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A Comprehensive and Systematic Review of Multi-Criteria Decision-Making (MCDM) Methods to Solve Decision-Making Problems: Two Decades from 2004 to 2024

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ABSTRACT

Decision-making in complex, multifaceted scenarios has become increasingly critical across diverse sectors, necessitating robust frameworks like Multi-Criteria Decision-Making (MCDM). Over the past two decades (2004–2024), MCDM has transformed from foundational methods like AHP and TOPSIS into dynamic hybrid models integrating artificial intelligence, fuzzy logic, and machine learning. Despite significant strides, the field faces challenges in addressing geographic disparities, underexplored domains and adapting to emerging global needs. This study provides a comprehensive review of MCDM's evolution, consolidating insights from 3,655 peer-reviewed articles sourced through Dimensions.ai and analyzed using bibliometric tools like VOSviewer. The research identifies publication trends, leading contributors, thematic clusters, and collaborative networks while pinpointing gaps and opportunities for future exploration. These Key findings highlight exponential growth in MCDM applications, particularly in sustainable energy, urban planning, and healthcare optimization. These advancements align with global priorities, including the United Nations Sustainable Development Goals (SDGs) such as clean energy, climate action, and sustainable cities. However, critical gaps remain in addressing issues like poverty alleviation, gender equity, and biodiversity conservation, emphasizing the need for broader interdisciplinary applications. This review concludes that MCDM's potential lies in embracing inclusivity, advancing into emerging technologies like blockchain and the metaverse, and fostering collaboration across underrepresented regions and domains. By harnessing real-time data, immersive simulations, and secure decision-making platforms, MCDM can redefine how global challenges are addressed.

1. Introduction

Multi-criteria decision-making (MCDM) is a comprehensive set of methodologies designed to assist decision-makers in evaluating and prioritizing alternatives when multiple, often conflicting

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criteria must be considered [1]. Unlike single-criteria approaches, MCDM frameworks integrate quantitative and qualitativefigure factors, providing a structured, systematic process for navigating complex decision-making environments. Broadly categorized into Multi-Attribute Decision-Making (MADM) and Multi-Objective Decision-Making (MODM), these methods are pivotal in addressing diverse challenges, ranging from resource allocation to strategic planning. MADM is typically used for discrete problems with limited alternatives, whereas MODM focuses on continuous problems, often involving optimization [2].

Decision-making is critical to organizational, societal, and individual processes, influencing outcomes across various sectors. In engineering, MCDM enables resource optimization, project evaluation, and risk assessment [3]. Environmental sciences rely on these methods for sustainable resource management, climate change mitigation, and impact analysis. MCDM is vital in technology assessment, resource prioritization, and patient care management [4]. Similarly, businesses use MCDM to evaluate suppliers, optimize financial portfolios, and develop strategic initiatives, while policymakers leverage these methods for urban planning, social welfare prioritization, and governance strategies. By systematically addressing the complexities and trade-offs inherent in these fields, MCDM ensures informed, balanced, and robust decisions [5].

The evolution of MCDM methods over the years reflects significant advancements in methodology and applications. Foundational methods such as the Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) have been widely adopted across disciplines [6]. Furthermore, integrating fuzzy logic, artificial intelligence (AI), and machine learning into traditional MCDM frameworks has led to the development of hybrid approaches, enhancing their applicability and effectiveness in solving modern decision-making problems. The availability of computational tools like VOSviewer has further facilitated the scalability and visual representation of complex MCDM datasets, driving exponential growth in research and applications [7].

The period from 2004 to 2024 represents two decades of transformative progress in MCDM, characterized by exponential growth in academic publications and industrial adoption. This era has witnessed the emergence of hybrid models that combine MCDM with advanced technologies like AI and big data, enabling decision-support systems with unprecedented precision and adaptability. Research contributions from leading countries such as China, India, and Lithuania have propelled the field forward with significant innovations in methodologies and applications. Moreover, MCDM's applicability has expanded into emerging domains, including renewable energy, smart cities, and blockchain technologies, highlighting its versatility and relevance.

Given this rapid expansion, a comprehensive and systematic review of MCDM methods over the past two decades is crucial. Such a review will consolidate existing knowledge and identify prevailing trends, highlight research gaps, and provide valuable insights for future research. By examining the evolution of MCDM from 2004 to 2024, this study aims to contribute to the growing body of literature and support the development of more effective and innovative decision-making frameworks for academia and industry.

1.2 Literature Review

The evolution of MCDM methods highlights their critical role in addressing complex decision-making scenarios across diverse sectors (Table 1). Foundational methods such as the AHP, TOPSIS, PROMETHEE, and ELECTRE have been extensively studied and applied. Zavadskas *et al.,* [8] reviewed these methods in-depth, analyzing their strengths, limitations, and historical evolution. Their work remains a cornerstone for understanding MCDM frameworks and their wide-ranging applicability. Hybrid approaches have emerged to address the limitations of standalone techniques. These models integrate traditional MCDM methods with advanced computational tools such as fuzzy logic, artificial intelligence (AI), and machine learning. Saoud *et al.*, [9] introduced "decideXpert," a collaborative decision-making system combining AHP-TOPSIS with fuzzy logic for enhanced group decision-making [9]. Radulescu and Radulescu [10] proposed a hybrid model integrating SAW, TOPSIS, VIKOR, and COPRAS methods for IoT selection problems, illustrating the versatility of hybrid frameworks in tackling complex technological challenges [10].

The flexibility of MCDM methods has led to their adoption across various fields:

i. *Engineering*: In engineering, MCDM methods have been instrumental in optimizing resource allocation and infrastructure development. Sivalingam and Subramaniam [11] applied a hybrid AHP-TOPSIS model to cobot selection in the fuel filter assembly process, emphasizing its practical relevance in industrial automation [11]. Topaloğlu [12] developed a new hybrid MCDM method for facility location selection, addressing logistical complexities in urban planning.
ii. *Environmental Sciences*: MCDM techniques, particularly PROMETHEE and ELECTRE, are widely employed in environmental sustainability. These methods have evaluated trade-offs between economic development and environmental preservation Zavadskas *et al.,* [8]. Stojčić *et al.*, [13] reviewed the application of MCDM methods in sustainability engineering, highlighting their role in climate change mitigation and resource management.
iii. *Healthcare*: The healthcare sector has leveraged MCDM for efficient resource prioritization and performance evaluation. Stević *et al.*, [14] introduced the MARCOS method to enhance supplier selection in healthcare, while Mahmoodirad *et al.*, [15] applied a picture fuzzy BCC model for evaluating hospital performance. These studies demonstrate MCDM's ability to navigate the complexities of healthcare decision-making.
iv. *Business and Economics*: MCDM methods are extensively utilized in strategic decision-making, supplier evaluation, and financial analysis. Karatas *et al.*, [16] applied MCDM techniques in Industry 4.0, exploring their role in addressing challenges in the healthcare sector. Pamučar and Ćirović [17] extended the MABAC method to improve logistics operations, showcasing its utility in business environments.

The methodological diversity within MCDM is evident in the distinction between the American and European schools. The American school emphasizes simplicity and value-based models such as AHP and SMART, while the European school focuses on outranking techniques like PROMETHEE and ELECTRE. Zavadskas *et al.*, [8] compared these approaches, highlighting their strengths and weaknesses. Hybrid methods, such as those proposed by Deveci *et al.*, [18], bridge the gaps by integrating complementary techniques for enhanced decision-making.

The integration of emerging technologies has expanded the scope of MCDM applications. He introduced a metaverse assessment model using ordinal priority approaches, demonstrating MCDM's applicability in virtual environments. Pamucar *et al.*, [19] proposed decision-support systems for sustainable urban transportation, while Radulescu and Radulescu [10] focused on IoT-related decision-making challenges. Ala *et al.*, [20] explored hybrid decision-making models for wind energy optimization, showcasing the adaptability of MCDM in renewable energy applications.

1.3 Research Gaps

Despite significant advancements, gaps remain in the application of MCDM methods. Zavadskas *et al.,* [8] and Stojčić *et al.*, [13] noted the underrepresentation of interdisciplinary applications in areas such as blockchain and IoT. Karatas *et al.*, [16] and Deveci *et al.*, [18] emphasized challenges in implementing AI-integrated MCDM frameworks, citing computational complexity and a lack of accessibility. Mahmoodirad *et al.*, [15] also highlighted the need for more studies addressing geographic diversity, as research remains concentrated in developed regions. Addressing these gaps through collaborative research and advanced computational tools can further enhance MCDM's role in solving complex decision problems. By leveraging its methodological robustness and integrating cutting-edge technologies, MCDM can continue to adapt to the evolving demands of modern decision-making.

Table 1
Past Literature on MCDM Methods

Authors	Title of Work	Findings	Domains
Zavadskas *et al.,* [8]	State of art surveys of overviews on MCDM/MADM methods	MCDM techniques are adaptable and widely used in decision-making	General MCDM Applications
Saoud *et al.,* [9]	DecideXpert: Collaborative system using AHP-TOPSIS and fuzzy techniques	Collaborative decision-making is improved through hybrid systems	Collaborative Decision-Making
Radulescu and Radulescu [10]	A Hybrid Group Multi-Criteria Approach for IoT Selection Problems	Hybrid models outperform standalone methods in IoT selection	IoT Selection
Sivalingam and Subramaniam [11]	Cobot selection using hybrid AHP-TOPSIS for fuel filter assembly process	AHP-TOPSIS ensures optimized cobot selection for industrial automation	Industrial Automation
Topaloğlu [12]	Development of a new hybrid method for facility location selection	Hybrid models are effective for logistical decisions	Logistics Optimization
Stojčić *et al.*, [13]	Application of MCDM methods in sustainability engineering: A Literature Review 2008–2018	MCDM is crucial for evaluating trade-offs in sustainability	Sustainability Engineering
Stević *et al.,* [14]	Sustainable supplier selection in healthcare industries using MARCOS	MARCOS enhances supplier evaluation processes	Healthcare Procurement
Mahmoodirad *et al.*, [15]	Data envelopment analysis-based performance evaluation of hospitals–Implementation of novel picture fuzzy BCC model.	Picture fuzzy methods improve evaluation accuracy	Hospital Performance Evaluation
Karatas *et al.,* [16]	Big Data for Healthcare Industry 4.0: Applications, challenges, and future perspectives	MCDM facilitates effective decision-making in complex data environments	Industry 4.0
Pamučar and Ćirović [17]	The selection of transport and handling resources in logistics centers	Enhanced MABAC achieves better results in logistics planning	Logistics Management
Deveci *et al.*, [18]	A decision support system for sustainable urban transportation in the Metaverse	MCDM improves sustainable urban transportation planning in virtual environments	Metaverse Technologies
Pamucar *et al.*, [19]	A metaverse assessment model for sustainable transportation	Supports urban transportation sustainability using MCDM	Urban Transportation
Ala *et al.*, [20]	Evaluating algorithms for wind energy optimization: A Hybrid Decision-Making	Hybrid models improve efficiency in renewable energy systems	Renewable Energy

Authors	Title of Work	Findings	Domains
	model. Expert Systems with Applications		
Chyad *et al.,* [21]	Exploring adversarial deep learning for skin detection applications	Adversarial deep learning enhances detection accuracy	AI and Multi-Color Channel Applications
Leung and Zhang [22]	Particle swarm optimization tuned LSTM for fuel price forecasting	Hybrid models improve forecasting accuracy	Energy Economics
Karagoz *et al.*, [23]	A novel intuitionist fuzzy CODAS approach for locating dismantling centers	Intuitionist fuzzy approaches improve dismantling center planning	Waste Management
Simic *et al.,* [24]	Fermat fuzzy group decision-making based CODAS approach for taxation of transit investments	Fuzzy methods optimize public finance in transit systems	Public Transit Investments
Deveci *et al.,* [25]	Personal mobility in Metaverse with autonomous vehicles using Q-rung orthopedic fuzzy sets	Optimized autonomous mobility decisions in virtual spaces	Mobility in the Metaverse

1.4 Organization of the Study

This study is organized into five sections. Section 1: Introduction discusses the significance of Multi-Criteria Decision-Making (MCDM), its evolution, and the research objectives of this systematic review. Section 2: Methodology details the data sources (Dimensions.ai). And bibliometric tools (VOSviewer, 1.6.20) were used for analysis. Section 3: Results present findings such as keyword trends, citation analysis, and collaboration patterns through visualizations. Section 4: Discussion interprets the results, highlights research gaps, explores emerging technologies, and offers actionable insights. Section 5: Conclusion summarizes key findings and provides recommendations for advancing MCDM research, emphasizing interdisciplinary approaches and future opportunities.

2. Methodology

This study adopts a bibliometric analysis approach to review MCDM research (2004–2024). Data was sourced from Dimensions.ai using keywords (Figure 1) like "AHP," "TOPSIS," "VIKOR," "PROMETHEE," and "ELECTRE," focusing on UGC Group II journals. 3655 Articles were analyzed using VOSviewer to identify publication trends, co-authorship networks, and thematic patterns. Key analyses included citation impact, keyword mapping, and collaboration clusters. Exclusion criteria included non-peer-reviewed works and irrelevant domains. The findings provide insights into trends, influential contributors, and research gaps in MCDM studies.

The analysis of the top 10 research categories highlights (Figure 2) the diverse applications of MCDM. Information and Computing Sciences lead with 2,552 publications, emphasizing the role of computational methods and algorithms in advancing MCDM research. Engineering follows with 1,503 studies showcasing its use in optimization and infrastructure development. Commerce, Management, Tourism, and Services rank third with 934 publications, reflecting MCDM's significance in strategic planning and business operations. Other prominent categories include Built Environment and Design (581), Mathematical Sciences (542), and Environmental Sciences (268), highlighting contributions to urban planning, theoretical development, and sustainability. Human Society (234), Economics(156), Earth Sciences (125), and Physical Sciences (65) further demonstrate MCDM's versatility across domains such as community development, economic policy, resource management, and technological innovation. This diversity underscores MCDM's pivotal role in addressing complex decision-making challenges.

The analysis categorizes MCDM research contributions based on alignment with the United Nations Sustainable Development Goals (SDGs), highlighting (Figure 3) a significant focus on environmental sustainability and energy. The most addressed SDG is Affordable and Clean Energy (SDG 7), with 886 studies emphasizing renewable energy and optimization. Climate Action (SDG 13) follows with 422 studies, while Responsible Consumption and Production (SDG 12) has 362. Contributions to Sustainable Cities and Communities (SDG 11) and Industry, Innovation, and Infrastructure (SDG 9) include 218 and 185 studies, respectively. Lesser-researched SDGs include Gender Equality (SDG 5), No Poverty (SDG 1), and Reduced Inequalities (SDG 10), highlighting gaps and future opportunities for research.

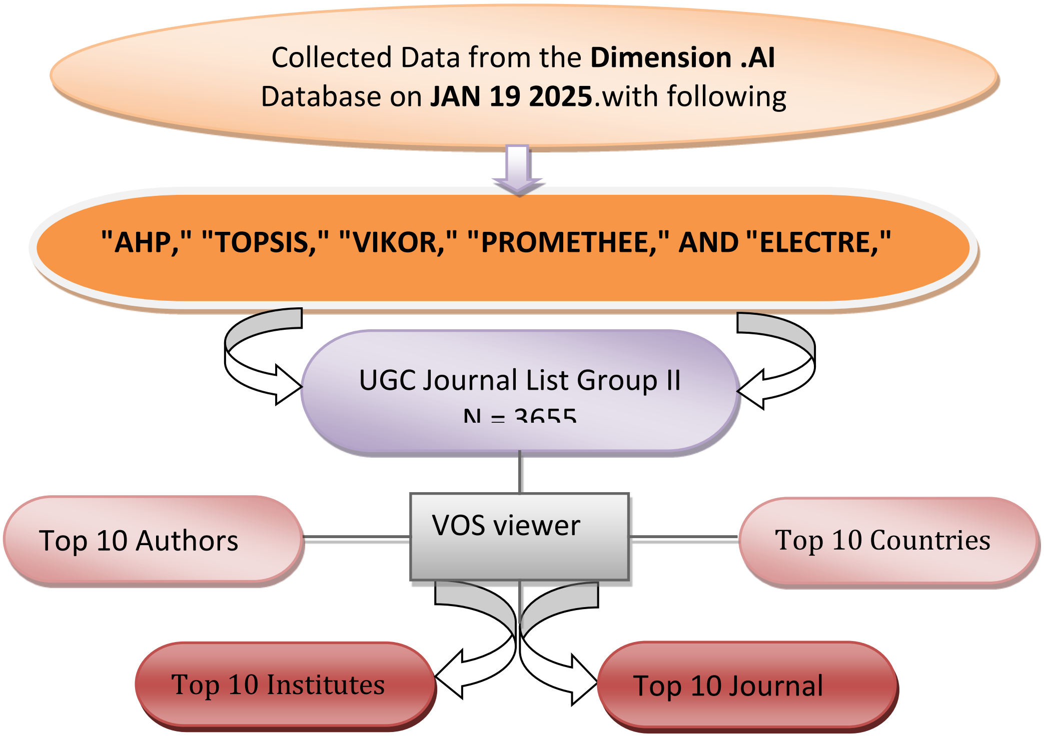

Fig. 1. Flowchart of bibliometric analysis

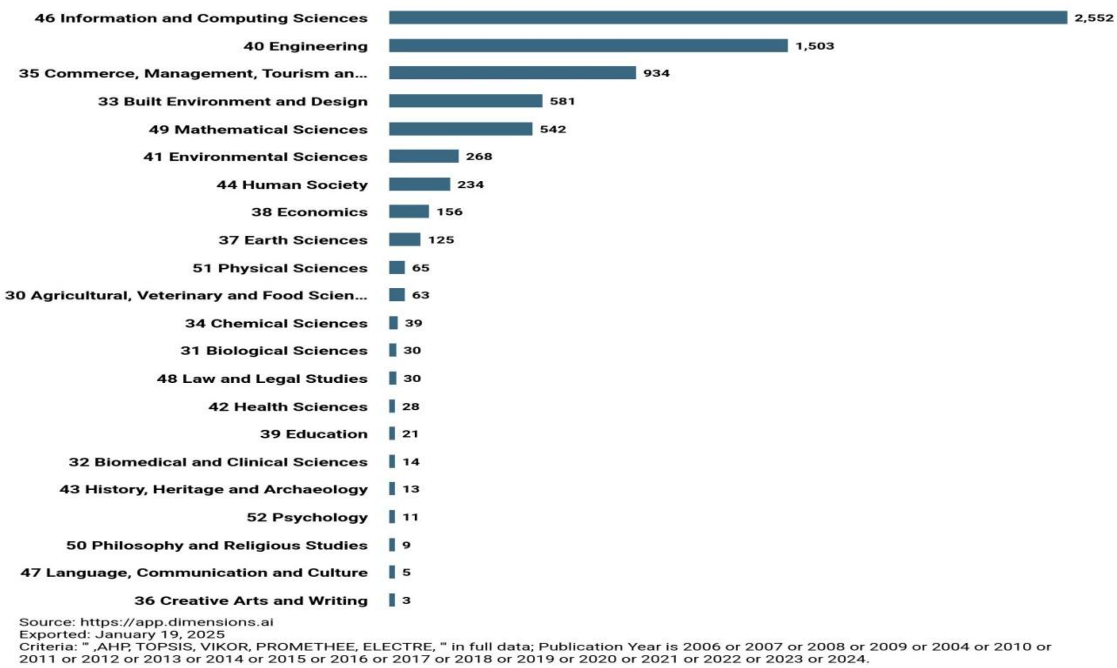

Fig. 2. Flowchart of no of publications in the fields of(ANZSRC 2020)

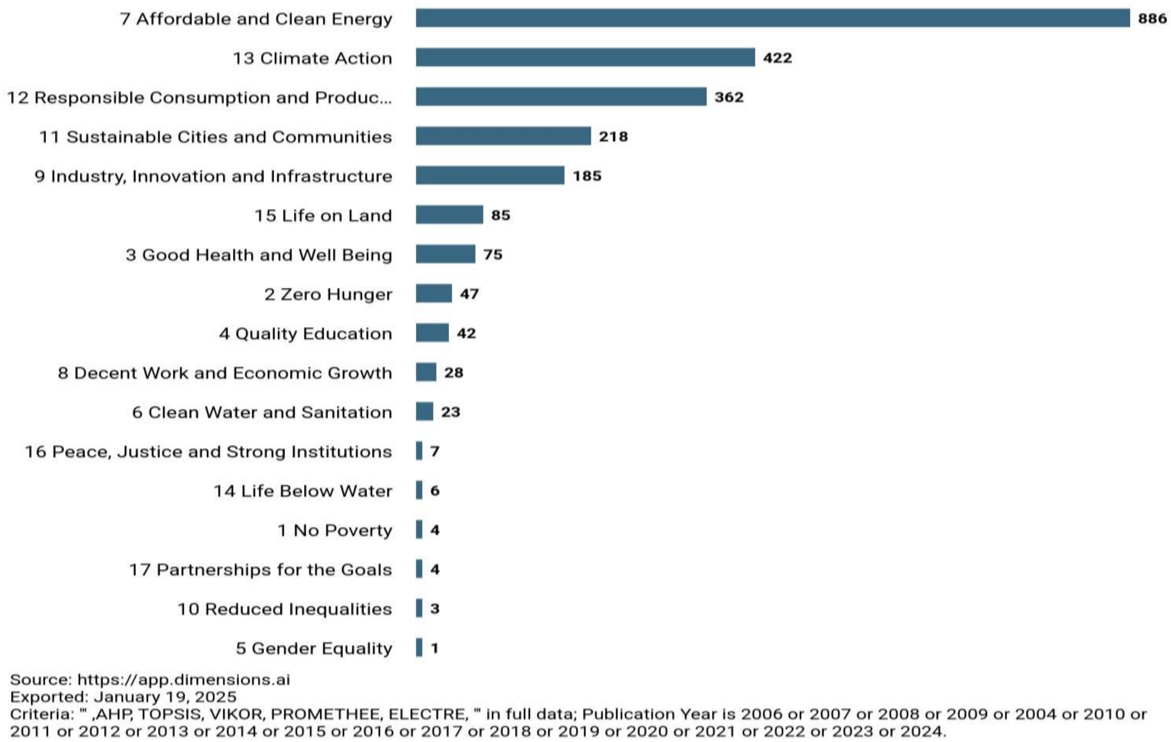

Fig. 3. Flowchart of no of publication in the fields of Sustainable Development Goals

3. Results

3.1 Trend Analysis of Publication

During the initial phase (Figure 4) from 2004 to 2008**,** the research landscape was nascent, with annual publications remaining minimal, ranging from 1 to 4 (Table 2). This reflects the early exploration of MCDM methods, with limited academic and industrial adoption. However, a modest increase in 2009, with seven publications, marked the beginning of growing interest in MCDM applications. The period from 2010 to 2014 witnessed gradual but consistent growth, as annual publications rose from 21 in 2010 to 101 in 2014. This growth can be attributed to the emergence of foundational MCDM methods such as AHP, TOPSIS, and PROMETHEE applied to practical decision-making problems in fields like engineering, business, and environmental management. The steady rise reflects the academic community's recognition of the versatility and relevance of MCDM frameworks. The most significant growth occurred between 2015 and 2020, with annual publications surging from 140 in 2015 to 619 in 2020. This period marked a transformative phase for MCDM research, driven by integrating advanced technologies such as artificial intelligence (AI), machine learning, and hybrid approaches. The increasing complexity of decision-making challenges across sectors such as renewable energy, urban planning, and healthcare contributed to this exponential growth. From 2021 to 2024, the field entered a maturity phase and sustained high productivity, with annual publications exceeding 700. 2024 saw the highest number of publications, reaching 911, underscoring MCDM's critical role in interdisciplinary research areas like sustainable development, smart cities, and climate action. While a slight plateau was observed between 2022 and 2023, this stability reflects the field's saturation in certain domains, accompanied by continuous expansion into emerging areas like blockchain, metaverse decision-support systems, and IoT.

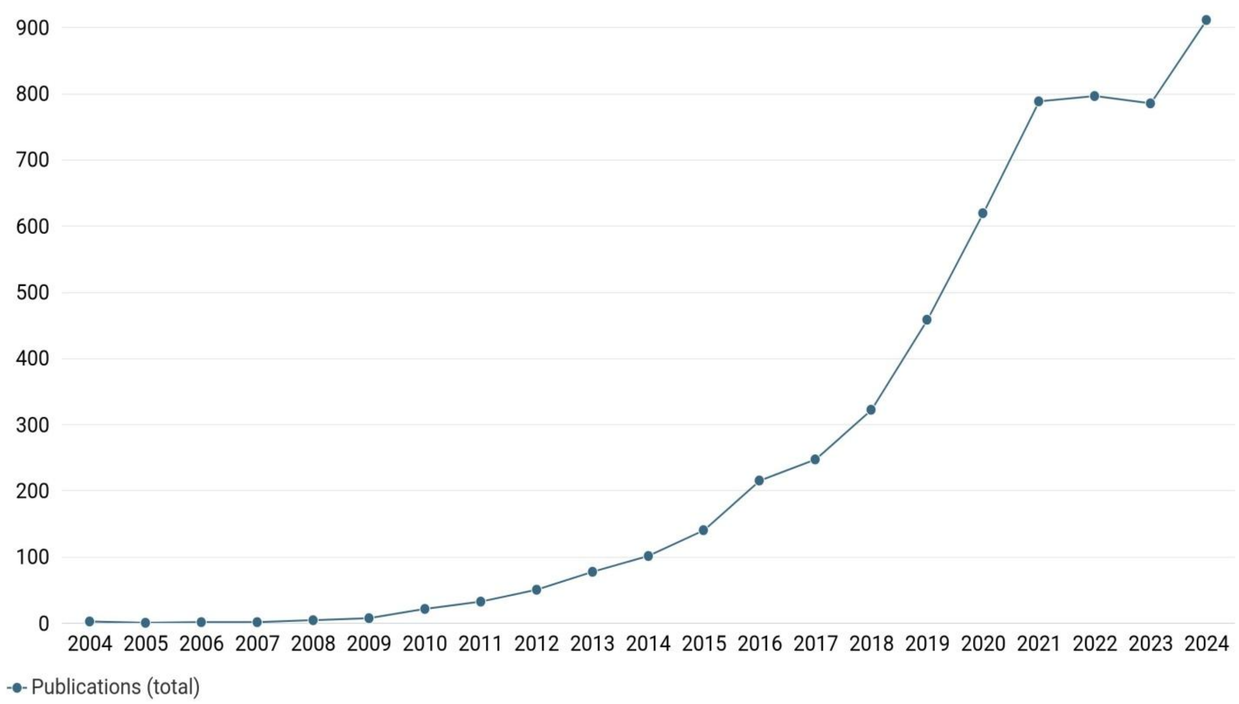

Fig. 4. Visualization shows the number of publications published in each year

Table 2
Publications Trend Analysis Table (2004 –2024)

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Publications	2	0	1	1	4	7	21	32	50	77	101	140	215	247	322	458	619	788	796	785	911

3.2 Trend Analysis of Citations

The citation trends for MCDM research from 2004 to 2024 highlight (Figure 5) its remarkable growth and expanding influence across disciplines. Between 2004 and 2008**,** citations remained low, totaling fewer than 20. This period reflects the early stage of MCDM research, with limited visibility and academic impact. Publications during this time were foundational but had not yet gained significant attention. From 2009 to 2014**,** citations steadily increased, rising from 39 in 2009 to 1,251 by 2014. This growth aligns with adopting MCDM techniques like AHP, TOPSIS, and PROMETHEE in engineering, management, and environmental studies. The rising use of these methods demonstrated their potential to address complex challenges. A significant leap occurred from 2015 to 2020, as citations surged from 1,912 to 15,638. This exponential increase reflects the integration of advanced tools, including artificial intelligence, hybrid frameworks, and fuzzy logic. MCDM became central to addressing pressing issues such as sustainability, healthcare systems, and renewable energy. Between 2021 and 2024, citations peaked, growing from 23,397 in 2021 to 34,960 in 2024. This phase marks the field's maturity, with wide-ranging applications in smart cities, climate action, and cutting-edge technologies like Industry 4.0 and the Metaverse. The consistent upward trend underscores MCDM's adaptability and relevance in tackling evolving decision-making needs.

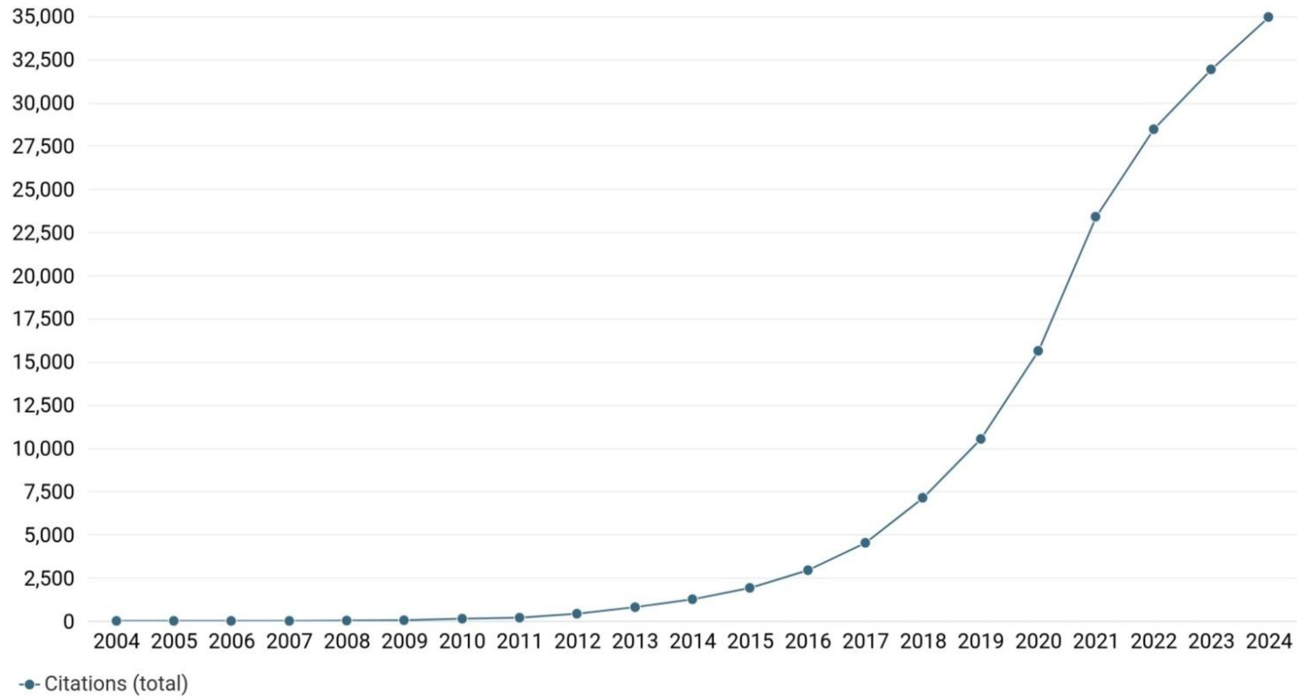

Fig. 5. Visualization shows the number of Citations in each year

3.3 Trend Analysis of publications with citations

The percentage of MCDM publications (Figure 6) with at least one citation from 2004 to 2024 reveals interesting trends regarding the academic impact of research over time. In the early years (2004–2006), citation activity was negligible, with no publications from 2004 and 2005 receiving citations. However, 100% of the publications in 2007 and 2008 were cited, reflecting focused but impactful research contributions during these years. Between 2009 and 2015, the percentage of cited publications remained consistently high, ranging from 93.51% to 97.14%. This period signifies growing academic interest in MCDM as foundational methods such as AHP and TOPSIS gained traction. The slightly fluctuating citation percentages indicate increasing adoption and application across various fields. From 2016 to 2020, citation rates remained stable, with values hovering between 93.38% and 96.89%. The consistent citation activity during this period reflects the integration of advanced technologies like AI and hybrid MCDM models, further solidifying their relevance and impact. However, a declining trend began after 2020, with the percentage of publications with citations dropping from 93.27% in 2021 to 45.12% in 2024. This decline suggests a saturation of the field in some areas, with newer publications requiring more time to gain recognition and citations. The high volume of publications in recent years likely contributed to the lower percentage, as newer works often take time to establish influence.

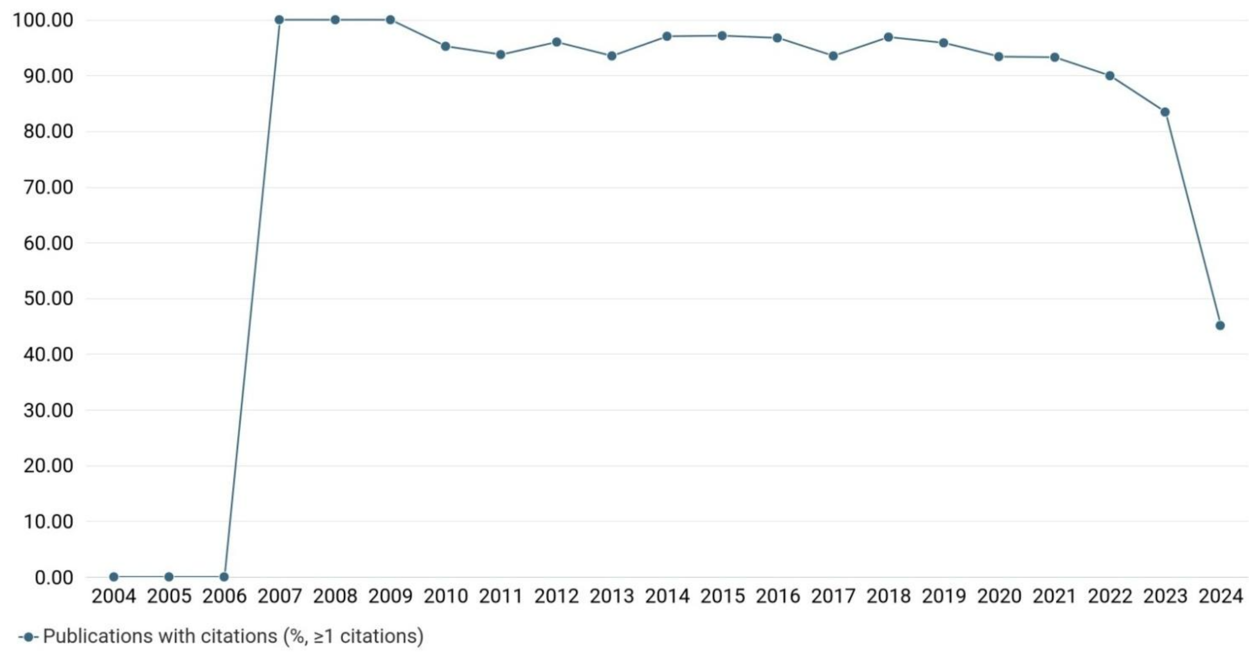

Fig. 6. Visualization shows the number of publications with citations (% ≥1)

3.4 Co-authorship Analysis

Co-author analysis examines the collaborative efforts among researchers by analyzing co-authored publications. Using tools like VOSviewer, such analyses generate visual networks where nodes represent authors, and edges signify their collaborative relationships. This approach highlights prominent researchers, patterns of collaboration, and clusters of academic partnerships. Additionally, it can assess collaboration at various levels, such as between countries or institutions, offering valuable insights into research dynamics and fostering stronger academic connections [26].

I. Authors: This investigation identifies 6387 authors after removing texts with a maximum of 25 authors apiece. Of these, only 249 authors match the criteria of having at least four documents and a minimum of 4 citations. Figure 7 demonstrates that among the 249 authors, 141 researchers had the highest number of linked works.

The analysis of the top 10 authors (Table 3) in MCDM research underscores their pivotal roles in shaping the field through prolific contributions, impactful citations, and academic influence. Dragan Pamucar is a leader in productivity, with 48 publications and 1,277 citations, maintaining a commendable average of 26.60 citations per article, reflecting his consistent contributions across diverse areas of MCDM. Similarly, Muhammet Deveci demonstrates strong academic influence with 34 publications and an impressive average of 31.09 citations, underscoring his relevance and consistent impact. Notably, Jurgita Antucheviciene emerges as a standout with the highest average citations per article (66.60), highlighting her exceptional research quality and influence. Jianli Zhou (62.90) and Edmundas Kazimieras Zavadskas (45.52) further exemplify academic excellence, achieving substantial impact through their significant contributions to advancing methodologies and applications in MCDM. Arunodaya Raj Mishra balances productivity and influence effectively, with 27 publications and an average of 41.00 citations, reflecting his robust academic presence. Authors like Huchang Liao (23.97 citations per article) and Zeshui Xu (15.58) maintain steady academic impact through foundational and interdisciplinary work, contributing to the field's growth and its application across various domains.

Meanwhile, Ali Ahmadian (11.25) and Daekook Kang (15.72) showcase focused contributions, excelling in niche areas of MCDM research. This group represents a dynamic balance between high productivity and exceptional influence. While some, like Pamucar D. and Deveci M. lead with extensive publication records, others, such as Antucheviciene and Zhou, achieve remarkable per-article impact, demonstrating the depth and quality of their research. Their work highlights the growing significance of MCDM in addressing complex decision-making challenges, bridging disciplines, and driving both theoretical advancements and practical applications globally.

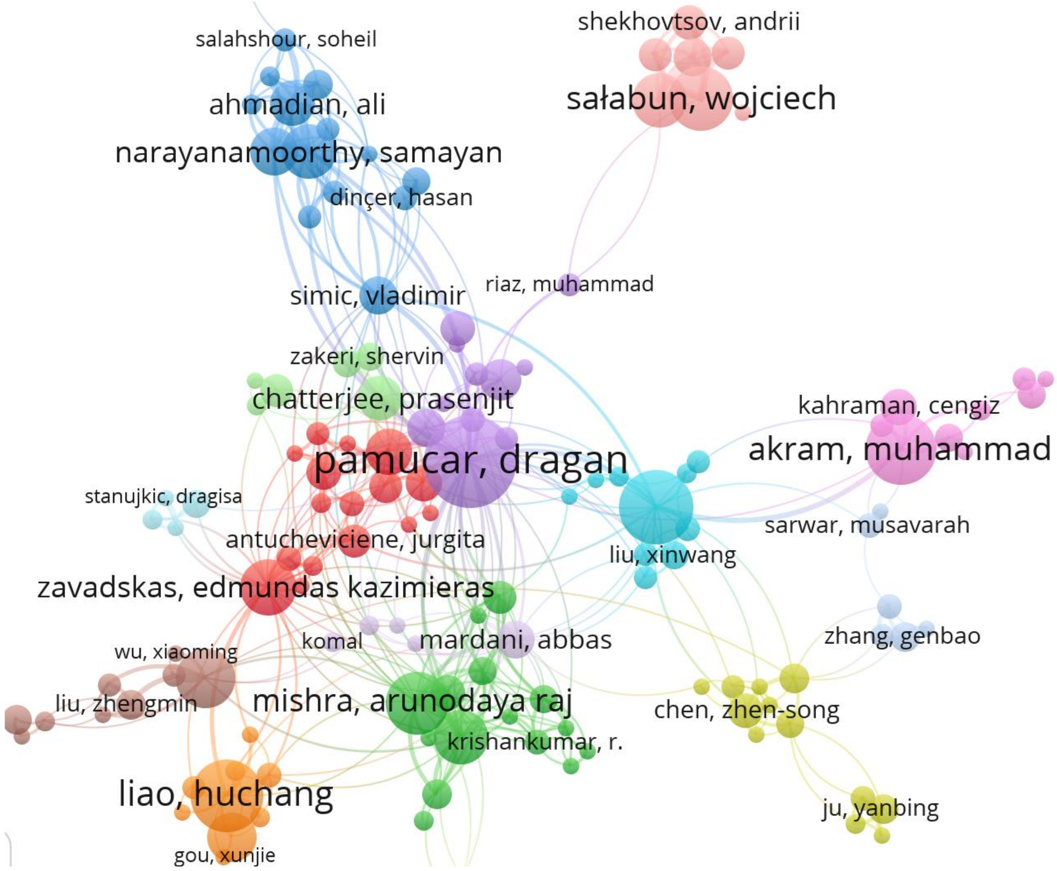

Fig. 7. Bibliometric map on co-authorship unit of authors with Network visualization mode

Table 3
Top 10 Authors publications, citations, and average citation per article

Rank	Author Name	Publications	Citations	Average Citations per Article
1	Dragan Pamucar	48	1,277	27
2	Muhammet Deveci	34	1,057	31
3	Huchang Liao	33	791	24
4	Arunodaya Raj Mishra	27	1,107	41
5	Edmundas Kazimieras Zavadskas	23	1,047	45
6	Zeshui Xu	19	296	16
7	Daekook Kang	18	283	16
8	Ali Ahmadian	16	180	11
9	Jianli Zhou	10	629	63
10	Jurgita Antucheviciene	10	666	67

ii. Organizations (Affiliations): VOSviewer also enables the analysis of organizations or affiliations that authors are associated with, in addition to examining individual authors [27]. By restricting the analysis to a maximum of 25 organizations per document, a total of 2315 organizations were found. After removing documents, only 386 organizations have at least 4 articles and citations that fit the criteria. Figure 8 demonstrates that out of these 386 organizations, 359 have the maximum number of linked works

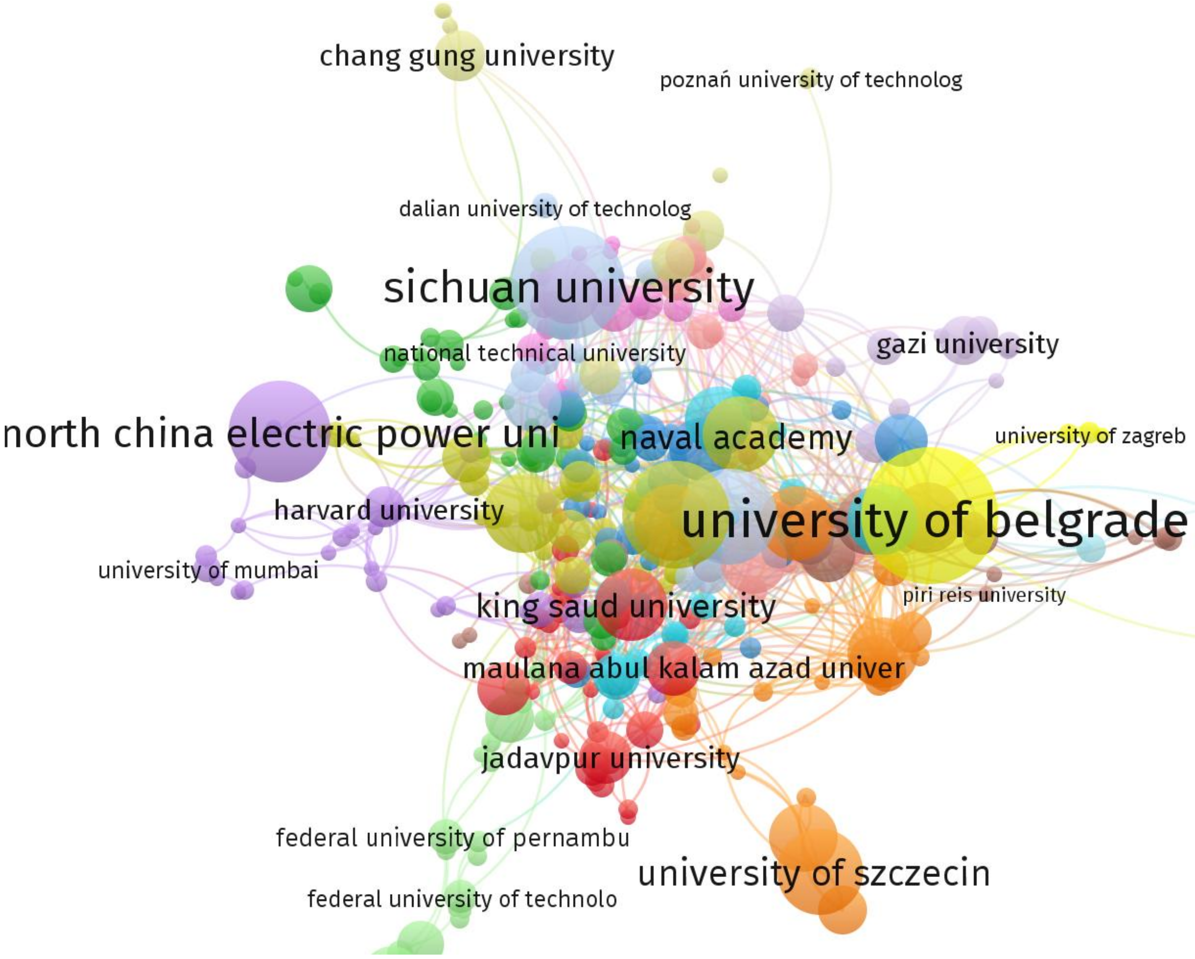

Fig. 8. Bibliometric map on Organization with Network visualization mode

The analysis of the top 10 organizations in MCDM research highlights (Table 4) their significant contributions in terms of productivity, citation impact, and collaboration strength. The University of Belgrade leads with 70 publications, 1,380 citations, and the highest total link strength (164), emphasizing its extensive research network and consistent influence. Sichuan University, with 54 publications and 1,388 citations, demonstrates high academic impact, while VilniusGediminas Technical University excels in collaboration with 101 link strength and 1,474 citations from 50 publications. The University of Defence, despite 26 publications, leads in citations (1,913), showcasing the remarkable quality of its research output. Institutions like the Naval Academy and Maulana Abul Kalam Azad University of Technology highlight the importance of collaboration and high-quality studies, with 885 and 1,615 citations, respectively. Organizations such as Yıldız Technical University and Istanbul Technical University maintain balanced contributions with steady productivity and strong academic influence. Lastly, Afyon Kocatepe University, with 17 publications and 914 citations, reflects a balanced role in advancing MCDM methodologies. The geographic diversity, from Europe to Asia, underscores the global effort in shaping this field through impactful and collaborative research.

Table 4
Top 10 Organizations Based on Publications, Citations, and Total Link Strength

Rank	Organization Name	Publications	Citations	Total Link Strength
1	University of Belgrade	70	1,380	164
2	Sichuan University	54	1,388	44
3	Vilnius Gediminas Technical University	50	1,474	101
4	University of Szczecin	37	1,329	40
5	Naval Academy	32	885	107
6	University of Defence	26	1,913	57
7	Yıldız Technical University	28	664	24
8	Maulana Abul Kalam Azad University of Technology	20	1,615	41
9	Istanbul Technical University	28	1,127	15
10	AfyonKocatepe University	17	914	34

ii. Countries: VOSviewer supports the analysis of nations inside co-authorship networks, enabling a full understanding of collaborative patterns [26]. This study identified 97 nations by eliminating articles that involved a maximum of 25 countries each. As indicated in Figure 9, only 75 organizations match the necessary criteria, which include having a minimum of 3 published papers and significant country-level citations.

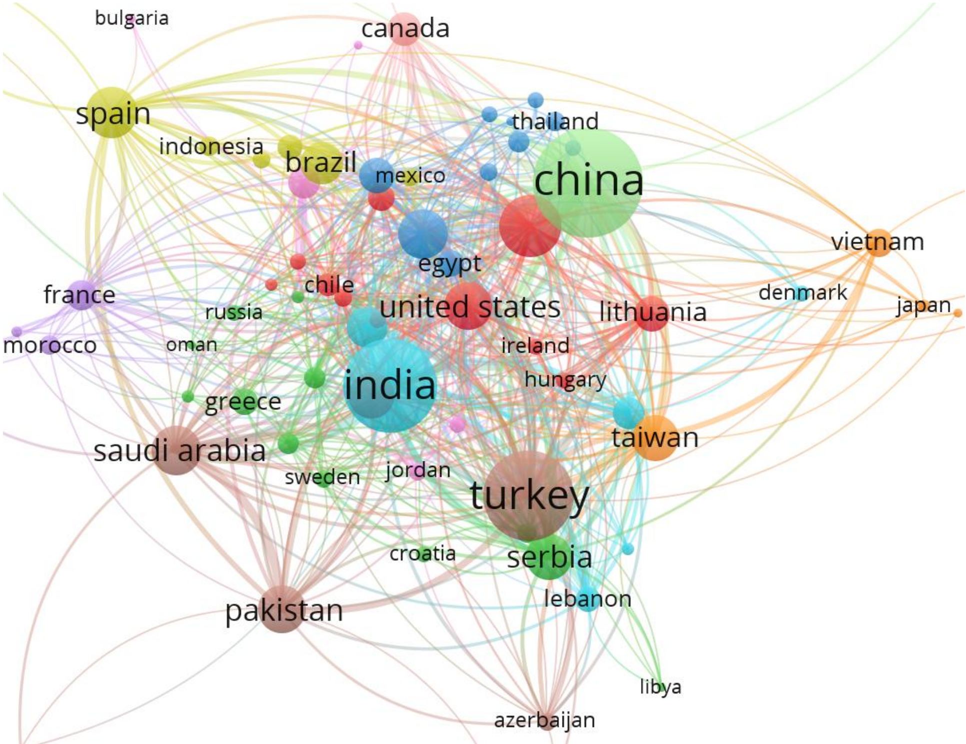

Fig. 9. Bibliometric map of Countries with Network visualization mode

The analysis of the top 10 countries in MCDM research highlights (Table 5) their significant contributions in publications, citations, and research impact. China leads with 570 publications and 13,967 citations, showcasing its dominance and a high average citation per article of 24.51. India and Turkey are strong contributors, with 418 and 385 publications, respectively, maintaining impressive citation counts (India: 9,442; Turkey: 8,828) and similar average citations per article. The United Kingdom, with 122 publications and 4,565 citations, achieves the highest average citation per article (37.42), reflecting exceptional research quality and global influence. Similarly, the United States produces high-impact research with 111 publications, 3,415 citations, and an average of 30.77 citations per article**.** Spain and Serbia maintain a balanced contribution, combining robust publication output with strong citation performance, achieving 26.29 and 32.32 citations per article, respectively.

Emerging contributors like Saudi Arabia show growing influence with 119 publications and 2,282 citations, while Poland and Taiwan demonstrate consistent performance, with Poland achieving a higher average citation per article (26.47) than Taiwan (18.52). This analysis underscores these countries' global efforts and diverse strengths in advancing MCDM research.

Table 5
Top 10 Countries Based on Publications, Citations, and Average Citations per Article

Rank	Country	Publications	Citations	Average Citations per Article
1	China	570	13,967	24.51
2	India	418	9,442	22.59
3	Turkey	385	8,828	22.93
4	United Kingdom	122	4,565	37.42
5	United States	111	3,415	30.77
6	Spain	126	3,311	26.29
7	Serbia	106	3,426	32.32
8	Saudi Arabia	119	2,282	19.18
9	Poland	100	2,647	26.47
10	Taiwan	100	1,852	18.52

3.5 Citation Analysis

VOSviewer is a popular tool for bibliometric analysis, allowing researchers to look into citation relationships across various units, including documents and sources. Each aspect plays a different purpose in enriching citation analysis, offering precise insights into intellectual linkages and research trends [27].

i. *Documents:* The study of citations primarily focuses on specific academic publications, including journal articles, conference papers, books, and patents. Using VOSviewer, researchers can analyze citation links among these papers, find influential publications, track the history of ideas, and discover the intellectual framework of a certain field of study.

There are 2504 documents found in this analysis. Merely 1945 documents satisfy the criterion with a minimum of 3 citations each. Figure 10 illustrates that, of the 295 documents, 129 papers had the greatest number of related things.

Table 6 highlights the top 10 influential co-authors based on their citations and contributions to various fields. Stević *et al.*, [14] lead with 866 citations in operations research, showcasing significant influence. Liu *et al.*, [28] appear with 631 citations, reflecting impactful work in environmental science. Yadav *et al.*, [29] and Slebi-Acevedo *et al.*, [30] contribute prominently to sustainable development and decision sciences, respectively. Akram *et al.*, [31] and Tzouramani *et al.*, [32] emphasize optimization techniques and sustainability. Liao *et al.*, [33] stand out for contributions to renewable energy, while Salimi *et al.*, [34] and Rahimi *et al.*, [35] focus on mathematical modeling and data science. These co-authors are affiliated with prestigious institutions, highlighting their research's multidisciplinary nature and impact on global academic discussions

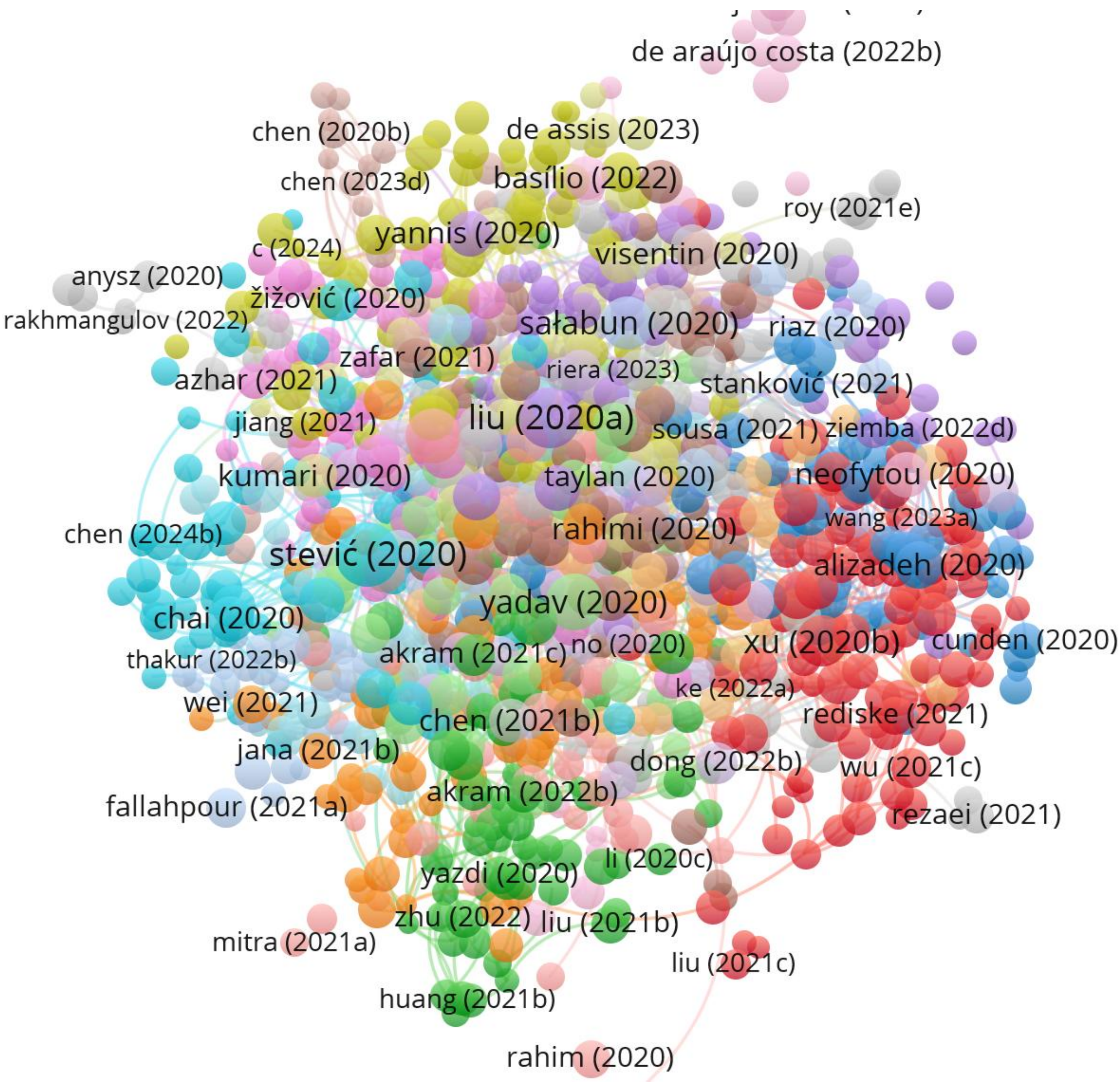

Fig. 10. Bibliometric map on co-citation of documents with Network visualization mode

Table 6
Top 10 Co-Authors with Institution and Field of Study

Co-Author	Citations	Links	Institution	Field of Study
Stević *et al.,* [14]	866	98	University of East Sarajevo	Operations Research
Liu *et al.,* [28]	631	17	Chinese Academy of Sciences	Environmental Science
Yadav *et al.,* [29]	458	4	Indian Institute of Technology	Sustainable Development
Slebi-Acevedo *et al.,* [30]	352	60	Poznan University of Technology	Decision Sciences
Akram *et al.,* [31]	197	23	University of Tehran	Optimization Techniques
Tzouramani *et al.,* [32]	143	17	University of Tehran	Sustainable Development
Liao *et al.,* [33]	143	17	National Taiwan University	Renewable Energy
Salimi *et al.,* [34]	119	13	University of Vienna	Mathematical Modeling
Rahimi *et al.,* [35]	67	14	Sharif University of Technology	Data Science

Sources: Journals and proceedings of conferences are significant examples of sources in academic publishing. With VOSviewer, scholars may assess trends in citations across different sources, often uncovering co-cited articles and comprehending their contribution to the knowledge base of a given topic or study area. There are 593 sources in this analysis (Figure 11). Merely 174 sources satisfy the required minimum of 3 documents and source citations. Figure 11 illustrates that of the 174 sources, 170 have the most related items.

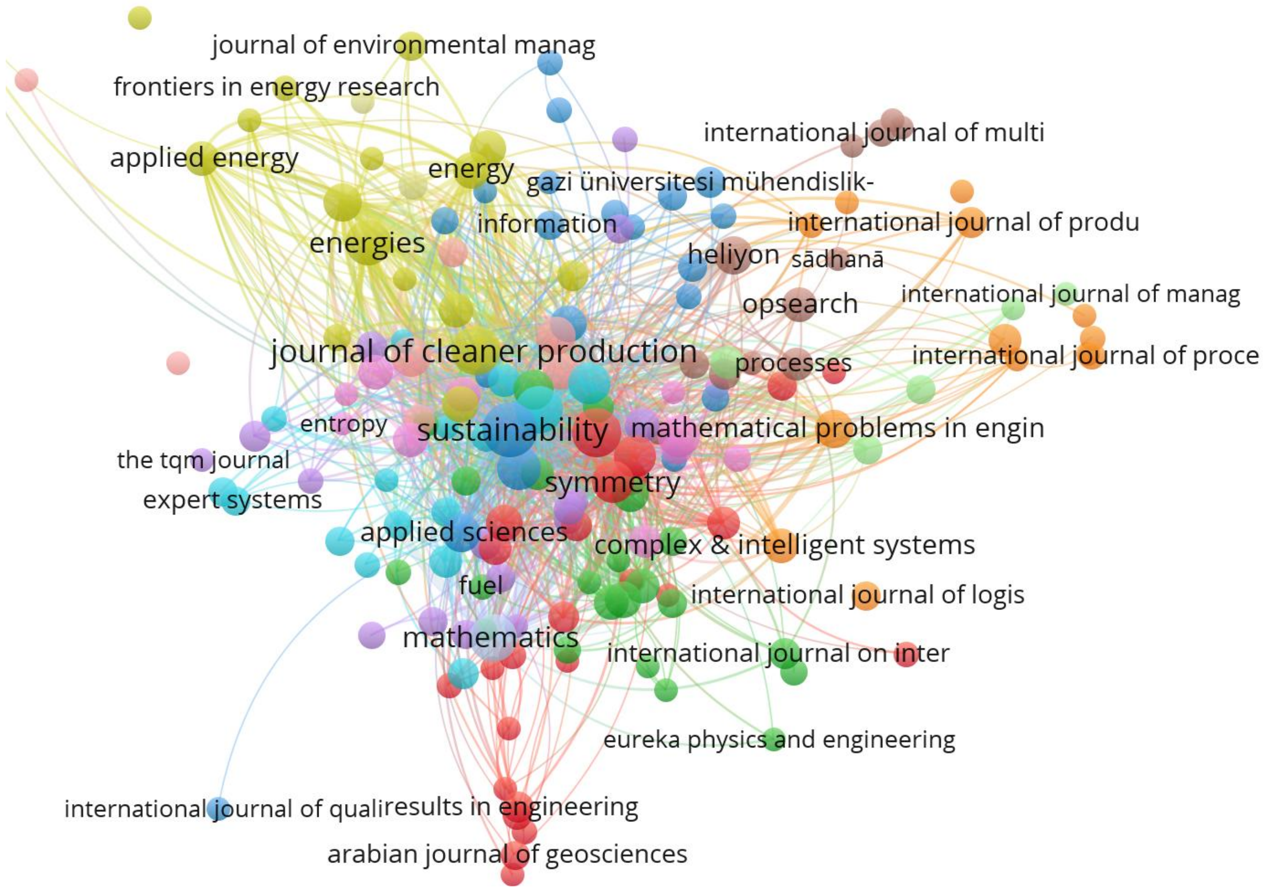

Fig. 11. Bibliometric map on co-citation of sources with Network visualization mode

The top 10 journals contribute significantly to research across multidisciplinary domains (Table 7). The *Journal of Cleaner Production* leads with the highest citations, emphasizing its focus on sustainability and cleaner production practices. *Expert Systems with Applications* follows, showcasing advancements in intelligent systems and their practical implementations. *Sustainability* stands out for addressing global environmental and social challenges, while *Symmetry* contributes to diverse fields, including mathematics and theoretical studies. Highly cited journals like *Environmental Science and Pollution Research* and *Renewable Energy* underline the importance of environmental conservation and renewable energy solutions. *Applied Soft Computing* highlights developments in computational methods, while *Energy Reports* focuses on energy innovations. *IEEE Access* and *Mathematics* demonstrate a balance between engineering, technology, and fundamental sciences.

For readers, these journals serve as essential resources for staying informed about sustainability, energy, and computational sciences advancements. Researchers are encouraged to explore *Applied Soft Computing* and *Expert Systems with Applications* for cutting-edge AI research and practical solutions. At the same time, *Sustainability* and *Renewable Energy* provide insights into addressing environmental and societal challenges.

Table 7
Top 10 journals based on citations

Rank	Source	Documents	Citations	Total Link Strength
1	Journal of Cleaner Production	85	3729	600
2	Expert Systems with Applications	90	3372	628
3	Sustainability	152	2481	520
4	Symmetry	40	1940	332
5	Environmental Science and Pollution Research	38	862	198
6	Renewable Energy	25	1090	204
7	Applied Soft Computing	73	2670	564
8	Energy Reports	18	362	127
9	IEEE Access	46	604	221
10	Mathematics	77	1328	344

4. Discussion

4.1 Contribution to SDGs

The systematic review of MCDM research reveals significant contributions to several United Nations SDGs, with notable progress in areas such as affordability and SDG 7, SDG 12, and SDG 13. MCDM methods have supported the optimization of renewable energy systems, sustainable manufacturing practices, and strategies for climate change mitigation, demonstrating their capacity to address pressing global challenges. Applications in industry, innovation, and SDG 9 and SDG 11 further highlight the role of these methods in urban planning, smart city development, and infrastructure optimization. Despite this progress, certain SDGs, such as SDG 1, SDG 10, and SDG 5, remain underexplored. Limited research has addressed decision-making frameworks for poverty alleviation, equitable resource distribution, and promoting inclusive growth. Similarly, the integration of MCDM in SDG 14 and SDG 15 is minimal, presenting opportunities to expand its application to these critical environmental areas. Future research could focus on integrating advanced technologies like artificial intelligence and IoT to address these gaps while fostering interdisciplinary collaboration and geographic diversity. By broadening its scope, MCDM can further enhance its contributions to achieving a sustainable and equitable future.

4.2 Emerging Technologies

The evolution of MCDM methods has been significantly shaped by integrating advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and the Metaverse. These technologies have enhanced the computational efficiency and flexibility of MCDM frameworks and broadened their applicability to modern, complex decision-making challenges. AI-driven MCDM models have emerged as powerful tools, leveraging machine learning algorithms to process large datasets, improve prediction accuracy, and enable adaptive decision-making. These systems have demonstrated exceptional value in domains such as healthcare, where they support resource prioritization and predictive diagnostics, and in renewable energy, optimizing energy production and distribution. IoT has further transformed decision-making processes by providing real-time data streams that can be directly integrated into MCDM frameworks. This capability has proven particularly impactful in smart cities, where IoT sensors monitor parameters such as traffic flow, energy consumption, and environmental conditions, enabling efficient resource allocation and urban planning. IoT facilitates predictive maintenance and supply chain optimization in industrial settings, where MCDM methods prioritize alternatives based on operational data.

The Metaverse represents a cutting-edge frontier for MCDM applications, enabling decision-makers to simulate, evaluate, and refine complex scenarios within immersive digital environments. For example, hybrid MCDM models have been applied to assess sustainable urban transportation solutions in the Metaverse, offering valuable insights for real-world implementation. Additionally, the Metaverse supports collaborative decision-making by allowing stakeholders to engage in virtual simulations and jointly analyze outcomes. Case studies highlight the practical impact of these technologies. Hybrid AI-MCDM approaches have been successfully implemented in renewable energy projects, optimizing site selection for wind and solar farms. IoT-enabled MCDM applications in smart grids have improved energy distribution and reduced operational costs.

Furthermore, metaverse-based simulations have provided innovative solutions for virtual training, infrastructure planning, and disaster response. The integration of these technologies underscores the dynamic and adaptive nature of MCDM methods in addressing contemporary challenges. By leveraging advancements in AI, IoT, and the Metaverse, MCDM continues to evolve as a critical tool for informed decision-making, fostering innovation, and driving sustainable solutions across diverse domains.

5. Conclusion

This review of MCDM methods over the past two decades (2004–2024) highlights significant advancements in methodologies and their transformative applications. Techniques such as AHP, TOPSIS, PROMETHEE, and ELECTRE have been extended through hybrid models integrating AI, fuzzy logic, and machine learning, enhancing their capacity to address complex decision-making scenarios. These frameworks have been pivotal in fields such as engineering, healthcare, environmental science, and business, demonstrating their versatility and relevance in solving real-world problems. The analysis reveals consistent growth in MCDM research output, particularly between 2015 and 2024, accompanied by increasing citation trends that underscore its academic and industrial impact. Developed nations, including China, India, and the United States, lead in contributions, while emerging countries like Saudi Arabia and Poland are showing growing engagement. Despite this progress, geographic disparities persist, with limited representation from underdeveloped regions.

Co-authorship analysis underscores the importance of collaborative networks among leading authors and institutions. Influential contributors, such as Dragan Pamucar and Edmundas Kazimieras Zavadskas, and prominent institutions like the University of Belgrade, have played a crucial role in advancing the field. These collaborations highlight the interdisciplinary nature of MCDM and its ability to address multifaceted challenges.

The study also demonstrates MCDM's critical contributions to the United Nations Sustainable Development Goals (SDGs), particularly SDG 7, SDG 12, and SDG 13. Applications in renewable energy, sustainable production, and climate mitigation exemplify the alignment of MCDM with global priorities. However, underexplored areas such as SDG 1, SDG 5, and SDG 10 present opportunities for future research to broaden its impact. Emerging technologies such as AI, IoT, and the Metaverse are reshaping the landscape of MCDM by enabling real-time data integration, immersive simulations, and advanced decision-making frameworks. Case studies demonstrate the practical benefits of these innovations in optimizing energy systems, smart cities, and industrial processes. While promising, these technologies require further development to overcome challenges related to computational complexity and accessibility.

Future research should focus on integrating MCDM with cutting-edge technologies to advance the field while expanding its applications to underrepresented regions and domains. Developing AI-driven frameworks, employing blockchain for secure decision-making, and leveraging metaverse platforms for virtual collaboration will enhance the adaptability and scalability of MCDM. Addressing geographic and technological disparities and exploring underutilized areas such as biodiversity conservation, social equity, and inclusive decision-making will ensure that MCDM remains a vital tool for addressing global challenges.

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Conflicts of Interest
The authors declare no conflicts of interest.

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