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A Review of Multi-Criteria Decision-Making (MCDM) Applications to Solve Energy Management Problems From 2010-2025: Current State and Future Research

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ABSTRACT

Energy management is a critical challenge in the global effort to achieve sustainability, improve efficiency, and balance economic and environmental priorities. Multi-Criteria Decision-Making (MCDM) techniques have emerged as powerful tools to address complex and competing criteria in energy systems. This paper reviews the current state of MCDM applications in energy management, focusing on renewable energy systems, energy efficiency, grid management, and policy planning from 2010-2025 using bibliometric analysis. It identifies popular methods such as AHP, TOPSIS, and hybrid models, highlighting their strengths and limitations. The analysis reveals trends, gaps, and challenges, such as handling uncertainty, integrating real-time data, and adapting to dynamic energy environments. Future research directions emphasize leveraging advanced technologies like artificial intelligence, blockchain, and IoT to enhance MCDM models and expanding their application to emerging areas like microgrids and sustainable urban systems. This review provides a comprehensive understanding of the field and outlines a roadmap for advancing MCDM applications in solving energy management problems.

1. Introduction

Energy management is the strategic process of planning, monitoring, and optimizing the production, distribution, and consumption of energy to achieve efficiency, sustainability, and cost-effectiveness. It plays a crucial role in addressing the growing global demand for energy while minimizing environmental impacts. Effective energy management involves integrating renewable energy sources, improving energy efficiency, and ensuring reliable energy supply through advanced technologies and innovative policies [1].

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In recent years, the shift toward sustainable development has intensified the focus on energy management as a critical component of mitigating climate change, reducing greenhouse gas emissions, and achieving energy security. Challenges such as fluctuating energy prices, resource scarcity, and the need for equitable energy access make decision-making in this field increasingly complex. This complexity highlights the importance of tools like MCDM, which enable stakeholders to evaluate multiple, often conflicting criteria, to arrive at optimal solutions for managing energy systems efficiently and sustainably.

1.1. Importance of energy management in the global context

Energy management has become a cornerstone of global efforts to ensure economic growth, environmental sustainability, and energy security [2].

i. Climate Change Mitigation: Energy management reduces greenhouse gas emissions by promoting renewable energy and energy-efficient technologies, aiding in the fight against global warming.
ii. Sustainability Promotion: It ensures the efficient use of resources, minimizes waste, and supports the transition to sustainable energy systems for long-term environmental balance.
iii. Energy Security: By diversifying energy sources, energy management reduces dependence on fossil fuels, enhances resilience, and ensures a stable energy supply even during global market fluctuations.
iv. Economic Growth: Effective energy management lowers energy costs, boosts industrial competitiveness, and stimulates economic development by encouraging investment in energy-efficient and renewable technologies.
v. Job Creation: It drives employment in clean energy sectors, including solar, wind, and energy storage, fostering innovation and industrial growth.
vi. Equitable Access: Energy management ensures affordable and reliable energy for all, addressing energy poverty in underserved regions and promoting inclusive development.
vii. Support for Global Goals: It directly aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 7, which seeks universal access to sustainable and modern energy.
viii. Improved Energy Reliability: Energy management facilitates the development of smart grids, energy storage, and advanced distribution systems, ensuring a reliable energy supply.
ix. Environmental Preservation: By reducing reliance on non-renewable resources, energy management protects ecosystems and biodiversity.

Energy management is thus pivotal for achieving a balanced, sustainable, and equitable energy future globally.

Challenges in energy systems

Energy systems across the globe face significant challenges as they strive to balance sustainability, cost, and efficiency. The increasing demand for energy, coupled with the urgent need to reduce environmental impacts, has created a complex landscape for decision-makers and stakeholders. One of the foremost challenges is achieving sustainability [3]. Traditional energy systems heavily rely on fossil fuels, which contribute to greenhouse gas emissions and environmental degradation. Transitioning to renewable energy sources, such as solar, wind, and hydropower, is imperative but often constrained by technological, infrastructural, and policy barriers [4,5].

Cost remains another critical challenge in energy systems. While renewable energy technologies have seen a decline in costs over the years, their initial investment remains high, particularly for developing nations. Additionally, the integration of renewable energy into existing grids often requires costly upgrades to infrastructure. Balancing affordability with the need for cleaner energy is a persistent issue, especially for nations with limited financial resources [6].

Efficiency is also a pressing concern. Many energy systems suffer from inefficiencies in production, distribution, and consumption [7]. For example, aging power grids result in significant energy losses during transmission. On the consumption side, outdated technologies and inefficient practices in industries and households contribute to energy waste. Addressing these inefficiencies requires investment in advanced technologies such as smart grids, energy storage systems, and energy-efficient appliances [8].

Overcoming these challenges necessitates a holistic approach that integrates technology, policy, and innovation while addressing social and economic considerations.

1.2. Role of MCDM techniques in energy management decision-making

Energy management involves complex decision-making processes that require the consideration of multiple, often conflicting criteria. These criteria may include cost, efficiency, sustainability, reliability, and social acceptance. MCDM techniques play a pivotal role in navigating these complexities, providing a structured and systematic approach to evaluating alternatives and selecting optimal solutions [9].

One of the primary strengths of MCDM techniques is their ability to handle conflicting objectives. For example, in renewable energy projects, decision-makers must balance the high initial investment costs with long-term environmental benefits and operational efficiency. MCDM methods such as Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and VIKOR help quantify and prioritize these factors, enabling informed and transparent decision-making.

MCDM techniques are also valuable in facilitating stakeholder engagement. Energy management decisions often involve diverse stakeholders, including governments, industries, and communities, each with their own priorities [10]. MCDM tools provide a common framework for integrating diverse perspectives, ensuring that the decision-making process is inclusive and equitable.

Furthermore, the adaptability of MCDM methods makes them well-suited for dynamic energy environments. They can incorporate uncertainties and scenarios, such as fluctuating energy prices or policy changes, to guide robust decision-making. By integrating advanced technologies like artificial intelligence and fuzzy logic, MCDM techniques are evolving to address emerging challenges in energy systems. So, MCDM techniques are indispensable in energy management, offering a comprehensive approach to decision-making that balances economic, environmental, and social dimensions. Their application ensures that energy systems are optimized for efficiency, sustainability, and resilience.

1.3. Scope and objectives of the proposed review

The scope of this paper encompasses a comprehensive review of the application of MCDM techniques in addressing energy management challenges. It focuses on exploring how MCDM methods are used to evaluate and optimize energy systems, considering various criteria such as cost, efficiency, sustainability, and reliability. The paper covers key application areas, including renewable energy systems, energy efficiency in industrial and residential settings, grid and power system management, and energy policy planning. It also examines the integration of traditional and advanced MCDM techniques, such as AHP, TOPSIS, VIKOR, and hybrid models, in solving real-world energy management problems.

The objectives of the paper are as follows:

i. To provide an overview of the current state of MCDM applications in energy management.
ii. To classify and analyze the most commonly used MCDM methods in various energy domains.
iii. To identify key trends, strengths, and limitations in the existing body of research.
iv. To explore emerging challenges in energy management that require innovative MCDM solutions.
v. To propose future research directions, emphasizing the integration of MCDM techniques with advanced technologies like AI, IoT, and blockchain.

By achieving these objectives, the paper aims to contribute to the ongoing discourse in energy management, offering insights to researchers, policymakers, and practitioners for advancing sustainable and efficient energy systems.

2. Overview of MCDM techniques in energy management

2.1. Introduction to MCDM methods

The MCDM methods are a set of tools designed to help decision-makers evaluate and select the best alternatives from a set of options when multiple, often conflicting, criteria need to be considered. These methods are widely used in complex decision-making scenarios, such as energy management, where factors like cost, efficiency, sustainability, and environmental impact must be balanced. MCDM techniques allow for the systematic evaluation of alternatives, enabling more informed, transparent, and rational decision-making. The versatility of MCDM methods makes them applicable in a wide range of fields, including engineering, economics, environmental management, and public policy.

2.2. Classification of MCDM techniques

Each MCDM technique offers unique advantages, making them suitable for different decision-making contexts. MCDM techniques are broadly classified into traditional and advanced methods, each serving distinct purposes based on the complexity and scope of decision problems [11]. Traditional MCDM methods typically focus on simpler decision-making processes and are based on well-established mathematical principles. These include techniques such as the Weighted Sum Model (WSM), Analytic Hierarchy Process (AHP), and Simple Additive Weighting (SAW). These methods are widely used for their simplicity and ease of implementation. They assume that the decision criteria are independent and additive, making them suitable for relatively straightforward decision scenarios with a limited number of alternatives and criteria [12].

In contrast, advanced MCDM methods are designed to handle more complex decision-making problems where traditional methods may struggle due to the involvement of a large number of criteria, alternatives, or conflicting objectives [13]. Advanced methods include Fuzzy MCDM, which incorporates uncertainty and vagueness in the decision-making process, and Grey Relational Analysis (GRA), which deals with incomplete or uncertain data. Machine learning-based techniques and Artificial Intelligence (AI) are increasingly being integrated into MCDM, enabling dynamic decision support systems that learn and adapt over time.

The classification of these techniques demonstrates a shift from simple, static models to more sophisticated, data-driven approaches that can accommodate real-world complexity and uncertainty, providing decision-makers with more accurate and reliable solutions.

2.3 Application Areas in Energy Management

2.3.1 Renewable Energy Systems

i. Selection of Energy Sources: MCDM techniques help decision-makers evaluate and select the most appropriate renewable energy sources (solar, wind, hydropower, geothermal, etc.) based on factors like cost, efficiency, environmental impact, and availability of resources. These techniques facilitate the identification of optimal energy mix strategies, considering both short-term and long-term sustainability goals [14].
ii. Site Selection for Solar and Wind Energy Projects: MCDM is used to assess potential sites for solar and wind energy installations by considering various factors such as geographic location, climate conditions, land availability, infrastructure access, and environmental impact [15]. Methods like AHP or TOPSIS help prioritize sites based on these criteria, ensuring the best possible outcome for energy production and investment.

2.3.2 Energy Efficiency and Optimization

i. Building Energy Systems: In the context of building energy systems, MCDM techniques are applied to optimize energy consumption, minimize costs, and reduce environmental impacts [16]. Factors such as energy use, building design, insulation, and lighting systems are assessed to identify the most energy-efficient solutions for residential, commercial, and industrial buildings. This includes optimizing heating, ventilation, air conditioning (HVAC) systems, and lighting strategies.
ii. Industrial Energy Management: MCDM methods are used to assess energy management strategies in industrial settings, helping manufacturers reduce energy consumption, improve process efficiency, and lower operational costs [17]. Techniques like AHP and TOPSIS can assist in evaluating different energy-saving technologies, process improvements, and renewable energy integrations.

2.3.3 Grid and Power System Management

i. Smart Grids and Load Balancing: MCDM is instrumental in managing and optimizing smart grid systems, which integrate renewable energy sources, storage, and distribution networks [18]. MCDM techniques help balance load distribution, optimize energy storage, and ensure grid stability. Decision-making in smart grid management includes assessing criteria like energy flow, demand patterns, renewable energy integration, and infrastructure needs.
ii. Demand-Side Management: MCDM techniques are used in demand-side management (DSM) to optimize the consumption of energy by end-users. By evaluating consumer behavior, energy pricing, and consumption patterns, decision-makers can develop strategies to reduce peak demand, encourage energy conservation, and implement demand response programs [19]. MCDM aids in selecting the most effective DSM policies and technologies based on their impact, feasibility, and cost-effectiveness.

2.3.4 Policy and Planning

i. National Energy Policy Decisions: MCDM methods play a crucial role in formulating national energy policies by evaluating various policy options based on criteria like economic feasibility, environmental impact, social acceptance, and energy security [20]. These techniques support policymakers in making informed decisions regarding energy resource allocation, renewable energy targets, carbon emission reduction plans, and energy transition strategies.

ii. Investment Prioritization: MCDM techniques help prioritize energy investments, especially in the context of limited resources. By considering factors such as return on investment, economic development potential, energy security, and sustainability, decision-makers can allocate funds effectively to the most promising energy projects [21]. These techniques are useful for selecting and evaluating energy infrastructure projects, such as the development of new power plants, grid expansions, and renewable energy installations.

So, MCDM techniques are widely used across various sectors of energy management to support efficient decision-making, optimize resource use, and ensure sustainable energy practices. These techniques enable stakeholders to navigate the complexity of energy systems and make well-rounded decisions that meet both short-term and long-term energy goals.

3. Methodology

3.1 Literature search strategy

For To ensure a comprehensive and systematic review of literature on the application of MCDM techniques for solving energy management problems, a carefully structured search strategy was employed. The primary database utilized for this review was Dimensions.ai, a robust and dynamic research database offering extensive access to peer-reviewed journal articles, conference proceedings, and research outputs from diverse disciplines [22]. Its advanced search capabilities, including filtering by citations, funding, and open access, made it an ideal choice for capturing the breadth of MCDM-related studies in the energy domain.

The search strategy involved the formulation of a set of well-defined keywords and search strings to identify relevant studies. Keywords were selected to encompass both the methodological and application-specific aspects of the research focus. The core terms included “multi-criteria decision-making,” “MCDM,” and “multi-objective optimization,” ensuring a broad coverage of decision-making techniques. Additional energy-specific keywords, such as “energy management,” “renewable energy integration,” “energy efficiency,” and “energy systems optimization,” were included to narrow the scope to energy-related applications. Furthermore, terms associated with specific MCDM methodologies, such as “AHP” (Analytic Hierarchy Process), “TOPSIS” (Technique for Order Preference by Similarity to Ideal Solution), “Fuzzy MCDM,” “VIKOR,” and “PROMETHEE,” were incorporated to capture studies employing these techniques. Boolean operators like AND, OR, and parentheses were used to create complex search strings, enhancing the precision of the search process.

The review focused on literature published between 2010 and 2025, a time frame selected to ensure the inclusion of recent advancements in MCDM methodologies and their applications to modern energy challenges. This period reflects the growing complexity of energy systems, the rise of renewable energy sources, and the increasing emphasis on sustainability, all of which necessitate advanced decision-making tools like MCDM. Only articles written in English were considered to maintain consistency and facilitate comprehensive analysis. By leveraging the capabilities of Dimensions.ai and adhering to a structured methodology, this review captures a holistic view of how MCDM techniques have been applied to address critical issues in energy management, providing valuable insights into their role in optimizing energy systems and supporting sustainable decision-making.

3.2. Inclusion and exclusion criteria for studies

To ensure the relevance, quality, and focus of the review, a set of inclusion and exclusion criteria was established [23]. These criteria served as guidelines to systematically select studies addressing the application of MCDM techniques in solving energy management problems. The criteria ensured that only the most pertinent and methodologically sound studies were included in the review.

Inclusion Criteria: Studies were included in the review if they directly applied MCDM techniques to address challenges in energy management. Priority was given to peer-reviewed journal articles only, that demonstrated methodological rigor and provided sufficient detail about the application of MCDM methods. The review focused on studies that utilized established MCDM methods, such as AHP (Analytic Hierarchy Process), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), VIKOR, PROMETHEE, or Fuzzy MCDM, to solve specific energy-related problems. These problems included renewable energy integration, energy efficiency improvement, energy systems optimization, and sustainable energy planning. Only studies published between 2010 and 2025 were considered to ensure the inclusion of recent advancements and trends in MCDM applications that includes 14394 articles under UGC CARE I and II which covers Scopus and Web of science database. This time frame captures the evolution of energy management challenges, particularly in light of technological developments and the global shift toward renewable and sustainable energy systems. Additionally, studies written in English were included to maintain uniformity in analysis and accessibility.

Exclusion Criteria: Studies were excluded if they did not focus explicitly on MCDM applications in energy management or if they lacked sufficient methodological detail. Articles that discussed MCDM in general terms without applying it to specific energy-related problems were excluded to maintain the specificity of the review. Duplicate studies, abstracts without full-text availability, and non-peer-reviewed sources, such as opinion articles and blog posts, were also excluded. Research focusing on other domains, such as healthcare, logistics, or unrelated engineering applications, was omitted unless a clear linkage to energy management was established. The application of these criteria involved a two-stage screening process. First, titles and abstracts were reviewed to identify studies that met the inclusion criteria. In the second stage, full-text articles were assessed to confirm their relevance and adherence to the review's objectives. This systematic approach ensured that the included studies provided valuable insights into how MCDM techniques have been used to address diverse energy management challenges.

By employing these inclusion and exclusion criteria, the review maintains a focused scope, enabling a comprehensive analysis of the role of MCDM in optimizing energy systems and supporting decision-making in energy management.

3.3. Analytical framework for classifying and comparing studies

The analytical framework for this review was designed to systematically classify and compare studies on the application of MCDM techniques in energy management. A bibliometric analysis was employed as the primary method, enabling a structured approach to understanding the scholarly research dynamics within this domain. This framework facilitated the identification of key patterns, trends, and relationships across the body of literature, offering insights into the evolution and impact of MCDM methodologies in energy management.

The bibliometric analysis encompassed a range of quantitative and qualitative techniques to evaluate the scholarly output. Key indicators such as publication trends, citation counts, and research collaboration networks were analyzed to identify development trends in MCDM applications. The review tracked the annual growth of publications to understand how interest in this area has evolved over time, particularly in response to emerging energy challenges and technological advancements.

Author contributions were assessed to identify leading researchers and their impact on the field. The analysis included examining the number of publications, citation metrics, and h-index values for prominent authors. Institutional affiliations of authors were also explored to determine the geographic and institutional distribution of research efforts, highlighting key contributors from academia, industry, and government organizations.

The framework also considered the publication sources, categorizing studies based on the journals, conference proceedings, and book chapters in which they appeared. Highly cited literature was identified to pinpoint seminal works and foundational studies that have significantly influenced subsequent research. This analysis shed light on the core methodologies, application areas, and theoretical advancements that underpin MCDM in energy management.

Studies were classified based on several dimensions, including the specific MCDM methods employed (e.g., AHP, TOPSIS, VIKOR, PROMETHEE, Fuzzy MCDM), the type of energy management problem addressed (e.g., renewable energy integration, energy efficiency, sustainable planning), and the geographic or sectoral focus of the research. This classification enabled a comparative analysis of different approaches and their effectiveness in solving energy management problems.

4. Current State of MCDM in Energy Management

4.1 Trends in research and publication

For The bibliometric data on publications from 2010 to 2025 reveals a significant upward trend in research activity related to MCDM applications in energy management. Starting with 50 publications in 2010, the field experienced steady growth through 2015, reaching 269 publications, followed by an accelerated increase from 2016 onwards.

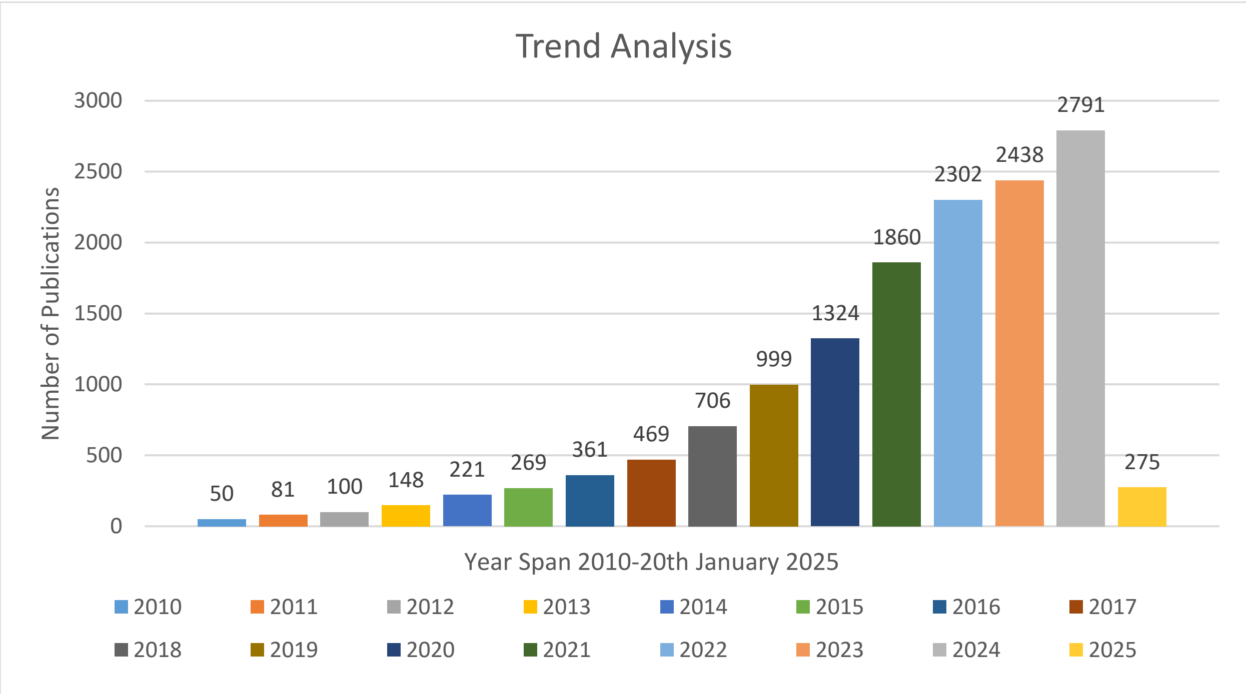

Fig. 1. Number of publications in the last 15 year

The period from 2018 to 2024 marks an exponential rise, with the number of publications peaking at 2,791 in 2024. This surge reflects the growing global emphasis on energy optimization, renewable energy integration, and sustainability, areas where MCDM techniques are increasingly applied. The slight dip in 2025 (275 publications so far) may indicate as the data is collected up to 20th January 2025 for the year rather than a decline as shown in Figure 1. Overall, the trend underscores the expanding relevance of MCDM methodologies in addressing complex energy challenges and suggests the field's maturation as an essential tool in energy systems research and decision-making.

4.2 Trends in Research category

Research trends show a strong focus on engineering (ANZSRC) and SDG 7 (*Affordable and Clean Energy*), highlighting MCDM's role in energy optimization, sustainability, and interdisciplinary applications across diverse fields as shown in Figure 2. The bibliometric analysis of research fields based on the ANZSRC 2020 classification reveals that the application of multi-criteria decision-making (MCDM) techniques in energy management is predominantly concentrated in engineering, which accounts for the largest share with 6,161 publications. This is followed by information and computing sciences (3,806 publications), highlighting the role of computational tools in advancing MCDM methodologies. Built environment and design (2,294 publications) and commerce, management, tourism, and services (2,155 publications) further reflect the interdisciplinary application of MCDM in urban energy planning and strategic decision-making. Environmental sciences (1,214 publications) emphasize the focus on sustainability and renewable energy, while mathematical sciences (877 publications) underscore the theoretical advancements in MCDM models. Fields like economics (565 publications) and earth sciences (548 publications) illustrate the integration of MCDM in addressing energy policy and resource optimization. Other fields, such as health sciences, education, and psychology, exhibit minimal representation, indicating limited cross-disciplinary research in these areas. The dominance of engineering and computing sciences highlights the technical foundation of MCDM applications, while the significant contributions from environmental sciences and commerce demonstrate its growing role in addressing global energy challenges.

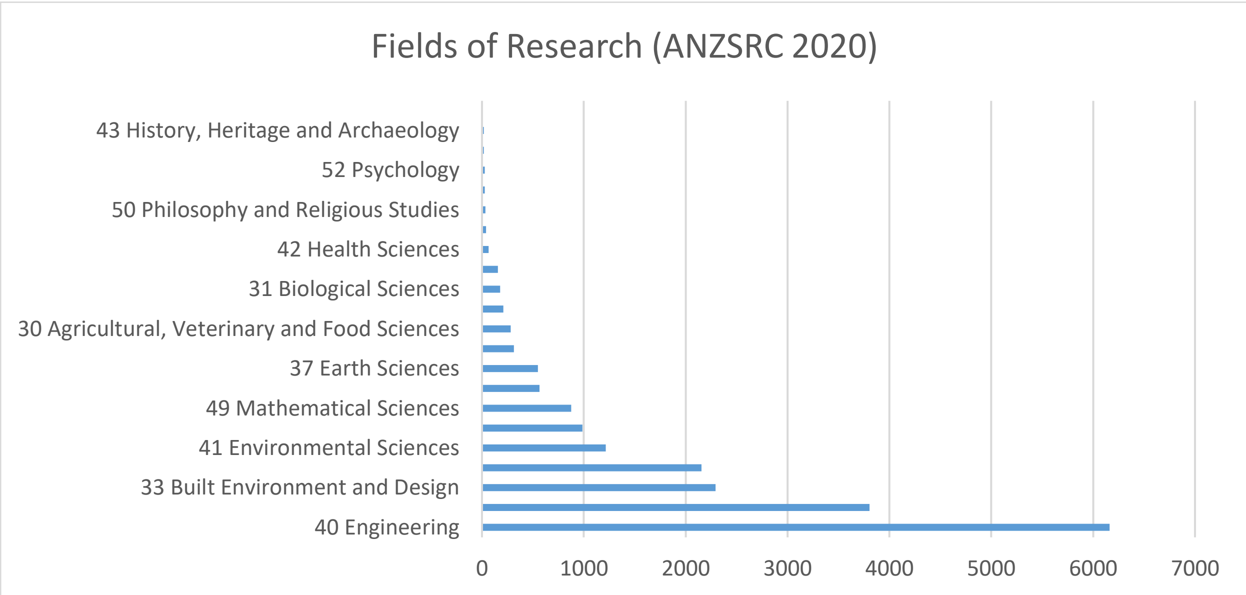

Fig. 2. Field of research vs. Number of Published Paper

The bibliometric analysis reveals the pivotal role of MCDM in advancing energy-related Sustainable Development Goals (SDGs). SDG 7 (*Affordable and Clean Energy*) leads with 5,660 publications, followed by SDG 13 (*Climate Action*, 2,833). MCDM supports energy optimization, urban planning, and industrial development (SDG 12, SDG 11, SDG 9) as shown in Figure 3. Limited contributions to social-focused SDGs, like *Gender Equality* and *Reduced Inequalities*, highlight untapped potential for expanding MCDM applications to broader sustainability objectives.

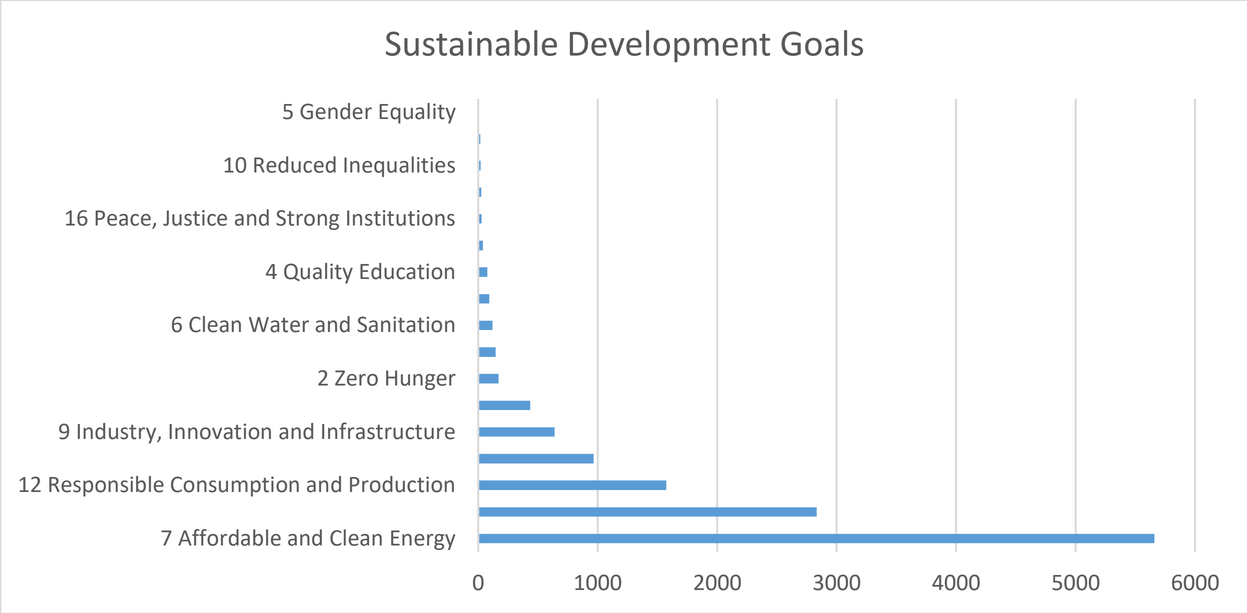

Fig. 3. Sustainable Development Goals vs. Number of Published Paper

4.3 Publication with Citations and Citation analysis

The bibliometric analysis of citation trends reveals a consistently high percentage of publications with ≥1 citation from 2010 to 2021, averaging above 95% as shown in Figure 4.

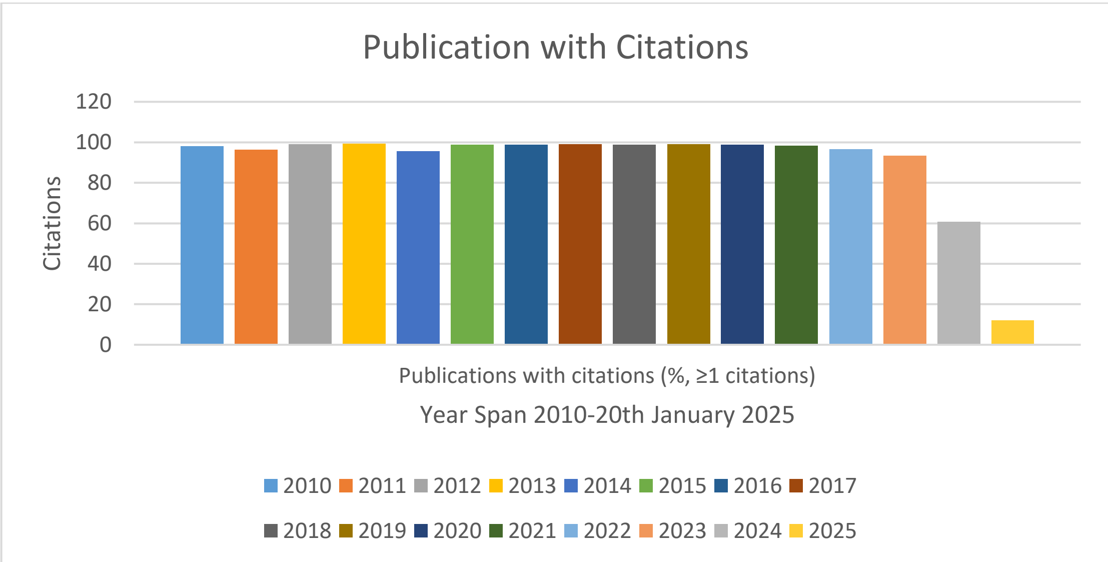

Fig. 4. Publication with Citations vs. Selected Year Span

Peaks in citation percentages, such as 99.32% in 2013 and 99% in 2019, highlight the lasting impact of research during these years. A gradual decline begins in 2022 (96.66%), dropping significantly for 2023 (93.27%) and 2024 (60.73%), with 2025 showing only 12%, likely due to the recency of publications and limited time for citations to accrue. This trend underscores the maturity and influence of earlier research while reflecting the natural lag in citation accumulation for more recent works.

Citation analysis of 100 researchers in multi-criteria decision-making (MCDM) reveals the most influential scholars based on their citation frequency as shown in Figure 5. The top five researchers are:

iii. Dragan Stevan S Pamucar (University of Belgrade, Serbia) – 217 publications, 6,959 citations, mean citations: 32.07
iv. Muhammet Deveci (Naval Academy, Turkey) – 144 publications, 4,452 citations, mean citations: 30.92
v. Hasan Dinçer (Istanbul Medipol University, Turkey) – 127 publications, 4,569 citations, mean citations: 35.98
vi. Serhat Yüksel (Istanbul Medipol University, Turkey) – 124 publications, 4,491 citations, mean citations: 36.22
vii. Edmundas Kazimieras Zavadskas (Vilnius Gediminas Technical University, Lithuania) – 122 publications, 10,686 citations, mean citations: 87.59

These researchers form a highly interconnected group in the field, with frequent citations among each other, illustrating their central roles in advancing MCDM applications for energy management.

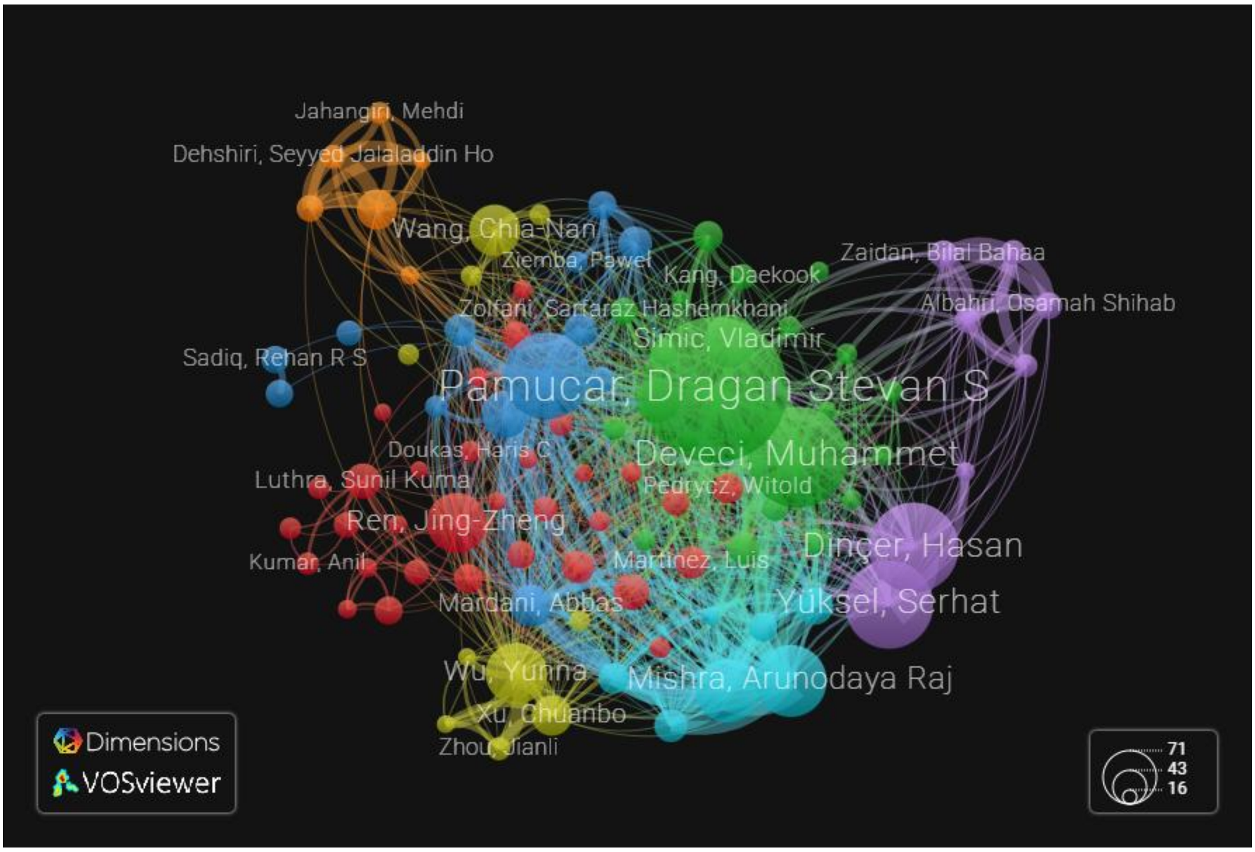

Fig. 5. Citation analysis of 100 researchers

4.4 Co-authorship analysis

Co-authorship analysis of 100 researchers provides valuable insights into collaborative networks and the structure of research communities as shown in Figure 6. The analysis focuses on identifying the largest set of connected items, which represent groups of researchers who frequently collaborate on publications [24]. These sets reveal the strength of the relationships between authors, determined by the number of co-authored publications. The larger the connected set, the more interconnected the group of researchers, highlighting prominent research teams and interdisciplinary collaborations. Publications with more than 25 authors are excluded to maintain focus on more targeted and meaningful collaborations. By examining the co-authorship relationships, we can identify key contributors, influential research clusters, and potential research synergies, offering a clearer understanding of the collaborative dynamics within the field of multi-criteria decision-making

(MCDM) applications in energy management. The visualization of the co-authorship network provides a clear depiction of how researchers are connected, with closely-knit groups signifying areas of concentrated research efforts and impact.

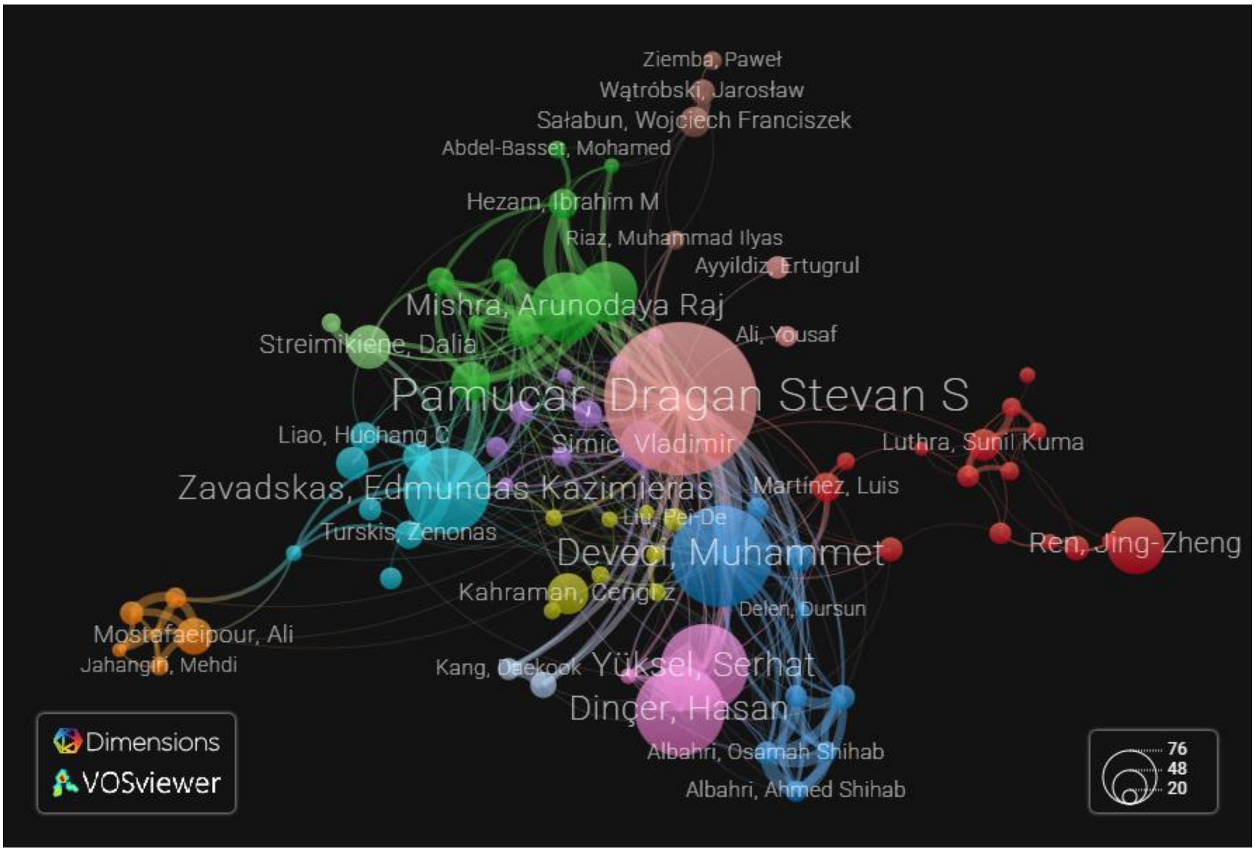

Fig. 6. Co-authorship analysis of 100 researchers

4.5 Sources of Publication

The top 10 research sources in MCDM applications for energy management, based on the number of publications and citations, are critical in advancing sustainable energy solutions [25]. These journals have significantly contributed to the field, with each showcasing impactful research on energy optimization, renewable sources, and sustainable practices.

i. Sustainability – 926 publications, 17,326 citations, mean citations: 18.71, focuses on sustainable development across diverse sectors, including energy management.
ii. Journal of Cleaner Production – 652 publications, 33,396 citations, mean citations: 51.22, publishes articles on cleaner production technologies and sustainable energy solutions.
iii. Energies – 506 publications, 9,162 citations, mean citations: 18.11, offers research on energy production, consumption, and management with an emphasis on renewable energy.
iv. Energy – 353 publications, 16,472 citations, mean citations: 46.66, explores the latest trends in energy systems, efficiency, and sustainability.
v. Renewable Energy – 277 publications, 13,774 citations, mean citations: 49.73, highlights renewable energy technologies and their integration into existing energy systems.
vi. Renewable and Sustainable Energy Reviews – 277 publications, 23,994 citations, mean citations: 86.62, focuses on reviewing cutting-edge renewable and sustainable energy research.

vii. Expert Systems with Applications – 256 publications, 14,516 citations, mean citations: 56.70, publishes articles on applying expert systems and decision support techniques in energy management.
viii. IEEE Access – 231 publications, 3,549 citations, mean citations: 15.36, offers research on advanced energy systems, including smart grids and MCDM approaches.
ix. Environmental Science and Pollution Research – 217 publications, 4,413 citations, mean citations: 20.34, features interdisciplinary research on environmental impact and energy management.
x. Applied Energy – 189 publications, 9,372 citations, mean citations: 49.59, publishes high-impact research on energy efficiency, optimization, and policy decisions.

These journals serve as key platforms for disseminating significant contributions to energy management through MCDM, offering valuable insights into both theoretical advancements and practical applications in the energy sector.

4.6 Country and Organization analysis

The analysis of countries contributing to MCDM applications for energy management, based on citations and total link strength, highlights key global players in the field [26]. The following top 10 countries have made significant contributions:

i. China – 600 documents, 18,273 citations, total link strength: 375. China leads in MCDM research for energy management, with high publication output and substantial citation impact, showcasing extensive collaboration across research networks.
ii. Turkey – 450 documents, 17,386 citations, total link strength: 323. Turkey's research on energy management using MCDM approaches is robust, with a strong citation count, reflecting significant contributions from its academic community.
iii. India – 365 documents, 11,569 citations, total link strength: 372. India's growing emphasis on energy optimization and sustainability through MCDM methods has resulted in a considerable body of work with substantial global citation reach.
iv. Iran – 260 documents, 11,155 citations, total link strength: 246. Iran has made notable strides in applying MCDM to energy management, particularly in renewable energy systems, with a moderate citation impact.
v. Malaysia – 94 documents, 8,456 citations, total link strength: 179. Malaysia's research contributions in MCDM for energy management are growing, reflecting its emerging role in sustainable energy studies, though with fewer publications compared to leading countries.
vi. United States – 130 documents, 7,185 citations, total link strength: 195. The U.S. has contributed to key energy management studies, particularly in MCDM methods for energy policy and optimization, with substantial international impact.
vii. Lithuania – 71 documents, 6,915 citations, total link strength: 93. Lithuania's contributions to MCDM applications in energy management are impactful, especially in academic circles, though its output remains smaller compared to other leading countries.
viii. United Kingdom – 139 documents, 4,882 citations, total link strength: 259. The UK continues to play a prominent role in energy management research, using MCDM methods to explore sustainable energy solutions with moderate citation impact.
ix. Spain – 82 documents, 4,285 citations, total link strength: 66. Spain is emerging as a significant player in the energy management field, with increasing research output and growing international recognition.
x. Saudi Arabia – 157 documents, 3,378 citations, total link strength: 294. Saudi Arabia's contributions to MCDM for energy management focus on optimizing energy systems,

especially in relation to the country's energy infrastructure, though citations are relatively lower.

These countries reflect the global spread of MCDM research in energy management, with China, Turkey, and India standing out for their substantial contributions in both publications and citations, indicating their leadership in this research area as shown in Figure 7.

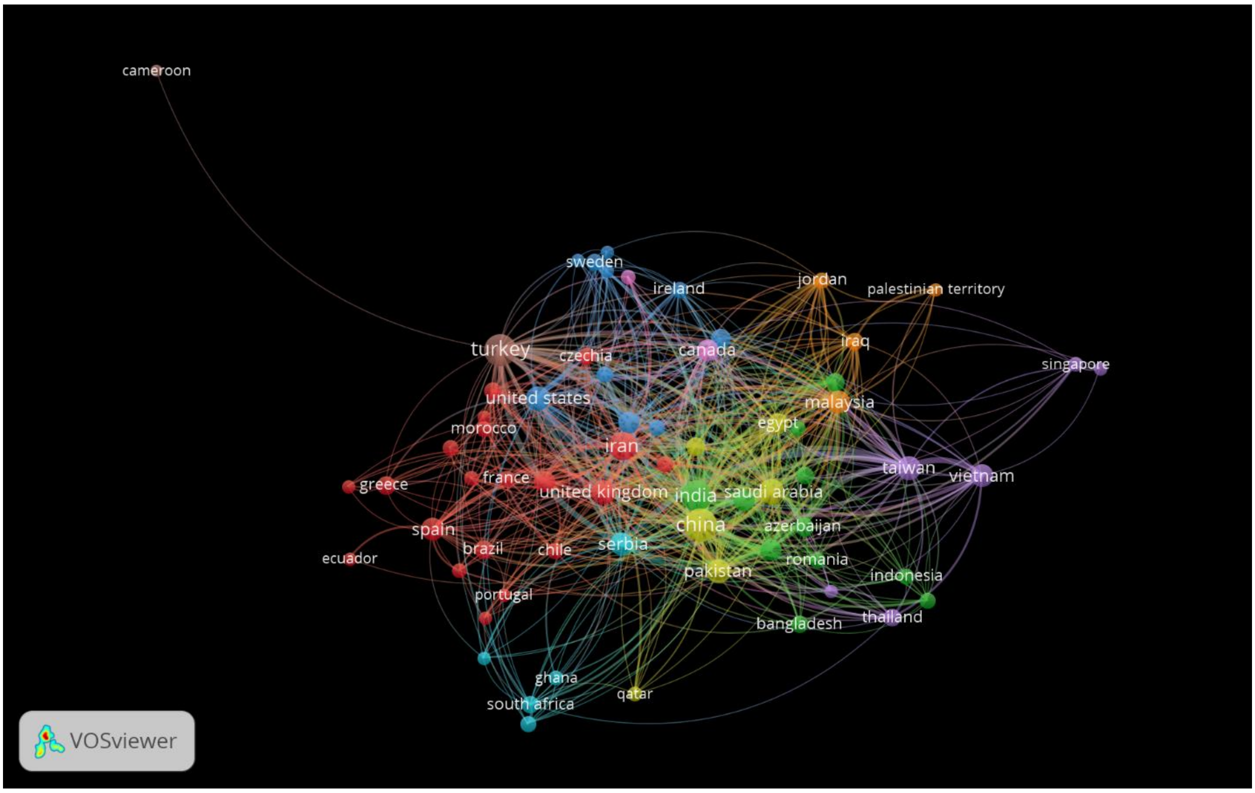

Fig. 7. Country wise citation analysis

The analysis of organizations contributing to multi-criteria decision-making (MCDM) applications in energy management, based on citations and total link strength, reveals key academic institutions that have made significant strides in this research domain. The following organizations have been particularly influential:

i. Vilnius Gediminas Technical University – 51 documents, 5,958 citations, total link strength: 77. This institution is a major contributor to MCDM research in energy management, with a high citation impact and notable collaboration strength.
ii. University of Technology Malaysia – 28 documents, 4,529 citations, total link strength: 52. Known for its focus on energy systems, the University of Technology Malaysia has made significant contributions, especially in optimizing energy management systems.
iii. Yıldız Technical University – 61 documents, 3,184 citations, total link strength: 40. This Turkish university has been a key player in energy management research using MCDM methods, with a solid publication record and a growing citation impact.
iv. North China Electric Power University – 64 documents, 3,055 citations, total link strength: 11. With a focus on energy systems and power management, this university has contributed significantly to the development of MCDM techniques in energy optimization.
v. Islamic Azad University, Tehran – 24 documents, 2,631 citations, total link strength: 27. This Iranian university has contributed to MCDM applications, particularly in energy systems modeling and optimization, with a moderate citation influence.

vi. Istanbul Technical University – 39 documents, 2,577 citations, total link strength: 18. Istanbul Technical University has been involved in research focusing on sustainable energy and energy systems optimization, utilizing MCDM approaches.

vii. University of Tehran – 52 documents, 2,067 citations, total link strength: 50. The University of Tehran's research has contributed to applying MCDM methods for optimizing energy resources and solving energy management challenges.

viii. University of Defence – 28 documents, 1,972 citations, total link strength: 48. This institution has made significant strides in the application of MCDM for energy management in defense-related energy systems.

ix. Universiti Sains Malaysia – 5 documents, 1,955 citations, total link strength: 6. Although a smaller contributor, Universiti Sains Malaysia has garnered significant citation attention in energy-related MCDM research.

x. Zhejiang University – 14 documents, 1,662 citations, total link strength: 19. Zhejiang University's contributions, though fewer in number, are influential in the context of energy management using MCDM techniques.

These organizations, from a diverse range of countries, play a pivotal role in advancing MCDM methods in energy management, with varying degrees of collaboration and citation impact as shown in Figure 8.

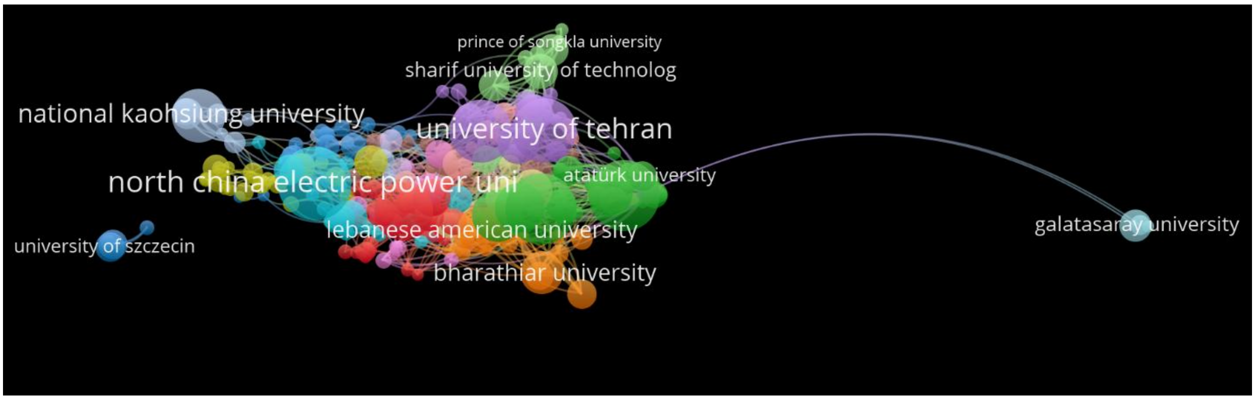

Fig. 8. Organization wise citation analysis

4.7 Influential paper analysis

The citation analysis of key documents in the field of multi-criteria decision-making (MCDM) applications for energy management reveals influential works based on citation count and link strength [27]. The following documents stand out:

- Behzadian *et al.,* [28] – 1,806 citations, 72 links

This paper is one of the most highly cited in the field, demonstrating its strong impact on energy management research using MCDM methods. The objective of this paper is to conduct a comprehensive literature survey to taxonomies the applications and methodologies of the TOPSIS method in MCDA/MCDM. The methodology involves reviewing 266 scholarly papers across nine application areas, categorized by publication year, journal, author nationality, and other methods combined with TOPSIS. The conclusion highlights key insights into TOPSIS and its diverse applications. Future work suggests further research in TOPSIS decision-making that is both forward-looking and practically oriented, providing a framework for academic researchers and practitioners [28].

- Kumar *et al.,* [29] – 1,212 citations, 143 links

This document is highly influential, with a large number of citations and extensive academic connections, making it a significant contribution to the MCDM-energy management domain. The objective of this article is to explore the role of MCDM techniques in energy planning for rural communities, considering multiple benchmarks like technical, social, economic, and environmental factors. The methodology involves reviewing various MCDM methods applied to renewable energy systems. The conclusion highlights the flexibility of MCDM in optimizing energy alternatives while considering multiple criteria simultaneously. Future work suggests further advancements in MCDM techniques for sustainable energy planning, especially for decentralized renewable energy systems, to address the complexities of rural electrification [29].

- Huang *et al.,* [30] – 1,001 citations, 15 links

This paper is well-cited, indicating its importance in applying MCDM for energy systems optimization, although it has fewer academic connections. The objective of this study is to review the applications of MCDA in environmental decision-making. The methodology involves analyzing over 300 papers from 2000 to 2009, categorized by environmental application, decision type, and MCDA methods used, such as AHP, multi-attribute utility theory, and outranking. The conclusion highlights significant growth in MCDA applications across various environmental sectors, with consistent results across methods. Future work suggests further exploration of parallel method applications in different regions to refine decision-making processes in environmental projects [30].

- Mardani et al., [31] – 893 citations, 52 links

This work has made a strong contribution to the use of MCDM in energy management, with a notable citation count and a decent number of academic links. The objective of this paper is to systematically review the applications and methodologies of fuzzy multi-criteria decision-making (FMCDM) techniques. The methodology involved reviewing 403 papers published between 1994 and 2014 from over 150 peer-reviewed journals, categorized by field, authorship, country, and research type. The conclusion highlights that hybrid fuzzy MCDM methods and fuzzy AHP were the most widely used, with Taiwan leading in contributions and engineering being the top field of application. Future work suggests exploring the integration of advanced fuzzy techniques in emerging fields and industries [31].

- Mardani *et al.,* [32] – 747 citations, 65 links

Another significant paper by Mardani, reflecting its relevance in the MCDM-energy management space, with a strong citation impact. The objective of this paper is to present a systematic review of MCDM techniques in sustainable and renewable energy systems. The methodology involved reviewing 54 papers published between 2003 and 2015 from over 20 high-ranking journals, classified into two main application groups and six technique categories. The conclusion highlights the growing interest in MCDM methods, with AHP/fuzzy AHP and integrated methods being the most prominent. Future work suggests further exploration of MCDM applications to address uncertainties and enhance decision-making in sustainable and renewable energy systems [32].

- Zavadskas *et al.*, [33] – 627 citations, 28 links

This document is well-cited, showcasing its importance in energy management research through MCDM techniques. The objective of this article is to review the theoretical bases and developments of multi-criteria decision-making (MCDM) methods. The methodology involves examining the evolution of MCDM techniques since the 1950s and 1960s, highlighting key advancements and the current state of the field. The conclusion emphasizes the growing research in MCDM, yet acknowledges ongoing debates over methodological choices and frameworks. Future work suggests further exploration of the strengths and weaknesses of different MCDM methods, providing insights into improving decision-making processes [33].

- San Cristóbal [34] – 542 citations, 90 links

A valuable contribution, this paper's citations and links suggest it is widely regarded in the field, particularly for MCDM applications in energy-related issues. The objective of this paper is to apply the VIKOR method in selecting a Renewable Energy project under Spain's Renewable Energy Plan. The methodology combines VIKOR with the Analytical Hierarchy Process (AHP) to weigh decision criteria based on stakeholders' preferences. The conclusion reveals that the Biomass plant (co-combustion in a conventional power plant) is the best option, followed by Wind power and Solar Thermo-electric alternatives. Future work suggests further refinement of decision-making frameworks for renewable energy projects and the inclusion of more diverse criteria [34].

- Sánchez-Lozano *et al.,* [35] – 466 citations, 66 links

This paper is cited extensively, with strong academic engagement, highlighting its significance in MCDM-based energy management studies. The objective of this paper is to evaluate the optimal placement of photovoltaic solar power plants in Cartagena, Spain, using GIS and MCDM methods. The methodology combines GIS for identifying constraints and weighting criteria with AHP for factor weighting and TOPSIS for evaluating site alternatives. The conclusion shows that GIS–MCDM integration effectively identifies suitable sites for renewable energy projects. Future work suggests enhancing the approach with more dynamic data and exploring its application to other renewable energy projects for broader decision-making contexts [35].

- Lee and Chang [36] – 449 citations, 118 links

A more recent publication with strong academic engagement, this work is increasingly cited, underlining its growing influence in the MCDM-energy management field. The objective of this paper is to rank renewable energy sources (RES) for electricity generation in Taiwan using four MCDM methods: WSM, VIKOR, TOPSIS, and ELECTRE. The methodology involves using the Shannon entropy weight method to assess criterion importance and conducting sensitivity analysis on the results. The conclusion identifies hydropower as the best overall choice, followed by solar, wind, biomass, and geothermal. Future work suggests further exploration of environmental, financial, and social aspects in RES selection and refining decision-making methods for energy policy [36].

- Suganthi *et al.,* [37] – 435 citations, 30 links

While slightly lower in citations compared to others, this paper still holds significance in MCDM applications for energy systems. The objective of this paper is to review the applications of fuzzy logic-based models in renewable energy systems such as solar, wind, bio-energy, micro-grids, and hybrid applications. The methodology involves analyzing recent uses of fuzzy logic for site assessment, installation of photovoltaic/wind farms, power point tracking, and optimization of conflicting criteria. The conclusion highlights that fuzzy models provide realistic estimates and are widely adopted for energy system modeling. Future work suggests further integration of fuzzy logic with other soft computing techniques for enhanced energy system optimization [37].

These documents demonstrate the evolution and impact of MCDM in energy management, with key contributions from Behzadian, Kumar, and Huang, highlighting their foundational role in shaping current research trends.

4.8. Key findings from the reviewed studies

Key findings from the reviewed studies on MCDM applications for energy management include:

i. High Impact of TOPSIS: Behzadian *et al.*, [28] study, a highly cited paper, highlighted the widespread use of the TOPSIS method in MCDM, emphasizing its diverse applications across multiple sectors and suggesting further exploration for practical decision-making frameworks.
ii. Flexibility in Energy Planning: Kumar *et al.,* [29] demonstrated MCDM's role in optimizing energy planning for rural communities, particularly in renewable energy systems, by balancing technical, economic, and environmental factors.

iii. Environmental Decision-Making: Huang *et al.,* [30] focused on the application of MCDA in environmental decision-making, identifying significant growth in its application across various environmental sectors and calling for more region-specific research.
iv. Hybrid Fuzzy MCDM Methods: Mardani *et al.,* [31] emphasized the prominence of hybrid fuzzy MCDM methods and fuzzy AHP, particularly in engineering applications. Taiwan's contribution was notable, and future work pointed toward integrating advanced fuzzy techniques in emerging industries.
v. Renewable Energy Evaluation: San Cristóbal [34] explored renewable energy project selection using the VIKOR method combined with AHP, concluding that biomass was the optimal choice for Spain's renewable energy plan and suggesting future work for refining decision-making frameworks.
vi. GIS-MCDM Integration: Sánchez-Lozano *et al.,* [35] showcased the integration of GIS and MCDM for site evaluation of photovoltaic solar power plants, concluding that this combination effectively supports the decision-making process for renewable energy installations.
vii. Ranking Renewable Energy Sources: Lee and Chang [36] used MCDM methods to rank renewable energy sources in Taiwan, identifying hydropower as the best option. Sensitivity analysis highlighted the importance of incorporating environmental, financial, and social aspects into decision-making processes.
viii. Fuzzy Logic in Energy Modeling: Suganthi *et al.,* [37] reviewed the use of fuzzy logic models in renewable energy systems, concluding that fuzzy models offer realistic estimates and are effective in optimizing energy systems when combined with other soft computing techniques.

These studies collectively illustrate the growing importance of MCDM methods in addressing the complexities of energy management, offering insights into the integration of various techniques and the need for continued innovation in decision-making frameworks for sustainable energy systems.

4.9 Classification of MCDM method

Table 1 provides an overview of various types of MCDM methods used in energy management problem-solving. It highlights the number of published research papers for each MCDM method, identifies the top author with the highest contributions, and lists the top sources (journals or conferences) where the most relevant studies have been published. This summary serves as a valuable resource for understanding the focus areas and leading contributors in the field.

Table 1
Application of different MCDM methods in Energy Management

Methods	No. published papers	Top author with highest publication	Top sources with highest publication
AHP	671	Yasir Ahmed Solangi, Jiangsu University, China	Sustainability-48
TOPSIS	438	Serhat Yüksel, Istanbul Medipol University, Turkey	Energy-44
VIKOR	122	Serhat Yüksel, Istanbul Medipol University, Turkey	Energy-12
ANP	95	He-Yau Kang, National Chin-Yi University of Technology, Taiwan	Energy-7

Table 1
Continued

BWM	**77**	**Ali Mostafaeipour, Duy Tan University, Vietnam**	**Journal of Cleaner Production-6**
SWARA	72	Serhat Yüksel, Istanbul Medipol University, Turkey	Sustainability-6
PROMETHEE	62	Paweł Ziemba, University of Szczecin, Poland	Sustainability-8
EDAS	55	Ali Mostafaeipour, Duy Tan University, Vietnam	Environmental Science and Pollution Research-5
COPRAS	43	Shabbiruddin, Sikkim Manipal University, India	Sustainability-3
GRA	43	Sobhan Mostafayi Darmian, Norwegian University of Science and Technology, Norway	Energy-73
WASPAS	42	Seyyed Jalaladdin Hosseini Dehshiri, Allameh Tabataba'i University, Iran	Sustainability-4
ELECTRE	36	Serhat Yüksel Istanbul Medipol University, Turkey	Sustainability-4
Fuzzy MCDM	30	Sen Guo, North China Electric Power University, China	Sustainability-3
COSMOS	22	Jan D Keller, German Meteorological Service, Germany	Renewable Energy-3
TODIM	22	Ali Mostafaeipour, Duy Tan University, Vietnam	Journal of Cleaner Production-4
MABAC	14	Dragan Stevan S Pamucar, University of Belgrade, Serbia	Renewable Energy-2
MOORA	13	Sassi Rekik, University of Monastir, Tunisia	The Science of The Total Environment-1
COMET	5	Wojciech Franciszek Sałabun West Pomeranian University of Technology, Poland	Applied Energy-1
MAUT	3	Graciele Rediske, Universidade Federal de Santa Maria, Brazil	Energy-1
MACBETH	2	Cengi z Kahraman, Istanbul Technical University, Turkey	Energies-1
PAPRIKA	2	Hoon-Seok Jang, Korea Electronics Technology Institute, South Korea	Energy Conversion and Management-1

5. Future Research Directions

5.1 Integration of MCDM with Emerging Technologies

The integration of MCDM with cutting-edge technologies is pivotal for advancing energy management solutions. Artificial intelligence (AI) and machine learning (ML) can enhance decision-making models by enabling real-time data processing and predictive analytics, optimizing energy usage patterns [38]. Blockchain technology, combined with the Internet of Things (IoT), can provide secure, transparent, and efficient energy transaction systems, especially in decentralized energy grids. Future research should focus on developing hybrid MCDM models that combine these technologies for improved decision support in energy management.

5.2. Enhancing the Robustness of MCDM Models

A key challenge in applying MCDM in energy management is the inherent uncertainty and dynamic nature of energy systems [39]. Future research should aim to enhance the robustness of

MCDM models by developing approaches to handle uncertain parameters such as fluctuating energy prices, supply variability, and demand spikes. Hybrid MCDM models, which combine traditional techniques with advanced algorithms, as well as adaptive models that evolve in real-time, should be explored to ensure greater accuracy and reliability in decision-making processes under variable conditions.

5.3. Expanding Application Domains

MCDM applications are increasingly being explored in diverse energy sectors. Microgrids and off-grid systems, which provide energy solutions for remote areas, present unique challenges for decision-making, such as balancing sustainability and cost-efficiency [40]. Research should extend to these areas, focusing on optimizing the design and operation of microgrids using MCDM. Additionally, MCDM models should be applied to sustainable urban energy systems, addressing challenges like smart grid integration, energy storage, and renewable energy adoption in urban settings, to promote energy efficiency and reduce carbon footprints.

5.4. Social and Policy Aspects in MCDM Applications

Future research should also incorporate social and policy dimensions into MCDM models for energy management. Decision-making in energy systems is influenced not only by technical and economic factors but also by social acceptance, policy regulations, and public preferences. Including these aspects can improve the real-world applicability of MCDM models [41]. Research should focus on developing methodologies that integrate stakeholder inputs and policy considerations into the decision-making process, ensuring that solutions are socially equitable, politically feasible, and aligned with sustainable development goals.

These directions represent promising avenues for future exploration in the MCDM field, aimed at advancing energy management solutions that are more efficient, adaptive, and socially responsive.

6. Conclusion

This review has provided an in-depth analysis of the application of MCDM methods in solving energy management problems. Key findings indicate that MCDM approaches are crucial for optimizing complex energy systems, particularly in enhancing the efficiency of energy distribution, integrating renewable energy, and addressing sustainability concerns. The integration of MCDM with advanced technologies like AI, ML, and IoT has emerged as a promising direction for future research, with the potential to further enhance decision-making capabilities in dynamic and uncertain energy environments.

The contributions of this review are significant, providing a comprehensive summary of the state of research in the field, identifying influential studies, and mapping key trends across countries, organizations, and journals. It highlights how MCDM applications have evolved, particularly in the context of energy management, and pinpoints areas where future research can make substantial impacts, such as in microgrids, off-grid systems, and urban energy planning.

In conclusion, MCDM plays a pivotal role in tackling the challenges associated with future energy management. As the world moves toward more complex and decentralized energy systems, MCDM will be indispensable for making informed, balanced decisions that consider economic, environmental, and social dimensions. Its integration with emerging technologies and expansion into new application domains will drive innovation, helping to create sustainable, resilient, and efficient energy solutions for the future.

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Conflicts of Interest

The author declares no conflicts of interest.

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