of Cleaner Production had a significantly higher IF of 11.1. Fast-track acceptance in journals like IEEE Access may sometimes lead to methodological shortcomings.

- Interdisciplinary Contributions

Environment and Engineering: Journal of Cleaner Production (2335 articles) and IEEE Access support research in sustainable production and green technologies. Health and Psychology: Frontiers in Psychology (1665 articles) and BMJ Open (1409 articles) highlight the intersection of decision-making with human behavior and clinical applications. Artificial Intelligence and Fuzzy Systems: Journal of Intelligent Fuzzy Systems (2088 articles) reinforces the technical foundation of fuzzy logic and decision support systems.

4.1.3. Most Relevant Authors

The authors who have published the highest number of articles related to MCDM/Fuzzy MCDM and the number of articles they have published are presented in Table 3.

Table 3.
Publication status of the authors

Authors	**Articles**
Xu, Zeshui	624
Pamučar, Dragan	418
Liu, Peide	359
Garg, Harish	338
Liao, Huchang	306
Zavadskas, Edmundas Kazimieras	290
Akram, Muhammad	273
Herrera-Viedma, Enrique	268
Pedrycz, Witold	228
Mahmood, Tahir	225

Table 3 presents the authors with the highest number of publications between 2014 and 2024.

Xu, Zeshui ranks first with 624 articles. Most Cited Article: Title: "Intuitionistic fuzzy aggregation operators" (2007). Citations: ~3000+ (Google Scholar, April 2025). Summary: New operators were defined for intuitionistic fuzzy sets and applied in MCDM. Collaboration Network: Collaborative work with researchers in China, India, and Iran has been documented on university websites.

Pamučar, Dragan is in second place with 418 articles. Most Cited Article: Title: "Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS)" (2020). Citations: ~1,200+ (Google Scholar, April 2025) Summary: The MARCOS method was integrated into supplier selection in the healthcare sector. Application: Studies related to military logistics and the defense industry have been included in NATO projects.

Table 3 indicates that researchers working in the field of MCDM and Fuzzy Logic demonstrate high productivity and contribute to a significant body of literature. Authors at the top of the list have played a key role in advancing both the theoretical and practical aspects of the field, significantly influencing the development of new approaches and methodologies.

4.1.4. Most Relevant Affiliations

Table 4 presents the publication outputs of the institutions or affiliations of the authors who have contributed to studies related to MCDM/Fuzzy MCDM.

Table 4.
Relevant affiliations that have contributed to research

Affiliation	**Article**
University of California System	8311

University of London	7592
Harvard University	6176
University System of Ohio	4336
Harvard University Medical Affiliates	4272
University of Texas System	4225
State University System of Florida	4173
University of Toronto	3987
University College London	3707
Pennsylvania Common Wealth System of Higher Education Pcshe	3676

Table 4 highlights the most prominent academic institutions that have made significant contributions to MCDM/Fuzzy MCDM research.

- Leading Institutions

The University of California System, with 8,311 articles, stands out as the leading institution in the field. It is followed by the University of London (7,592 articles) and Harvard University (6,176 articles), both demonstrating their strong research infrastructure and international prominence in areas such as MCDM and Fuzzy Logic.

- Research and Collaboration Potential

The institutions listed in Table 4 are noteworthy not only for their high publication outputs but also for their substantial contributions to the methodological and practical development of the field. The geographical and cultural diversity of these institutions highlights the widespread interdisciplinary collaborations in complex domains such as MCDM and Fuzzy Logic. This diversity fosters more comprehensive research and enriches both theoretical and applied knowledge.

4.1.5. Most Productive Countries

Figure 5 shows the countries that have published and received the most citations in MCDM/Fuzzy MCDM research.

On the map, countries with the highest number of publications are shown in dark color, those with fewer publications are in blue, and countries with no publications are in grey.

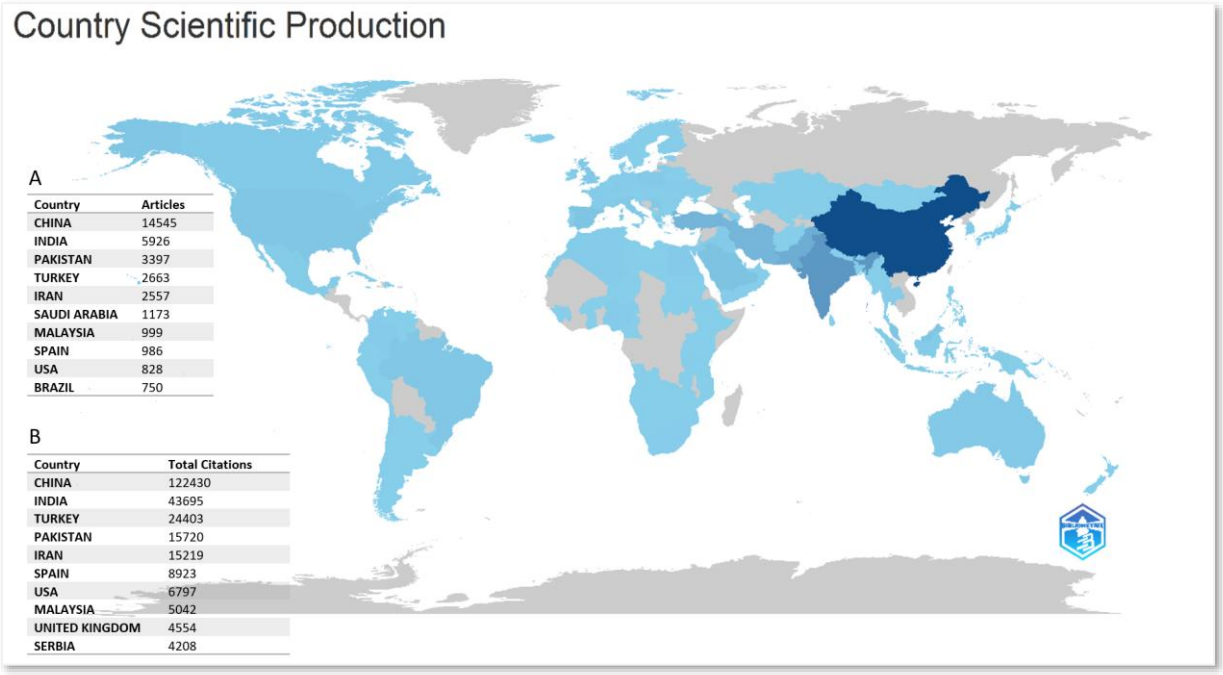

Fig. 5. Country scientific production

The data shown in Figure 5(A) represent the number of articles published by countries between 2014 and 2024. China is the clear leader in this field, with 14,545 articles, establishing itself as one of the main hubs for research activity. India (5,926) and Pakistan (3,397) have also made significant contributions, with universities and research centers in these countries actively involved in MCDM/Fuzzy MCDM studies. Turkey (2,663), Iran (2,557), and Saudi Arabia (1,173) are also noteworthy regional leaders making valuable contributions.

Figure 5(B) displays the total number of citations, representing the scientific impact of the published articles. China leads not only in the number of articles but also in scientific influence, with 122,430 citations. This indicates that China is not only highly productive but also plays a guiding role in shaping the literature. Countries such as India (46,950) and Turkey (24,403) also show that their publications have garnered considerable interest within the international academic community.

Asia stands out as a leading continent in this domain, particularly with countries like China, India, Pakistan, Turkey, and Iran taking the lead. Citation counts generally parallel the number of publications; however, in some countries (e.g., the USA and the UK), fewer but highly influential publications dominate.

4.1.6. Country Collaboration

The relationships among the countries with the highest number of collaborative publications are illustrated in Figure 6.

The table within the figure displays the collaboration frequencies between countries. The "From" column indicates the country initiating the collaboration, the "To" column shows the partner country, and the "Frequency" column represents the number of collaborations.

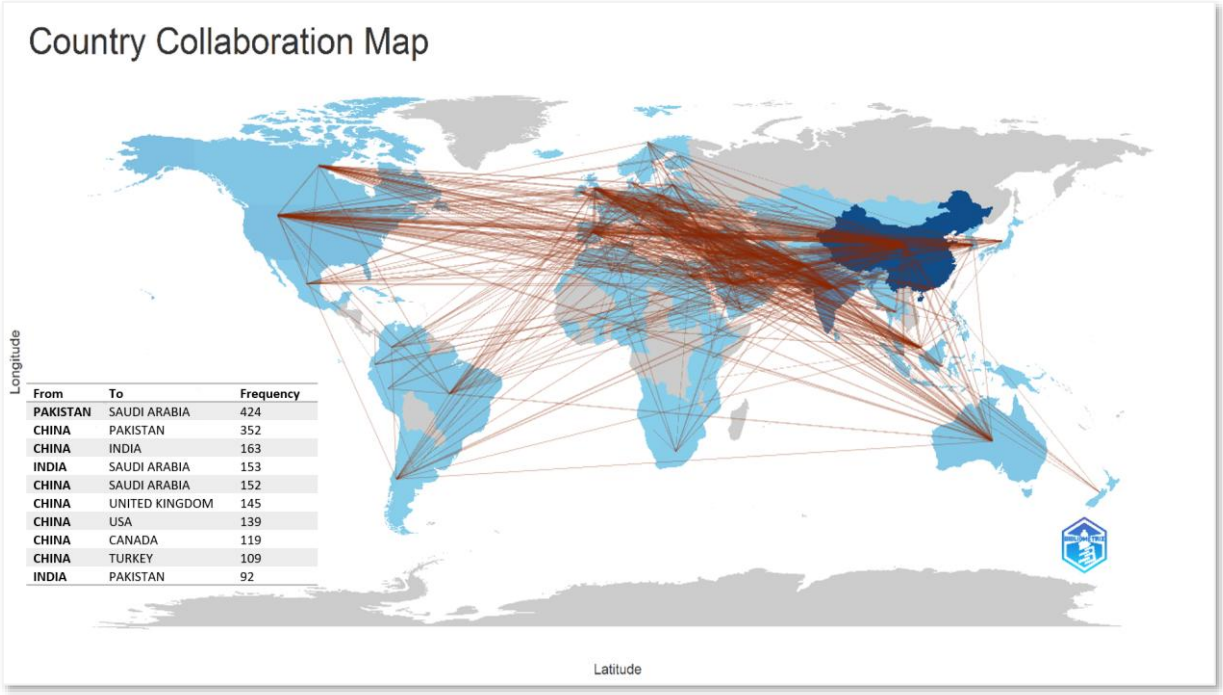

Fig. 6. Countries' Collaboration World Map

Figure 6 illustrates the international collaboration among countries involved in academic publications related to MCDM/Fuzzy MCDM.

- Country Collaboration Analysis

Pakistan & Saudi Arabia (424 collaborations) → This is the strongest partnership, suggesting that these two countries either co-author the highest number of publications or frequently cite each other's work in the field of Fuzzy MCDM. China & India (163), China & Saudi Arabia (152), China & the USA (139), and China & Turkey (109) → These data clearly indicate China's extensive academic collaboration with various countries. China's Dominance: The data show that China is potentially the global leader in Fuzzy MCDM research, engaging in numerous collaborative efforts with researchers from multiple countries.

- Academic Collaboration Trends

China's collaboration with scientifically productive countries such as India, the USA, and Turkey shows that these nations are also highly active in the field of Fuzzy MCDM. The high number of collaborations between Pakistan and Saudi Arabia may indicate that researchers from these countries often work closely together or frequently reference each other's studies.

4.1.7. Most Cited Documents

The most productive article is the one with the highest cumulative citation count. Accordingly, the top ten most cited articles are presented in Table 5.

Table 5.
Most Global Cited Documents

Paper	**DOI**	**Total Citations**
YAGER RR, 2014, IEEE TRANS FUZZY SYST	10.1109/TFUZZ.2013.2278989	2433
ZHANG X, 2014, INT J INTELL SYST	10.1002/int.21676	1388
GÜNDOĞDU FK, 2019, J INTELLIGENT FUZZY SYST	10.3233/JIFS-181401	780
PENG X, 2015, INT J INTELL SYST	10.1002/int.21738	777
LIU P, 2018, INT J INTELL SYST-a	10.1002/int.21927	769
SENAPATI T, 2020, J AMBIENT INTELL HUMANIZED COMPUT	10.1007/s12652-019-01377-0	744
GUO S, 2017, KNOWL BASED SYST	10.1016/j.knosys.2017.01.010	710
MAHMOOD T, 2019, NEURAL COMPUT APPL	10.1007/s00521-018-3521-2	659
HERRERA-VIEDMA E, 2014, INF FUSION	10.1016/j.inffus.2013.04.002	611
GARG H, 2016, INT J INTELL SYST-a	10.1002/int.21809	603

The article titled "Pythagorean Membership Grades in Multicriteria Decision Making" by Yager R.R. (2014), published in the journal IEEE Transactions on Fuzzy Systems, ranks first with 2433 citations. The second most cited paper, with 1388 citations, is "Extension of TOPSIS to Multiple Criteria Decision Making with Pythagorean Fuzzy Sets" by Zhang X. and Xu Z. (2014), published in the International Journal of Intelligent Systems. Ranked third is the study titled "Spherical fuzzy sets and spherical fuzzy TOPSIS method" by Gündoğdu F. and Kahraman C. (2019), published in the Journal of Intelligent & Fuzzy Systems, with 780 citations.

4.2. Scientific Mapping Analysis

Scientific mapping refers to the integrated application of computational techniques to visualize, analyze, and model various scientific and technical activities.

4.2.1. Word Cloud

The word cloud presented in Figure 7 represents the most prominent research themes aimed at understanding the effectiveness and outcomes of MCDM/Fuzzy MCDM methods.

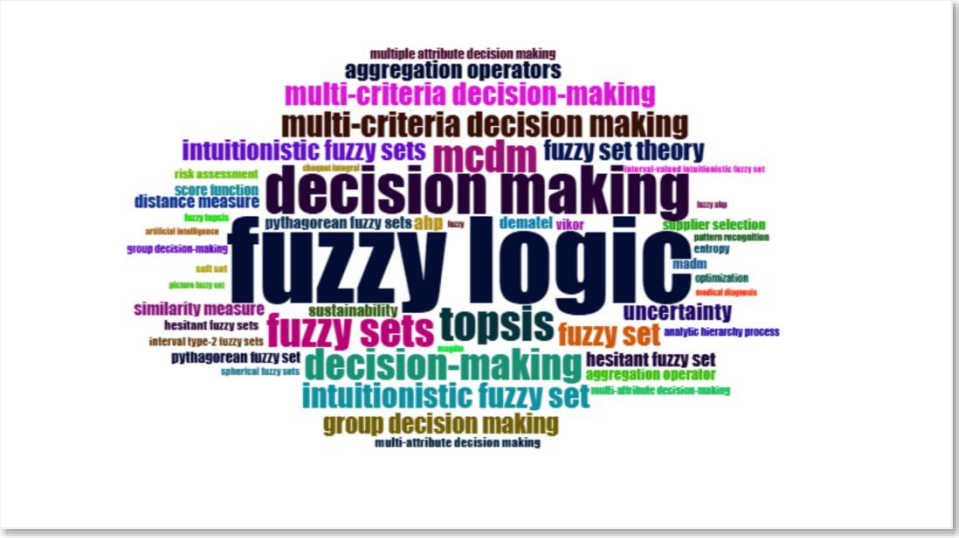

Fig. 7. Word Cloud

The words in Figure 7 reflect the content and focus areas of research related to MCDM/Fuzzy MCDM. These words can be categorized into different themes:

- Key Concepts & Theories

These terms form the foundation of fuzzy logic and MCDM. fuzzy logic (1382) → The term with the highest frequency, indicating that fuzzy logic is crucial for MCDM. fuzzy sets (536), fuzzy set (371), fuzzy set theory (320) → Fuzzy sets are used to manage uncertainty in decision-making processes. intuitionistic fuzzy set (404), intuitionistic fuzzy sets (325) → Expanded versions of classical fuzzy sets. hesitant fuzzy set (231) → A type of fuzzy set used in situations with indecisiveness. pythagorean fuzzy set (183), pythagorean fuzzy sets (198) → A model that evaluates dual membership grades more flexibly.

The terms in this category form the mathematical foundation of Fuzzy MCDM. "Fuzzy logic" and "fuzzy sets" stand out as the most fundamental theoretical concepts.

- Decision Making & MCDM Methods

These terms refer to the methods used in decision-making processes. decision making (787), decision-making (505) → General decision-making processes. multi-criteria decision making (410), multi-criteria decision-making (370) → multi-criteria decision-making processes. MCDM (518) → The abbreviation for Multi-Criteria Decision Making. group decision making (315) → Group-based decision-making processes. ahp (237) → Analytical Hierarchy Process (AHP), one of the most commonly used MCDM methods. dematel (198) → A method used to analyze the relationships between criteria. The dominant concepts in this category are "decision making" and "MCDM". The 315 frequency of the term "group decision making" indicates the popularity of group-based decision-making studies.

- Techniques & Measures Used in MCDM Methods

These terms refer to some of the mathematical and statistical tools used in MCDM methods. topsis (566) → One of the most popular MCDM techniques. aggregation operators (294), aggregation operator (186) → Operators used to combine different criteria. distance measure (212) → Metrics used to measure the distance between criteria or alternatives. similarity measure (211) → Metrics used to measure similarity between alternatives. score function (177) → Functions used to rank alternatives.

In this category, the TOPSIS method stands out. Additionally, distance measures, similarity measures, and score functions play a significant role in decision-making.

- Uncertainty & Sustainability Concepts

These terms focus on managing uncertainty in decision-making processes and sustainability issues. uncertainty (284) → Refers to uncertainty in decision-making processes. sustainability (197) → Indicates that research related to sustainability is linked with Fuzzy MCDM. The term "uncertainty" with a frequency of 284 highlights the importance of managing uncertainty. "Sustainability" shows how sustainable decision-making processes are addressed in the context of Fuzzy MCDM. Advanced Fuzzy Sets (Intuitionistic, Hesitant, Pythagorean): This is an important area, indicating the use of new approaches in cases where classical fuzzy logic is insufficient.

4.2.2. Trend Topics

The trend topics in the MCDM/Fuzzy MCDM literature from 2014 to 2024 are shown in Table 6.

Table 6.
Trending Topics by Year

Term	Frequency	Year (Q1)	Year (Q2)	Year (Q3)
decision making	10086	2018	2020	2023
fuzzy sets	5526	2018	2020	2023
fuzzy logic	3085	2017	2020	2022
mathematical operators	1361	2018	2021	2023
aggregation operator	964	2019	2021	2023
decisions makings	959	2022	2023	2024
sensitivity analysis	938	2020	2022	2023
uncertainty	906	2019	2022	2023
fuzzy rules	706	2017	2019	2022
sustainable development	690	2019	2022	2023
human	578	2018	2021	2023
multicriteria decision-making	566	2022	2023	2024
multi criteria decision-making	501	2022	2023	2024
multiple attribute decision making	443	2017	2019	2022
multi criteria decision making	422	2016	2018	2020
optimization	349	2016	2018	2022
fuzzy systems	311	2016	2018	2021
linear programming	291	2016	2019	2021
set theory	175	2016	2017	2019
problem solving	119	2015	2017	2019
deep learning	67	2023	2024	2024
computational linguistics	60	2015	2016	2016
reconfigurable hardware	49	2016	2016	2016
multiple criteria decision analysis	46	2015	2017	2020
machine-learning	41	2023	2024	2024

The findings presented in Table 6 reveal the popularity and research intensity of key terms in the relevant literature over time. By considering the years when the terms first appeared, significant inferences can be made regarding the development process of the field and research trends.

Between 2015 and 2017, it is observed that the majority of terms in the literature were based on more theoretical foundations. Terms like problem solving, multiple criteria decision analysis, and

computational linguistics were frequently used during this period, indicating the classical and foundational approaches in the field.

The years 2018–2020 stand out as a period where topics such as decision-making under uncertainty and fuzzy logic gained prominence. During this period, terms like decision making, fuzzy sets, fuzzy logic, mathematical operators, and uncertainty were heavily used and widely represented in the literature. This suggests that models considering fuzziness and multi-criteria aspects in decision-making processes were becoming increasingly important.

From 2022 onwards, in parallel with technological advancements, more contemporary and data-driven terms started to emerge in the literature. Concepts such as multi-criteria decision-making, deep learning, and machine learning gained prominence during this period, marking the formation of a new research axis where multi-criteria decision-making approaches were integrated with artificial intelligence and machine learning.

These findings indicate that the general trend in the literature has evolved from classical and theoretical foundations to more innovative, application-oriented, and technology-based methods. This shift in the field suggests that interdisciplinary integrated approaches will gain more importance in future research.

4.2.4. Keyword Analysis

Figure 8 is a network map created using VOSviewer software. Such maps are typically used to visualize the relationships between key terms or concepts in scientific publications.

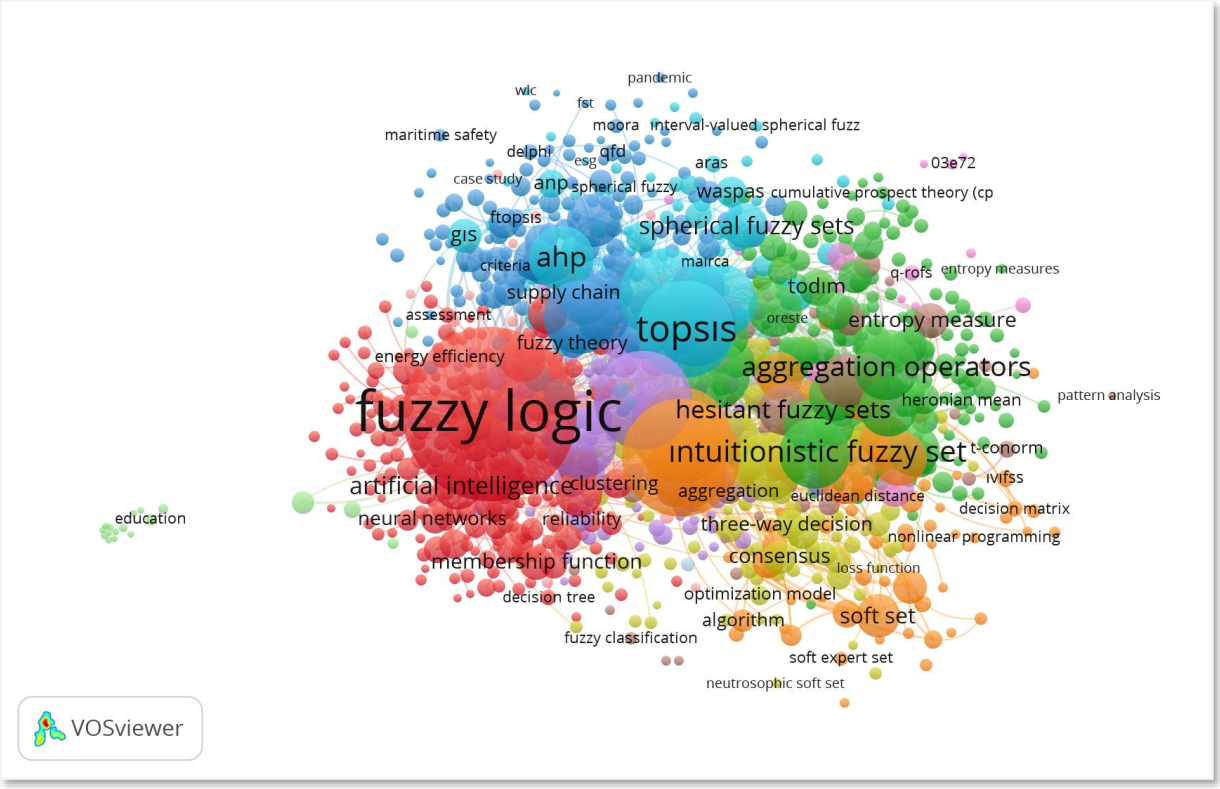

Fig. 8. Keyword Network Map

The terms provided in Figure 8 are categorized by their meanings, methodological approaches, and application areas, with each group being detailed and explained as follows:

- BLUE: Multi-Criteria Decision Making (MCDM) Methods and Optimization

TOPSIS: A technique that measures the proximity of alternatives to the ideal solution. For example, supplier selection in supply chain management. MAIRCA: A method used to evaluate the

performance of alternatives in multi-criteria problems. TODIM: A behavioural decision-making model that takes psychological factors into account. Three-way Decision Consensus: A triple decision mechanism (accept, reject, defer) under uncertainty. Optimization Model Algorithm: A general optimization framework used in problems like resource allocation or cost minimization. GLS (Generalized Least Squares): A regression method used in statistical data analysis to correct variance instability. Aggregation Operators: Operators used to combine fuzzy or crisp data into a single value (e.g., weighted average).

The blue category encompasses analytical decision-making and optimization techniques. These methods are commonly used in industrial planning, financial risk management, and operational research. Particularly, TOPSIS and MAIRCA offer flexible structures for ranking alternatives in complex scenarios.

- GREEN: Fuzzy Logic and Extended Set Theories

Spherical Fuzzy Sets (Spherical might be a misspelling): A set theory that represents membership, non-membership, and hesitation degrees in three-dimensional space. Hesitant Fuzzy Sets: Used to model uncertainty in decision-makers' preferences. Intuitionistic Fuzzy Sets: An extension of classical fuzzy sets that separately handles membership and non-membership degrees. Neutrosophic Soft Set: A hybrid set theory that models uncertainty, inconsistency, and neutrality simultaneously. Fuzzy Logic: A system that works with uncertain data and makes graded inferences instead of binary logic ("0-1"). Membership Function: A function that defines the membership degree of elements in fuzzy sets. Soft Expert Set: A model that mathematically formalizes expert opinions.

The green category is related to uncertainty management and flexible decision models. Spherical and Intuitionistic fuzzy sets are used in fields like medical diagnostic systems or environmental risk assessment to process complex data.

- ORANGE: Application Areas and Practical Solutions

Maritime Safety: Optimization of safety protocols in maritime settings (e.g., accident risk analysis using fuzzy MCDM). Energy Efficiency: Decision models for reducing energy consumption (smart grid management). Case Study: Case analyses where theoretical methods are applied to real-world problems. Education: Performance evaluation or curriculum optimization in education.

The orange category represents interdisciplinary applications. For example, fuzzy logic can be used to minimize human errors in Maritime Safety, while Energy Efficiency plays a critical role in evaluating renewable energy projects.

- RED: Artificial Intelligence and Data Analytics

Artificial Intelligence: Machine learning and deep learning algorithms. Neural Networks: Pattern recognition and prediction models. Decision Tree: Hierarchical decision rules for classification and regression. Fuzzy Classification: Fuzzy logic-based classification systems.

The red category is related to data-driven solutions and automation. For instance, Fuzzy Classification provides high accuracy in uncertain data sets, such as tumour detection in medical images.

This categorization highlights the synergy between theoretical methodologies and practical applications. Specifically, the integration of fuzzy logic and artificial intelligence presents a productive area for future research. Clarifying ambiguous terms and fostering interdisciplinary collaborations will accelerate the development of the field.

5. Discussion

In this study, a bibliometric analysis was conducted to understand the development and usage of MCDM/Fuzzy MCDM methods in the scientific literature. The literature review process, using the

Scopus database, allowed for the inclusion of 13278 articles published between 2014 and 2024 out of 30144 articles. This analysis thoroughly presents the effective use of MCDM methods in various fields, author collaborations, research trends, and important works.

The data analysis reveals that there is a significant academic production in the MCDM/Fuzzy MCDM field, with an annual growth rate of 13.38%. This indicates that the research field is dynamically developing and has the potential for further growth in the future. On the other hand, the decrease in citations per article can be attributed to the increasing number of articles in the field and the fact that these publications have not yet received enough citations. This suggests that the surplus of information in the literature and the rapidly increasing number of publications may negatively affect the visibility of individual works.

Among the journals with the highest number of publications, open-access journals such as Sustainability, PLOS One, and IEEE Access stand out. The high increase in the number of publications in these journals reflects the significant place these fields occupy in the global research agenda. However, the fast acceptance processes of these journals may sometimes lead to methodological weaknesses. Additionally, the high publication number of Sustainability reflects the growing interest in the sustainability field and the impact of funding and policy priorities on these journals.

From the perspective of authors, researchers such as Zeshui Xu and Dragan Pamučar are the most prolific names in the MCDM and Fuzzy MCDM fields. These authors have made significant contributions to both the theoretical and practical developments of the field and have been pioneers in identifying new approaches in the field. Particularly, Xu's development of operators for intuitionistic fuzzy sets and Pamučar's new MCDM methods used in supplier selection in the healthcare sector are major milestones in the field.

When examining the data on leading academic institutions contributing to MCDM/Fuzzy MCDM topics, it is seen that the University of California System holds a leading position in this field. This university has reached the highest number with 8311 articles, demonstrating the strength of its research infrastructure and the contributions it has made to methodological developments in the field. Other prestigious institutions such as Harvard University and the University of London also hold significant positions with 6176 and 7592 articles, respectively. This indicates that these institutions have a strong research capacity in complex topics like MCDM and Fuzzy Logic on the international stage.

Furthermore, the geographical diversity and international collaborations of these institutions pave the way for interdisciplinary studies. Topics such as MCDM and Fuzzy Logic become more comprehensive with contributions from researchers from various fields, enriching both theoretical and practical knowledge. The high number of articles from these institutions allows them to create a broader scientific impact.

The most publishing and most cited countries in the MCDM/Fuzzy MCDM field are shown. China stands out as the most productive country in this field, with 14545 articles, not only in terms of productivity but also as a leader in scientific impact with 122430 citations. The high productivity and citation count of China indicate that the country has a strong research infrastructure in the Fuzzy MCDM field and plays a leading role in guiding the literature. Countries such as India, Pakistan, and Turkey also make significant contributions, having a major impact in this field.

China's academic collaboration with countries such as India, Pakistan, Turkey, and Iran shows that these countries are also active in the MCDM/Fuzzy MCDM field and are conducting important research. The collaboration between these countries not only increases regional scientific interaction but also fosters global scientific collaboration. The frequency of collaborations between countries and the relationships between them are displayed. In particular, the intense collaboration between

China and India, as well as China and Saudi Arabia, shows that these countries are actively conducting research in the Fuzzy MCDM field. The high frequency of collaboration between Pakistan and Saudi Arabia reveals that the research ecosystems of these two countries are tightly integrated and they heavily reference each other's work. China's collaborations with scientifically strong countries like India, the United States, and Turkey indicate its active participation in the global research community and the increase in scientific knowledge sharing with these countries.

The most cited articles in the MCDM/Fuzzy MCDM field can be considered as cornerstones of the field and represent methodological advancements. In particular, the article titled "Pythagorean Membership Grades in Multicriteria Decision Making" written by Yager RR and published in IEEE Transactions on Fuzzy Systems is the most cited article in this field, with 2433 citations. This study is a significant milestone in the Fuzzy MCDM field and is frequently referenced by researchers.

The scientific mapping analysis provides important perspectives on the development of MCDM/Fuzzy MCDM methods and emerging trends. Based on the results presented, the following key points are discussed:

- Dominance of Fuzzy Logic and MCDM Methods

The word cloud analysis clearly highlights the central role of core concepts such as fuzzy logic, fuzzy sets, and multicriteria decision making (MCDM). The high frequency of these terms indicates that they form the foundation of the field and that much of the research is based on these core theories. The importance of the term fuzzy logic (1382 times) underscores its critical role in managing uncertainty and its vital role in decision-making processes. Additionally, fuzzy sets and their extended versions, such as intuitionistic fuzzy sets and hesitant fuzzy sets, are gaining more importance as they provide more sophisticated models for situations where classical fuzzy logic falls short. These advanced fuzzy sets play an important role in modeling more complex uncertainties and improving decision processes.

- Evolution of Decision-Making Models

The shift from traditional decision-making techniques to more complex multicriteria approaches is clearly visible in the word cloud and analysis of trend topics. The increasing frequency of methods like MCDM, TOPSIS, AHP, and MAIRCA indicates that research is now focusing on models that consider multiple factors. Furthermore, the increasing frequency of terms like group decision-making and aggregation operators highlights that decision-making processes are becoming more collaborative, with multiple inputs being integrated to produce more holistic and accurate solutions. The evolution of MCDM methods is not only managing uncertainty but also progressing towards developing optimized approaches that can provide practical and applicable solutions in the real world.

- Integration of Advanced Techniques and Technologies

The terms deep learning and machine learning appearing in recent trend topics indicate the intersection of classical decision-making models and emerging technologies. These techniques enable MCDM methods to generate more sophisticated, data-driven solutions. The integration of machine learning algorithms enhances the predictive power of MCDM methods, allowing for more accurate and efficient decision-making. This intersection creates a promising direction for future research, particularly in optimization and artificial intelligence.

- Applications and Practical Solutions

The keyword network analysis reveals the potential application of MCDM/Fuzzy MCDM methods in various fields. Particularly, areas such as energy efficiency, maritime safety, and sustainability stand out. This reflects a global trend towards solving environmental and resource-based issues with

smarter decision-making frameworks. The integration of fuzzy logic in these areas helps optimize processes, reduce risks, and manage uncertainty. Moreover, the use of methods like fuzzy classification in medical imaging highlights the practical value of these methods. The diversification in application areas shows that the MCDM/Fuzzy MCDM field has become interdisciplinary and is playing an increasingly important role in different industries.

- Technological Innovations and Future Directions

The categorization in the keyword network map emphasizes the integration of fuzzy logic with emerging technologies such as artificial intelligence, neural networks, and data analytics. The rise of neural networks and fuzzy classification terms indicates the increasing importance of integrating these technologies into decision-making processes. These technologies are crucial for effectively managing both uncertain data and large datasets and will play a significant role in decision-making processes in the future. In the future, deeper integrations with machine learning and artificial intelligence will be required to make MCDM/Fuzzy MCDM methods more adaptive, dynamic, and efficient.

- Implications for Research and Collaboration

The scientific mapping analysis highlights global collaboration trends in the MCDM/Fuzzy MCDM field, particularly the leadership of countries like China, India, and the United States. The importance of international collaborations plays a critical role in pushing the boundaries of research and in the development of the field. Furthermore, the concentration of research activities in Asia shows the region's leadership in producing innovative research and setting global trends in this field.

In conclusion, the scientific mapping analysis of the MCDM/Fuzzy MCDM field reveals that this area is rapidly developing. The integration of advanced decision-making methods, optimization techniques, and artificial intelligence is becoming increasingly important. The future of this field signals a period in which interdisciplinary collaborations, the integration of new technologies, and the expansion of application areas will take center stage.

5.1. Limitations of the Study

Although this study aims to thoroughly examine the development of MCDM/Fuzzy MCDM methods in the scientific literature, several limitations exist:

- Data Source and Access Limitations

The data source used in this study is limited to the Scopus database. While Scopus is a comprehensive database, other academic databases (e.g., Web of Science, Google Scholar), as well as books, book chapters, and conference proceedings, have been excluded. This means that the literature review is not fully comprehensive, and therefore, some important works may have been omitted from the analysis.

- Time Constraints

This study analyzed 13,278 articles published only between 2014 and 2024. While this period provides a sufficient timeframe to examine recent developments, excluding studies published in previous years hinders a full understanding of long-term trends in the MCDM/Fuzzy MCDM field. Studies with a broader historical perspective could have addressed the earlier evolution of this field more comprehensively.

- Language and Publication Type Limitations

The study focused only on articles published in English. Significant works published in other languages have been overlooked. This may have excluded studies published in countries such as China and India. Additionally, only journal articles and publications have been considered, while other types of

academic publications, such as books, reports, theses, or conference papers, have not been included in the analysis.

- Analysis Based Solely on Quantitative Data

The bibliometric analysis used in this study is primarily based on numerical data, which means that there was limited examination of qualitative factors such as the methodological depth, application areas, or theoretical contributions of the research. Numerical data only reflect the volume of research outputs and provide limited insight into the quality, innovative contributions, and practical potential of the studies.

- Methodology and Generalizability

Since bibliometric analysis is largely based on numerical data, it was only able to trace large-scale trends and research directions. This approach has limited ability to analyze theoretical or methodological innovations found in individual studies. Moreover, while the study has focused on a specific research area to provide a general guide, it does not reflect all MCDM application areas and methodological approaches.

- Impact of Geographical and Cultural Factors

The geographical and cultural differences in the use of MCDM/Fuzzy MCDM methods require a more in-depth examination of how these methods are adapted in different regions. However, this study only examined global trends in general and is limited in revealing differences across specific regions. More research is needed, especially regarding how these methods differ in various cultural and geographical contexts.

These limitations offer significant opportunities for future research. Using broader databases in literature reviews, analyzing longer time periods, and including publications in different languages and types could expand the scope of the research and allow for more in-depth results.

6. Conclusion

This study conducted a comprehensive bibliometric review to analyze the development and use of MCDM/Fuzzy MCDM methods in the scientific literature. The analysis reveals that research in the MCDM/Fuzzy MCDM field has been rapidly increasing, showing dynamic growth with high growth rates. Despite the overwhelming amount of information in the literature and the increasing number of publications from 2014 to 2024, individual studies in this field have started to gain more visibility.

The academic output of MCDM/Fuzzy MCDM methods is particularly supported by the large number of papers published in open-access journals. While the fast acceptance processes in these journals may lead to methodological weaknesses, they also demonstrate that this field holds a significant position in the global research agenda. Prominent authors and academic institutions have made significant contributions to research in this field and have led the development of innovative approaches.

Countries led by China stand out in terms of productivity and scientific impact in the MCDM/Fuzzy MCDM field. Academic collaborations between countries have increased knowledge sharing and global scientific interaction, allowing for the enrichment of interdisciplinary studies. The collaborations between countries such as China, India, Pakistan, and Turkey indicate that research in this field has a global impact.

The literature review and scientific mapping analysis emphasize the importance of integrating fundamental concepts and emerging technologies in this field. Fuzzy logic and MCDM methods are fundamental tools used to manage uncertainty in decision-making processes and produce more accurate solutions. Furthermore, the integration of advanced technologies such as deep learning and

machine learning will enable MCDM methods to produce more sophisticated, data-driven solutions, contributing to making decision-making processes more efficient in the future.

The application areas of MCDM/Fuzzy MCDM methods are expanding, offering significant solutions in fields such as energy efficiency, maritime safety, and sustainability. Moreover, practical applications in areas like medical imaging highlight the interdisciplinary nature of these methods and their importance across different industries.

In conclusion, the future of MCDM/Fuzzy MCDM methods seems to be shaped by interdisciplinary collaborations and the integration of new technologies. The continued growth of this field will enable the development of more adaptive, dynamic, and efficient decision-making methods and contribute to solving global challenges.

6.1. Suggestions for Future Research

Scientific research in the MCDM/Fuzzy MCDM field is rapidly developing, and there are many potential directions for future studies. Research in the following areas could enhance the body of knowledge in this field and contribute to the development of more efficient solutions:

- Advanced Algorithms and Artificial Intelligence Integration

In the future, integrating MCDM/Fuzzy MCDM methods with more advanced machine learning algorithms and artificial intelligence techniques will be an important research topic. Specifically, modern AI approaches like deep learning and evolutionary algorithms are believed to make decision-making processes more precise and efficient. Such studies will enable effective decisions on more complex and large data sets.

- Big Data and Fuzzy MCDM

The integration of big data analytics with MCDM/Fuzzy MCDM methods can make decision-making processes more efficient, especially in areas where data volume is large. Future research could focus on the applications of these methods on big data sets, aiming to improve decision-making processes involving high-dimensional data.

- Sectoral Applications and Industry-Focused Research

The application areas of MCDM/Fuzzy MCDM methods are increasingly diversifying. It is important to deepen studies in areas such as sustainability, energy efficiency, healthcare, maritime safety, and logistics. Sector-focused research should investigate how the practical applications of these methods can be made more effective. In particular, the integration of environmental and social factors in decision-making processes will contribute to developing more sustainable solutions in these areas.

- Fuzzy Sets and Alternative Models

A broader exploration of alternative models, such as fuzzy sets and advanced fuzzy sets (e.g., intuitionistic fuzzy sets and hesitant fuzzy sets), will allow for more sophisticated and real-world applicable solutions in decision-making processes. These models' ability to model uncertainties in decision problems more accurately could offer more effective solutions in applied fields.

- Exploring Human Factors in Decision-Making Processes

Human factors are particularly important in group decision-making processes. Therefore, research on the integration of MCDM/Fuzzy MCDM methods with human behavior can make decision-making processes more realistic and applicable. Research focusing on group decision-making theories, individual decision-making models, and community dynamics could be a significant topic in the future.

- MCDM in Complex Systems

Modeling and solving complex systems is emerging as a new research area for MCDM and Fuzzy MCDM methods. Specifically, improving decision-making processes in complex and dynamic systems

could contribute to understanding much larger and more complicated systems. These types of systems may be associated with large-scale projects such as urban planning, transportation, and environmental management.

- International and Interdisciplinary Collaborations

Increasing international and interdisciplinary collaborations in MCDM/Fuzzy MCDM studies is important. Bringing together experts from different fields will allow for new perspectives and innovative solutions. Furthermore, collaborations in this field will help generate joint solutions to global-scale problems.

- Development of Innovative Methods

In addition to MCDM/Fuzzy MCDM methods, developing more innovative and unique decision-making methods will be an important step in the evolution of this field. Specifically, creating hybrid models by combining various decision-making techniques will allow for more flexible and efficient decision-making processes.

Future research should aim to make a strong impact not only theoretically but also through practical applications. In this regard, a more comprehensive approach to MCDM/Fuzzy MCDM methods will ensure that decision-making processes are carried out more effectively and efficiently.

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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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