Multi-criteria Analysis Methods: recent applications and trends

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Abstract
Multicriteria Analysis has been incorporated as a tool to support complex decisions nowadays, although in its beginnings the most frequent applications were in areas such as administration and finance. Currently, the relationship between technological and social needs have a great weight in studies where sustainability is the thematic axis. This research was carried out by consulting Web of Science, ProQuest and sciELO databases, with the support of Vosviewer and CiteSpace bibliometric processing software. In terms of new and traditional methods, some relevant trends were identified, such as the neutrosophic model and machine learning, which are being successfully incorporated together with Artificial Intelligence tools. The most relevant applications identified are related to the location of sites for sustainable energy generation, suitable sites for waste confinement, prediction of flood susceptible areas, development of cities and various organizational decisions to combat climate change.

Keywords: Multi-criteria analysis, Multi-criteria decision analysis, Multi-criteria decision making.

1 Introduction

Decision-making is the choice made with available information to try to solve a specific problem. Decision-making methods can be single-criterion if they evaluate a plan against a single objective, or multi-criteria if they do so with respect to several objectives. The following terms, Multi-criteria decision-making (MCDM) and Multi-Criteria Decision Analysis (MCDA), are also commonly found in the literature to indistinctly denote methods that identify and select the relevant factors in the decision process, a set of options, and the process to compare them against each other. Benjamin Franklin was the first to develop what is known as such, and since the 50s, different methods have been developed in this field [1].

Multi-criteria approaches are the most attractive for decision-making since they simultaneously consider all relevant factors related to the problem, preferences, and the value system of the decision-maker [2]. Furthermore, multi-criteria methods include various methods, techniques, as well as valuation and evaluation tools in the pursuit of ensuring more informed decisions and adopting new planning paradigms [3].

1.1 Generic MCDA mathematical model

The various MCDA methods differ from each other by the level of complexity of the algorithms, the weighting methods for the criteria, the forms of evaluation, the possibility of uncertainty in the information, and the type of data aggregation. However, they share a common mathematical expression from eq. (1)-(3)

$$A=\{Ai \mid i=1, 2,\ldots, m\} \quad (1)$$
$$C=\{Cj \mid j=1, 2,\ldots,n\} \quad (2)$$
$$W=\{Wj \mid j=1, 2,\ldots, n\} \quad (3)$$

Where A is a set of finite and different options, and m represents the number of them. C is a set of certain criteria that are used to evaluate A, and n is the number of them. W is a set of weights assigned to each criterion according to its importance.

The options are homogeneous but the criteria can have different units without interrelation between them, and even with conflicting objectives (while some criterion is maximized, another or others are minimized).

When organizing the information, an MCDA matrix is formed as shown in Table 1.

Table 1.
MCDA Matrix.

Option	C_1	C_2	…	C_n
A_1	X_{11}	X_{12}	…	X_{1n}
A_2	X_{21}	X_{22}	…	X_{2n}
…	…	…	X_{ij}	…
A_m	X_{m1}	X_{m2}	…	X_{mn}

Source: Adapted from Pearman & Phillips, 2009.

X_{mn} represents the value of A_i related to C_j, and together with the weighting vector $W = \{W_1, W_2, \ldots, W_n\}$, they constitute the basic inputs for any MCDA problem. Subsequently, the scores of the options are calculated and ranked from the best to the worst option.

1.2 Types of problems for MCDA

The identification of the type of multi-criteria problem becomes essential for an MCDA method to assist in its solution. According to [4], decision problems can be classified into taxonomy problems (without preference order) or ordinal classification problems (with preference order). The latter include multi-criteria decision problems since actions are described with preference orders

according to specific evaluation criteria. Fig. 1 summarizes the set of MCDA problem types.

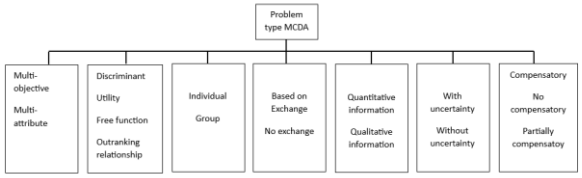

Figure 1. Types of MCDA problems.
Source: Adapted from Baizyldayeva, 2013.

The most common types of problems are related to those of the multi-objective (MODM, multi-objective decision making) and multi-attribute (MADM, multi-attribute decision making) types. The MODM type constitutes an optimization problem in which the solution is found within a feasible region of the solution space; the criteria are goals and the limitations are clearly defined. In contrast, the MADM type or discrete problem has a finite number of options, and the best one is chosen from among that number; the limitations are unclear and there is little interaction among decision-makers.

Since there is no universally accepted model, it is highly recommended to select a model based on data needs, the decision problem, and complexity. Furthermore, it is important to consider that there is difficulty in obtaining adequate quality and availability of data with MCDA methods, comprehensive evaluation methods and evaluation criteria are lacking, and temporal or spatial changes influence biases [5]. On the other hand, MCDA is a structured and transparent process, which makes it suitable for evaluating aspects with heterogeneous variables that are understandable to stakeholders, such as sustainability for example [6]. At the same time, fuzzy models have been developed to resolve the insufficiency of numbers in complex contexts where knowledge is lacking and information is imprecise [7].

1.3 The process of Multi-Criteria Analysis

The objectives set at the beginning of the MCDA may change, rather than being permanent. The MCDA determines to what extent the identified options create value by achieving the objectives, and one can even face deciding between two options: conducting the MCDA or not. Choosing to conduct the MCDA means that someone has judged that the analysis brings relatively more value than not doing it. Fig. 2 shows the eight-step process for Multi-Criteria Analysis [8].

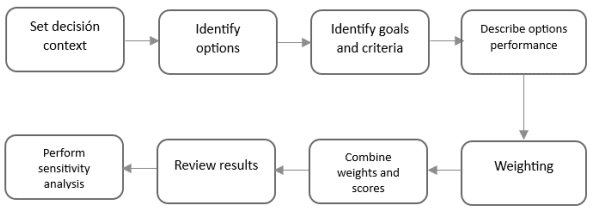

Figure 2. The steps of Multi-Criteria Analysis.
Source: Adapted from Pearman & Phillips, 2009.

From the previous steps, the weighting of the factors or decision criteria is highly relevant, making it advisable to choose multiple methods, as well as a comparative evaluation among them to identify the most appropriate one in a specific situation. Traditional weighting methods include: AHP, MACBETH, DEMATEL, CRITIC, and ENTROPY; AHP is the most popular method.

Expert knowledge can be distorted when using subjective weighting methods, and with complex problems, the comparison of criteria requires a lot of time. However, the use of Artificial Intelligence and Machine Learning (ML) is supporting the incorporation of artificial experts in combination with theoretical decision-makers, to lead to more scalable and independent solutions [9].

1.4 Classification of multi-criteria methods

It is estimated that there are more than 200 multi-criteria analysis methods, and for a specific situation, different choices of methods can be made, which makes the very choice of the MCDM method to use complex [10]. There is even the possibility of obtaining the same results using different methods in a given case. For example, the MULTIMOORA, TOPSIS, and VIKOR, VIKOR, COPRAS, and PROMETHEE, COPRAS, and VIKOR methods can lead to the same results, but there may be results that do not match, such as those of VIKOR, COPRAS, and TOPSIS and the ranking results of MULTIMOORA and PROMETHEE [11].

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Sensitivity analysis in MCDA serves to review the validation of the results and the reliability of the results in the face of changes, as well as to expand applications in sustainability problems, geographic information systems, and healthcare [14]. The sensitivity approaches used in MCDA can be of three types:

- Based on changing the weights of the criteria (the vast majority of research).
- Based on changing the values that describe the alternatives (a very small percentage of studies).
- Other approaches, which are based on Monte Carlo simulation, analysis of variance, or modification of method parameters.

1.5 Current applications of MCDA methods

The applications of MCDA methods are concentrated in a set of specific areas [15,16], as described in Table 2.

Table 2.
Main application areas of MCDA methods.

Application areas	Examples
Healthcare	COVID evaluation in regional health Occupational health Health risk assessment
Energy sector	Prioritization of renewable energy sources, energy policies
Engineering and Production	Material selection for optimal design, optimal process parameters
Labor	Personnel selection problems, task selection
Supply Chain Management	Sustainable supplier selection, green supplier evaluation and selection
Organizations	Corporate sustainability, system selection in enterprises
Education	E-learning, contextual learning modeling
Transportation	Urban passenger transportation systems, integrated transportation systems
Civil Engineering	Risk analysis in buildings under natural disasters
Finance and Economics	Project portfolio management

Source: Adapted from Pramanik et al,2021.

2 State-of-the-art review

2.1 New MCDA methods and their applications

In the past decade, new MCDA methods were developed as described in Table 3; both objective and subjective methods are included. The FUCOM and MEREC methods are the ones that have aroused the greatest interest in the scientific community in recent years [17].

Table 3. New methods MCDA in recent years.

Year	Method	Author(s)	Main characteristics
2015	BWM Best-Worst Method	Rezaei, J.	The best criteria and the worst criteria are identified first. Next, pairwise comparisons are performed between each of these two criteria (the best and the worst) and the other criteria. Finally, a maximin problem is formulated and solved to determine the weights of the different criteria.
2016	CILOS Criterion Impact Loss	Zavadskas, E.K.; Podvezko, V.	It is an objective method that considers the loss of importance or impact of the criteria that remain when a criterion achieves the maximum or minimum value.
2016	IDOCRIW Integrated Determination of Objective CRIteria Weight	Zavadskas, E.K.; Podvezko, V.	It is a hybrid method that combines the weights obtained by ENTROPY and CILOS. The advantages of one method are compensated by the weaknesses of the other.
2019	FUCOM Full Consistency Method	Pamucar, D. Zeljko, S. & Sremac, S.	It is a subjective method based on pairwise comparison and the deviation from maximum consistency.
2019	LBWA Level Based Weight Assessment	Zizovic	It is a subjective weighting method that seeks to solve the difficulties of pairwise comparison, removing the inconsistencies in expert choices that other methods overlook, such as BWM and AHP.
2020	SAPEVO-M Simple Aggregation of Preferences Expressed by Ordinal Vectors—Multi Decision Makers	Gomes S. Santos M., Souza de Barros L.F., Manzolillo A., Regina dos Santos M.	It is an evolution of the SAPEVO method; it is aimed at a single-decision analysis. It is based on the ordinal transformation of preferences and subsequently, pairwise comparisons are made between alternatives, criteria, or variables.
2023	MEREC Method Based on the Removal Effects of Criteria	Shahiir M., Soon L., Mahani S., Zaini M., Vonn H.	It is an objective method that considers the impact of removing a criterion on the performance values of the decision alternatives.

Source: Adapted from Ayan et. al, 2023.

Other methods have been proposed recently, such as the INCOME method (Intelligent characteristic objects), which combines the k-Nearest Neighbor (kNN) algorithm and the COMET method. The kNN algorithm is of a non-parametric type, since it does not need or assume data

about the distribution and relies solely on training data. The INCOME method would overcome the classical limitations of MCDA methods and has been validated with a case study to select gas energy plants [9].

The applications of MCDA methods can be analyzed by application areas, as shown in Table 4. As observed, the incursion into different business areas is very notable in strategic, tactical, and operational decisions, up to broader economic analyses. On the other hand, in the case of fuzzy MADM and MODM methods, applications have been concentrated since the last decade in computer science, engineering, mathematics, decision sciences, business and management, and environmental sciences [18].

Table 4.
New multi-criteria methods with their applications.

Method	Application areas
CILOS and IDOCRIW	Quality Assurance in construction contracts, construction market performance, evaluation of a safe and healthy construction environment.
FUCOM	Business economics, purchasing decisions, supplier selection, tourism, streaming platforms, logistics optimization, facility layout, organizational structure, inventory management, transportation, business processes, facility location, strategic decisions, energy, recycling, healthcare, urban mobility.
LBWA	Business economics, environmental areas, public transportation, small and medium enterprises, HR in a transportation company and savings fund selection, sustainable food supplier selection, waste in fast-moving consumer goods, sustainable transportation, renewable energy resources, and healthcare.
SAPEVO-M	Analysis of aeronautical systems, investment portfolio management, transport truck selection, numerical control, and water treatment.
MEREC	Financial performance in hospitals and tourism, efficiency and productivity in commercial banks, mitigation of climate change effects in cities, optimal localization, renewable energy source selection, circular energy, diverse applications in materials engineering and manufacturing processes, urban planning and development, urban transportation planning, logistics optimization, and supplier selection.

Source: Adapted from Pramanik,2021.

2.2 Trends in MCDA applications

The applications of MCDA methods to complex problems are influenced by social, business, and technological needs in a given temporal context. For example, concern for sustainability in the past decade was addressed in a review on the use of multi-criteria analysis in this field from 2008 to 2018. In the end, it was concluded that the methods used in sustainable engineering are based on traditional approaches, with a notable trend toward the application of uncertainty, fuzzy, grey, rough, and neutrosophic theories [19].

In the field of renewable energies, a literature review concluded that the traditional methods AHP, ANP, ELECTRE, and TOPSIS, and to a lesser extent, PROMETHEE, remain the most widely used in the evaluation of investments in renewable energy [20]. On the other hand, another recent review on the use of MCDA in renewable energies confirmed that traditional methods continue to have a notable presence [21].

In other areas of interest, the aforementioned trend has been observed. For instance, in a literature review on MCDA in tourism, it was concluded that the AHP and TOPSIS methods are the most widely used methods for hotel evaluation and selection, tourism destination assessment, and the most attractive research topics in that industry [22]. Another review, focused on food chains, concluded that multi-criteria analysis is one of the most appropriate and promising approaches to comprehensively capture the complex and wide-ranging effects of agricultural practices and food supply chains [6].

Multi-criteria analysis can also be integrated with other tools to solve complex location problems, such as the case of geographic information systems (GIS) with MCDA. At the most rudimentary level, GIS-MCDA is a process that transforms and combines geographic data and values with decision-maker preferences, for collaborative decision-making with a technological, social, and political perspective [23].

3. Methodology

In this research, the literature on MCDA in all application areas is reviewed. In comparison with existing reviews, it aims to contribute to the understanding of:

a. The current landscape of the most widely used MCDA methods in the last ten years.
b. The main application areas in MCDA in the last five years.
c. The future trends generated from current ones in MCDA.

Bibliometric analysis has been incorporated due to the need to process large volumes of information with available technology and the advantages it offers [24]; CiteSpace 6.3 R1 Basic software was used for this research. The analysis methodology followed for the present study is described in Fig. 3.

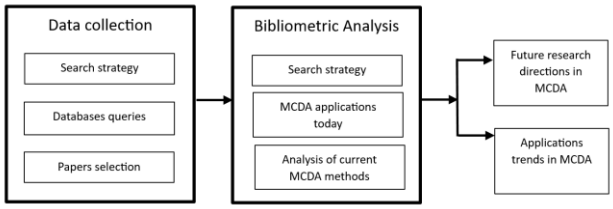

Figure 3. Methodology for analyzing MCDA applications.
Source: The authors.

This research is structured into 2 sections:

Section 1. The results obtained in the period from 2014 to 2024 using bibliometric analysis are presented, including: a) consulted databases, b) countries with the most publications, c) main authors, d) main publications, e) research areas, f) topic maps, as well as a selection of the main authors along with their contributions to MCDA.

Section 2. A grouping of the main applications of MCDA at present is presented, based on the consultation of databases and their analysis.

Finally, conclusions and future directions of MCDA methods expected in the coming years are presented.

4 Results

The query was performed in the Web of Science, PROQUEST, and sciELO databases, considering scientific articles from the last 10 years, from 2015 to what was published during 2025. The keywords used in this search were: análisis multicriterio, multicriteria análisis, multicriteria decision analysis, multicriteria decision making, and multicriteria evaluation. Although the acronym MCDA is widely used in this field of knowledge, it can be confused with similar acronyms from other disciplines, so it was omitted from the searches. In total, 30,144 documents were registered. Ninety-six percent (96%) of all consulted documents came from the Web of Science (WOS) database, while PROQUEST and sciELO completed the total with 2% respectively. China is the country with the highest number of publications with 18% of the total publications, followed by Taiwan (15%), India (11%), USA (8%), and Iran (8%).

4.1 Main authors in MCDA in recent years

n order to have an overview of current approaches, Wang JQ, Zavadskas, and Pamucar were selected to review their most influential works and some of their latest works. Fig. 4 shows the ten most relevant authors in MCDA and Fig. 5 shows the collaboration network among the main research authors on the subject; Pamucar, Wang, and Zavadskas stand out.

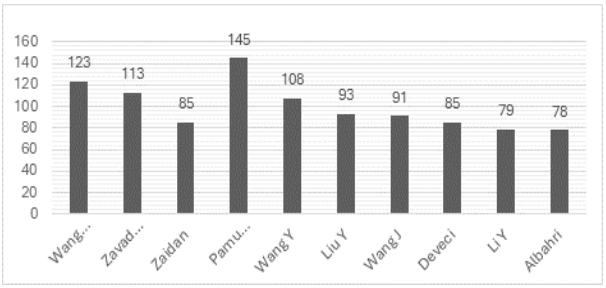

Figure 4. The top ten authors in MCDA.
Source: Obtained from Web of Science (https://www.webofscience.com/wos/alldb/basic-search)

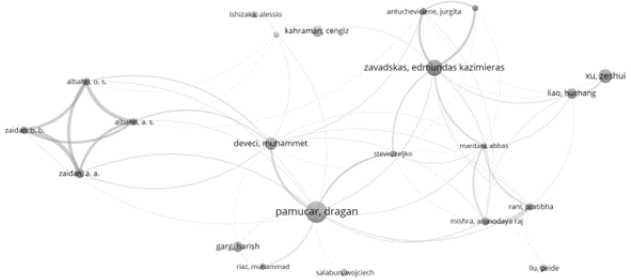

Figure 5. Map of the collaboration networks of the main authors on MCDA.
Source: Obtained from VOSViewer.

4.1.1 Main works of Wang
Highest impact publications:

- Proposal to solve stochastic MCDM problems with uncertain, imprecise, and missing preference information, by defining relevance relations in interval grey numbers and an SMAA-ELECTRE model to handle stochastic grey MCDM problems [25].
- An innovative method to address Multi-Criteria Group Decision-Making (MCGDM) problems with Z-numbers under the condition that weight information is completely unknown. The method was presented to evaluate atmospheric pollution potential [26].
- A novel outranking approach for multi-criteria problems where a set of numbers exists in the unit real interval and not just a specific number with a neutrosophic set. The operations of interval neutrosophic sets and their related properties are introduced, to subsequently define relations for interval neutrosophic numbers (INNs) based on ELECTRE IV [27].

Most recent research:

- A support framework to evaluate water resource carrying capacity in advance: hesitant probabilistic fuzzy sets (HPFS) are selected as the representation of evaluation information in the expert group, and subsequently, a multi-criteria group decision-making (MCGDM) method based on TODIM-PROMETHEE II is developed to overcome the inherent constraints of the PROMETHEE II method and make it suitable for

practical decision-making with bounded rationality [28].
- Conducting an FMEA (Failure Mode and Effect Analysis) based on probabilistic linguistic information and the TODIM method (Portuguese acronym for interactive and multi-criteria decision-making) to identify risks in wind turbine systems [29].
- A multi-criteria group decision-making (MCGDM) method to handle the problem of Building Energy Efficiency Retrofitting (BEER) project selection using fuzzy sets to describe evaluation information in a complex and uncertain environment [30].

4.1.2 Main works of Zavadskas
Highest impact publications:

- A new method called SECA, for the simultaneous evaluation of criteria and alternatives using a multi-objective non-linear programming model [31].
- A new MCDM method called Mixed Aggregation by Comprehensive Normalization Technique (MACONT) to address complex MCDM problems. A comprehensive normalization technique based on criteria types is introduced and, subsequently, it uses two mixed aggregation operators to aggregate the distance values between each alternative and the reference alternative across different criteria from compensatory and non-compensatory perspectives [32].
- A new MCDM method called EDAS (Evaluation based on Distance from Average Solution). There is a phenomenon called rank reversal (RR) that occurs when adding new information about alternatives or criteria in a discrete multi-criteria decision-making (MCDM) problem, and causes a change in the original ranking of alternatives. This method proves to be more efficient than the TOPSIS method with respect to this phenomenon [33].

Most recent research:
- Advertising in the Metaverse proposing an improved version of the Best Worst Method (BWM) [34], a method called OPARA (Objective Pairwise Adjusted Ratio Analysis) without using normalization and applies it to personnel selection [35].
- Evaluation of digital transformation in banks through an integrated approach of the SWARA (integrated stepwise weight assessment ratio analysis) method and WASPAS (weighted aggregated sum product assessment) [36].
- In a road paver machinery selection, weighting was performed using the MF D-SWARA (Improved Fuzzy D Step-Wise Weight Assessment Ratio Analysis) method to weight the criteria, along with a new fuzzy ARAS-Z (Additive Ratio Assessment) method to obtain a stable model [37].
- A new methodology to evaluate various building renovation alternatives based on sustainability criteria and real-time measurements of inhabitants' emotions. This methodology integrates an intelligent multi-criteria decision support system based on the COPRAS method, the facial recognition system, and BIM methodology [38].
- Developed a method called DNMARCOS (Double normalized measurement alternatives and ranking according to the compromise Solution) to select construction equipment, integrating MEREC into criteria weighting [39].

4.1.3 Main works of Pamucar
Highest impact publications:

- Development of the multi-criteria method Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS), which starts from an anti-ideal solution and an ideal solution at the beginning of the matrix formation, determining the closest degree of utility in relation to both solutions. The addressed application case is sustainable supplier selection in a hospital [40].
- Integration of the DEMATEL (Decision Making Trial and Evaluation Laboratory) method with the new MABAC (Multi-Attributive Border Approximation area Comparison) method in a forklift investment evaluation case. DEMATEL was used to obtain the criteria weight coefficients; the evaluation and selection of the forklifts was carried out using the new MABAC method, which presented greater consistency than SAW, COPRAS, TOPSIS, MOORA, and VIKOR [41].
- Development of a new method for solving multi-criteria problems: Full Consistency Method (FUCOM). The results show that FUCOM provides better results than the BWM and AHP methods, when considering the relationship between consistency and the required number of criteria comparisons [42].

Most recent research:
- Development of a fuzzy Measurement Alternatives and Ranking according to the COmpromise Solution (fuzzy MARCOS) method in combination with a new fuzzy linguistic scale quantified in triangular fuzzy numbers (TFNs). The fuzzy PIvot Pairwise RElative Criteria Importance Assessment method—fuzzy PIPRECIA—was used to determine criteria weights from which road network sections were evaluated to determine traffic risk [43].
- Case study on sustainable supply chain management considering the triple dimension of sustainability (economic, social, and environmental) to select suppliers. The relative weights of management practices are extracted using the fuzzy best-worst method (F-BWM) and subsequently, the traditional Combined Compromise Solution (CoCoSo) method. The application focused on a household appliance manufacturer [44].

4.2 Main journals and research areas on MCDA

The journals Sustainability, European Journal of Operational Research, Journal of Cleaner Production, Energies, and Journal of Environmental Management are the most relevant journals for publications related to MCDA in the last ten years. The journal Sustainability has published the most research (28%), followed by the Journal of Cleaner Production (16%). The other relevant journals, as shown in Fig. 6, are related to computer science and mathematics; English is the preferred language for publishing.

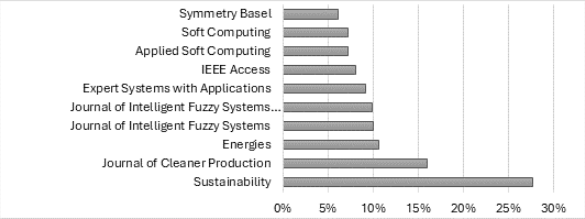

Figure 6. Main publications in MCDA in recent years.
Source: Obtained from Web of Science (https://www.webofscience.com/wos/alldb/basic-search).

The main research areas are Engineering, Mathematics, and Computer Science, followed by Business Economics, Environmental Sciences, and Energy & Fuels Technology. Fig. 7 shows the top ten research areas in Multi-Criteria Analysis.

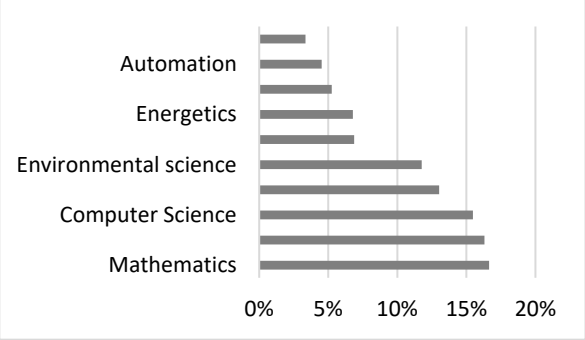

Figure 7. Main current research areas in MCDA.
Source: Obtained from Web of Science (https://www.webofscience.com/wos/alldb/basic-search).

4.3 Thematic networks in MCDA in recent years

Fig. 8 shows the network of items obtained in two clusters identified by red and green colors. The main words on the map are Method, Analysis, and Approach, followed by selection, evaluation, and assessment; multicriteria decision and GIS also appear. The network shows that MCDA is oriented toward case studies on selection and evaluation decisions; the word GIS indicates a frequent combination of geographic information systems with MCDA methods. The map was generated with 300 occurrences per item to obtain a total set of 10 items.

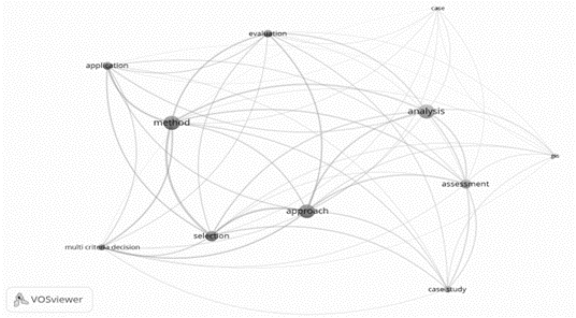

Figure 8. Map of items related to Multi-Criteria Analysis.
Source: Obtained from VOSviewer 1.6.20.

The clustering was performed with the support of CiteSpace 6.3 R1 software. Fig. 9 shows the nine topic groups or clusters obtained regarding the applications of MCDA methods. Cluster # 2 (turkeys energy policies) was redefined as energy policies after analyzing the results obtained by the software.

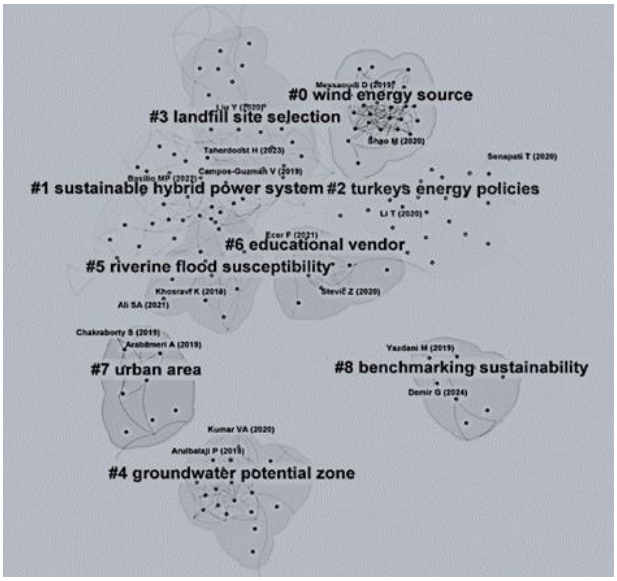

Figure 9. Map of thematic clusters on MCDA.
Source: Obtained from CiteSpace 6.3 R1.

Fig. 10 represents the network of topics with links between each of them along a timeline from 2021 to 2025.

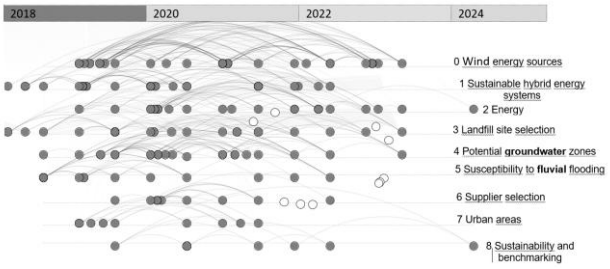

Figure 1. Network map of topics in MCDA.
Source: Obtained from CiteSpace 6.3 R1.

Fig. 11 shows the main scientific and technological disciplines that are related to MCDA today.

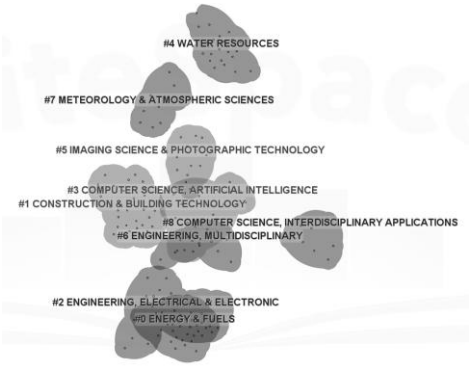

Figure 11. Cluster map by scientific and technological disciplines.
Source: Obtained from CiteSpace 6.3 R1.

4.4 Main applications of MCDA in recent years

This section briefly describes the most relevant articles from each group or cluster according to the map in Fig. 9; the main articles by number of citations and the most prominent methods in each thematic group or cluster were included.

- Cluster 0. Wind energy sources

The main cited article addresses a comprehensive approach to determine the best locations for wind and solar energy projects in Arabia. Spatial analysis within the Geographic Information System (GIS) was used to identify suitable areas for establishing solar photovoltaic and wind farms based on multi-criteria evaluation methods [45]. The next most cited article also integrates GIS with MCDA in the assessment of solar installations in Tunisia [46]. On the other hand, the most cited authors in this cluster were Shao M., Messaoudi D., and Saraswat S.K. Finally, MCDA methods used in this cluster include fuzzy AHP, BWM, and the kNN model.

- Cluster 1. Sustainable hybrid energy systems

The main article in the cluster is a research study that applies MCDA to evaluate different models of electric cars. The popular TOPSIS method was used, instead of fuzzy sets, to account for uncertainty [47]. The most cited authors by the cluster members were Campos-Guzmán, Basilio M.P., and Salabun W.

The MCDA methods used in the most relevant research of this cluster include AHP and its variants, such as the case study for selecting sustainable suppliers in construction [48]. In a combination of TOPSIS with BWM, it was proposed to economically evaluate power transmission systems [49]. Another study integrates COPRAS (Complex Proportional Assessment) and Additive Ratio Assessment (ARAS) methods with Life Cycle Assessment to evaluate potential long-term impacts of electrical energy technologies [50].

- Cluster 2. Energy policies

The main article in this cluster is a study with a comprehensive multidimensional sensitivity analysis approach to evaluate the robustness of renewable energy source development in selected European countries [51]. The most cited authors by the members of this cluster are Senapati, Li T., and Saraswat S.K.

The case studies in this cluster address solutions for selecting sustainable energy sources. For example, a case study in India evaluates suitable alternative energy sources based on eight MCDA methods and ENTROPY and CRITIC weighting methods [52]. In another case study in China, the best selection of energy sources for offshore ship charging stations is sought using a new expert weighting method combining CRITIC and SWARA II [53]. A more general study that also uses SWARA aims to analyze renewable energy alternatives in Brazil and identify the most suitable option for investment in the sustainable development of the country [54].

- Cluster 3. Landfill site selection

The main articles in this cluster are the study to evaluate the robustness of renewable energy source development in specific European countries [55] and a research study that proposes a comprehensive evaluation to select an effective and sustainable remediation method to rapidly restore an ecosystem based on AHP and FVIKOR (Fuzzy VIKOR) [56]. Another relevant piece of research presents a hybrid framework combining GIS, PROMETHEE II, with kNN machine learning algorithms to predict the best land use [57]. The most cited authors by the members of this cluster are Taherdoost H., Liu Y., and Rahimi S.

- Cluster 4. Groundwater potential zones

The main article is a work in which groundwater potential zones (GWPZ) are interpreted using an analytic hierarchy process (AHP) integrated with physicochemical analysis; the case is applied in a region of India [58].

AHP has been frequently used in this cluster and across different regions of the world. A second relevant article is a study that also deals with the detection of groundwater zones in India: cost-effective, efficient, and time-saving tools such as remote sensing and GIS were integrated to produce thematic map layers for overlay analysis with the analytic hierarchy process (AHP) to delineate such zones

[59]. In another research piece, spatial decision support systems (SDSS) were used to evaluate and define sites with groundwater potential in the central region of Nigeria; a state-of-the-art information-based multi-parametric analytic hierarchy process (AHP) was applied to define prospective groundwater areas [60]. The most cited authors in the cluster are Kumar V.A., Arulbalaji P., and Biswas S.

- Cluster 5. River flooding susceptibility

The prediction of flood-susceptible zones is a topic of wide interest in which MCDA is being integrated as a support tool for management and prediction, including the generation of flood maps. One of the main works consists of an evaluation of river flooding susceptibility in India using multi-criteria decision-making (MCDM) and an extensive geospatial database through the integration of fourteen geomorphological, meteorological, hydro-climatic, and anthropogenic factors. The methodology incorporates an FAHP model that uses triangular fuzzy numbers (TFN) to determine the importance weights (IW) of various parameters and their subclasses according to Saaty's scale [59].

In another study in India, three hybrid machine learning (ML) models were used: fuzzy-ANN (artificial neural network), fuzzy-RBF (radial basis function), and fuzzy-SVM (support vector machine) with 12 topographic, hydrological, and other factors that influence flooding to determine flood-susceptible zones. In the end, the fuzzy-RBF model outperformed the other hybrid machine learning models for modeling flood susceptibility [61].

MCDA has also been integrated with Geographic Information Systems to solve complex problems such as flood analysis. A case study presented an innovative approach to model the infiltration efficiency index (IEI) for Geographic Information Systems analysis, with a methodology that integrates very high resolution (VHR) remote sensing data, GIS-MCDA, and statistical methods. The methodology was tested and demonstrated in a watershed in Ukraine [62]. The most cited authors of the cluster are: Khosravi K., Ali S.A., and Nachappa T.G.

- Cluster 6. Supplier selection

The main article consists of a research study in which a decision-making model is proposed to select educational suppliers within the Metaverse with a focus on extended reality (XR). It includes a consensus-based measurement of alternatives and a ranking model according to the compromise solution (MARCOS), which incorporates single-valued neutrosophic (SVN) information and SVN Dombi-Archimedean weighted aggregation operators [63]. In another relevant study by the same author, a model is developed that combines the merits of PHF sets (probabilistic hesitant fuzzy data), generalized Dombi operators, and an MCDM method called measurement of alternatives and ranking according to compromise solution (MARCOS) for consensus building in a group decision-making scenario. The proposed model provides a higher degree of adaptability and flexibility to handle complexities in healthcare supplier selection problems [64].

Another research work presented a multi-criteria decision-making model for the optimal design of briquetting machines through the evaluation of alternatives with the MARCOS method and validated by TOPSIS. The results obtained showed that the fuzzy MARCOS method was able to rank the designs based on their performance and the final values of the overall utility function [65]. The most cited authors of the cluster are: Stevic Z., Ecer F., and Stankovic M.

- Cluster 7. Urban area

The main article focuses on generating a risk map in a region of India through a qualitative analysis of composite factors (CF) and an analytic hierarchy process (AHP). In addition, the quantitative analysis (fuzzy logic) considered eight criteria affected by flooding: slope, distance from the main river, land use/land cover (LULC), soil, drainage density, elevation, geomorphology, and proximity to the stream confluence [66]. On the other hand, in a case study in Iran, a flood hazard index (FHI) map was prepared considering seven factors that influence flooding: elevation, slope, flow accumulation, river distance, rainfall intensity, land cover, and geology. In this case, the weighting, just like the case in India, was performed with AHP combining Shannon Entropy (SE) and Entropy-AHP [67].

In another case study in India, a GIS-based multi-criteria decision-making analytic hierarchy process (MCDM-AHP) model was developed to identify potential flood hazard zones (FHZ), flood vulnerability zones (FVZ), and flood risk zones (FRZ) for the region in question [68]. The most cited authors of this cluster are: Arabameri A., Chakraborty S., and Allafta H.

- Cluster 8. Sustainability benchmarking

The main work is the proposal of a new MCDM technique called WFJM developed through a fuzzy environment and applies it to the benchmarking problem for oil companies [69]. Another relevant study addresses autism diagnosis based on machine learning (ML) in a three-phase triage. First, the dataset used comprises 19 medical and sociodemographic characteristics of 1296 autistic patients who received autism diagnoses through the intelligent triage method. Second, this dataset formed the basis for rigorously testing eight ML models, considering normal and adversarial attack scenarios, and evaluating classifier performance. The third phase developed a robust decision-making framework encompassing the creation of a decision matrix (DM) and the development of the 2-tuple linguistic Fermatean fuzzy decision method by opinion score (2TLFFDOSM) to compare multiple ML models from normal and adversarial perspectives [70]. The most

cited authors of this cluster are Yazdani M., Demir G., and Salih M. M.

In summary, recent trends in Multi-Criteria Analysis show a marked expansion toward hybrid approaches, integration with artificial intelligence and machine learning, and a growing application in spatial problems through GIS–MCDA. Recent literature highlights four central lines of advancement:

First, the AI–MCDA hybridization is consolidated, where machine learning algorithms such as XGBoost or Gradient Boosted Trees are used for weight estimation, criteria validation, and robustness analysis without replacing the value structure inherent to MCDA. This integration strengthens the stability of rankings and improves the interpretation of results under scenarios of high uncertainty [71].

Second, the GIS–AI/ML–MCDA triad is formalized as a dominant trend in territorial planning, optimal siting of renewable energies, risk mapping, and urban design. Reviews evidence the importance of documenting criteria, normalization, and spatial validation methods [72].

Third, the use of MCDA for public policy evaluation is strengthened, especially through the SMCE and SOCRATES frameworks, which incorporate sensitivity, robustness analysis, and social participation. These approaches are essential for complex decisions in energy and sustainability contexts [73][74].

Fuzzy and neutrosophic logic continues to gain ground as they allow modeling the indeterminacy of judgments in fields such as waste management, environmental risks, and supplier selection. Together, these trends underline a transition from traditional MCDA toward more integrated, robust methodological approaches oriented toward transparency and the participation of stakeholders involved in multi-criteria decision-making.

5 Conclusions

The leadership in the development of research in Multi-Criteria Analysis is held by China, Taiwan, and India, followed by the USA, Turkey, Brazil, Italy, and England. This fact has been consistent over the last ten years. Regarding the authorship of works on MCDA, researcher networks are concentrated in European institutions (Zavadskas, Pamukar, Stevic). On the other hand, the contribution of researchers from Asian institutions is becoming increasingly significant (Wang, Liu, Li).

The main publications on MCDA are led by Sustainability and the Journal of Cleaner Production, followed by other prestigious journals such as Energies, IEEE, Expert Systems with Applications, and the Journal of Intelligent Fuzzy Systems. This shows that sustainability continues to be a field of general interest for MCDA applications, since the first two journals have this orientation in their editorial line.

Based on the analysis over the horizon of the last 10 years, it was identified that Engineering, Mathematics, and Computer Science are the areas with the greatest interest in the scientific community. However, the fields of knowledge are very broad, making it difficult to deduce toward which problems research has been directed. The identification of the nine thematic clusters supported by CiteSpace software provides a better overview. Fig. 12 shows the interrelated topics simplified into 7 clusters. This is congruent with the theme of sustainability, which is the axis of the main publications on MCDA in recent years. The main application areas of multi-criteria analysis are: energy systems, flood planning, sustainable urban development, and groundwater localization.

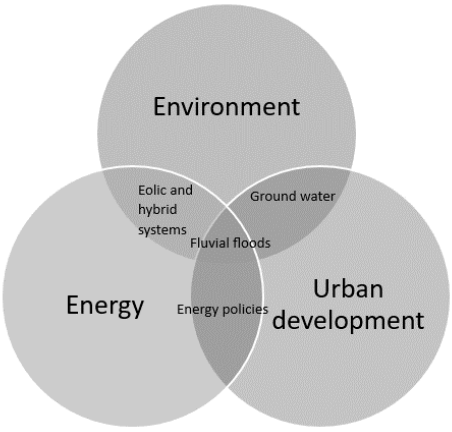

Figure 12. Main application areas of MCDA.
Source: The authors.

It is highly probable that concern for sustainability, particularly decisions on energy and combating climate change, will be the most complex to resolve in the near future; therefore, Multi-Criteria Analysis will become increasingly valuable as a support tool for decision-makers. The Multi-Criteria Analysis toolkit is broad; there are more than two hundred methods, but the observed trends follow two tracks:

- Traditional methods. AHP, PROMETHEE, TOPSIS, BWM, and kNN are the most widely used; however, it is noted that the incorporation of fuzzy logic is more frequent.
- New methods. Weighting methods such as ENTROPY and CRITIC have emerged, as well as new multi-criteria methods such as COPRAS, PIPRECIA, CoCoSo, MABAC, and FUCOM.

On the other hand, current research in Multi-Criteria Analysis is oriented toward the neutrosophic model and machine learning, and this approach is projected to gain more relevance in the coming years. Finally, integration with GIS systems is more frequent in decisions regarding site location with multiple sustainability criteria.

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