

# Recent advances in multi-criteria decision analysis: A comprehensive review of applications and trends

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**Abstract.** In recent years, multi-criteria decision support methods have become widely used research tools by both scientists and practitioners. Theoretical works involving new multi-criteria methods and developments of existing methods immediately find applications in areas of business practice. This paper attempts to sort out the areas of application of MCDA methods. For this purpose, the relevant literature from 2018–2023 was reviewed. The inclusion selection criteria were defined as addressing multi-criteria practical issues, open accessibility, comprehensive research methodology and findings, and the use of an MCDA method in the evaluation process. Detailed research identified that the main areas of use of MCDA methods are healthcare, energy management, supplier selection, and transportation. Due to the timeliness and importance of the problem, a detailed study of the use of MCDA methods in sustainability issues was separated. The paper contributes contributions to both theory and economic practice. The article provides a series of recommendations both on the methodological side of the problems to be solved and shows the practical prism of individual decision models, offering ready-to-use decision models, and providing a comprehensive review of recent MCDA advancements, fostering informed and reliable decision-making. Additionally, this review sheds light on the latest developments in MCDA, emphasizing trends in Decision Support Systems (DSS) and prominent application areas in contemporary research.

**Keywords:** Decision making, practical challenges, multi-criteria decision analysis, literature review, applications and trends

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## 1. Introduction

Effective decision-making is paramount to success in today's rapidly evolving technological area, especially in industries undergoing rapid transformation [1]. The arrival of advanced technologies has brought a new dimension to the complexity of the issues that decision-makers face [2]. These issues are often characterized by many criteria, intricate variables, and multifaceted challenges that can overwhelm human analytical capabilities [3]. Consequently, there is a pressing need for innovative approaches to support decision-making processes, empowering individuals and organizations to make well-considered, comprehensive, and informed choices in this dynamic space [4].

One of the primary tools that have emerged to enhance the decision-making process is the application of Multi-Criteria Decision Analysis (MCDA) methods [5]. These sophisticated techniques are pivotal in developing Decision Support Systems (DSS), providing a structured decision-making framework [6]. Their strength lies in their ability to consider and weigh multiple inputs, allowing a better understanding of the importance of each input in the evaluation process [7]. This, in turn, facilitates the systematic resolution of complex decision problems and offers invaluable insights into the desirability and viability of different decision alternatives.

The versatility and adaptability of MCDA methods have made them highly sought-after tools for addressing a wide range of practical problems [8]. These techniques have been effectively employed in a diverse array of domains, including healthcare, where complex treatment decisions involve multiple criteria [9], green supplier selection, where environmental and cost considerations are paramount [10], sustainable transport, where various economic, environmental, and social factors are at play [11], sport management, which often handles the complex player selection and team composition problems [12], and renewable energy sources, a critical area that necessitates the consideration of numerous factors for effective and sustainable energy generation [13]. As the field of MCDA continues to evolve, embracing new methods and expanding its extensions, it is crucial to look at the recent advancements and trends within this domain. By doing so, the latest applications and evolving directions in the practical implementation of MCDA can be indicated, highlighting its ever-growing relevance in contemporary problem-solving scenarios.

To this end, this paper aims to provide an extensive review of recent research endeavors centered on practical multi-criteria problems. The review encompasses research papers published within six years, from 2018 to 2023. The selection criteria for including research papers in this review were determined as follows: 1) each paper had to address practical multi-criteria problems, 2) be openly accessible, 3) provide a comprehensive description of the research methodology and findings, and 4) utilize a multi-criteria approach as part of the evaluation process. This review sought to shed light on the latest developments in the MCDA field, emphasizing trends in the evolution of Decision Support Systems and highlighting the most prominent application areas in contemporary research. The main contributions of the study are:

- Comparison of research approaches in various practical problems: it provides decision-makers and researchers with a valuable resource for assessing the suitability and effectiveness of different MCDA methods in a diverse array of real-world scenarios.
- Empowering decision-makers with ready-to-use decision models: the research equips the decision-makers with already developed decision models, allowing them to solve the challenges in the discussed practical fields with the ready-to-use models and let them modify the currently existing approaches, adjusting them to their needs.
- Comprehensive review of recent MCDA advancements: the review provides a valuable resource for researchers and decision-makers by offering insights into the latest trends in Decision Support Systems and highlighting areas of practical application, thereby contributing to informed and up-to-date decision-making.

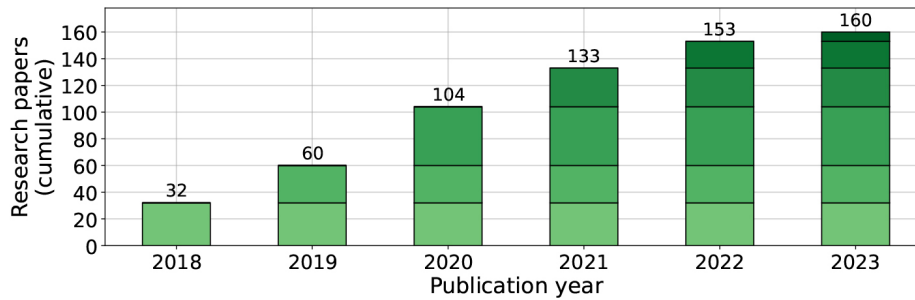


Fig. 1. Distribution of MCDA applications regarding the publication year within 160 reviewed scientific papers.

The rest of the paper is organized as follows. Section 2 presents the overview of current applications and trends in using Multi-Criteria Decision Analysis methods in practical problems. Section 3 provides a discussion of the analyzed research papers. Finally, Section 4 shows the conclusions drawn from the research and summarizes the most important aspects of the review with its limitations.

## 2. Applications and trends of MCDA

In the dynamic field of decision analysis, exploring recent applications and trends in Multi-Criteria Decision Analysis (MCDA) has become increasingly vital. This review is based on an extensive search conducted on Google Scholar using the keyword “*multi-criteria decision analysis*” with the identified papers systematically stored and categorized in the Mendeley Reference Manager library. Moreover, the search was done for five selected practical fields (*healthcare, energy development, supplier selection, transport, sustainable development*), combining them with the mentioned core part keyword. In addition, the papers directed to other fields were included in the *rest* applications. The search criteria were further extended by filtering papers with a publication date greater than 2017, ensuring a focus on the latest developments in the field. This thorough approach ensures that the review covers the latest developments, offering a comprehensive and up-to-date perspective on applications and trends in MCDA.

The numerous papers retrieved through this method provide a rich source of information on how MCDA methods are being applied across various domains and industries. By focusing on publications post-2017, the review ensures that the documented applications reflect the latest use cases of MCDA in addressing contemporary decision-making challenges. Moreover, categorizing these papers in the Mendeley Reference Manager enables a systematic analysis of trends, identifying recurring themes and emerging patterns. This review, thus, stands as a valuable resource for decision-makers, researchers, and practitioners seeking insights into the diverse applications and evolving trends within the MCDA landscape.

The expansive review of recent Multi-Criteria Decision Analysis applications spans a spectrum of practical fields, demonstrating its wide impact across diverse industries. The distribution of practical fields considered in the review reveals a balanced focus, with significant attention given to healthcare (27 papers), energy development (27 papers), supplier selection (25 papers), transport (26 papers), and sustainable development (25 papers). The research papers directed to other fields than presented above were also included in the review (30 papers). This deliberate allocation ensures a comprehensive exploration of MCDA applications, offering insights into how these methods are tailored to address specific challenges within these critical domains. With particular attention to detail and strategic distribution of papers, the review provides valuable guidance for decision-makers navigating a myriad of practical scenarios within selected sectors.

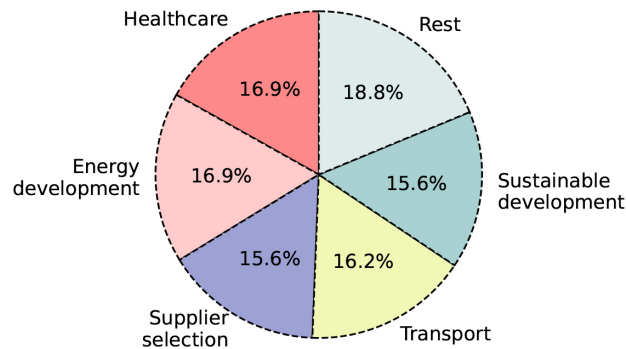


Fig. 2. Distribution of MCDA application research fields within 160 reviewed scientific papers.

### 2.1. MCDA applications in healthcare

Healthcare is at the forefront of societal priorities, and the continued development of technology in this field is of paramount importance. Advances in healthcare technology not only improve patient care and outcomes but also streamline processes, improve diagnostic accuracy, and contribute to the overall efficiency of healthcare systems. From precision medicine to telehealth solutions, technology is crucial in revolutionizing healthcare delivery and access. Integrating cutting-edge technologies such as artificial intelligence, remote monitoring devices, and electronic medical records enables healthcare professionals to make more informed decisions, tailor treatment to individual needs, and provide personalized care. The continuous evolution of healthcare technology is raising the standard of patient care and fostering a proactive and preventative approach to well-being, marking an era of transformation at the interface of healthcare and technology.

Multi-Criteria Decision Analysis has emerged as a powerful tool in healthcare, facilitating complex decision-making processes by considering multiple criteria and variables. In healthcare, decisions often involve many factors, including patient outcomes, cost-effectiveness, and ethical considerations. MCDA methods provide a structured framework to evaluate and prioritize these diverse criteria systematically, aiding healthcare professionals and policymakers in making well-informed choices. Multi-Criteria Decision Analysis contributes to evidence-based decision-making, fostering a more comprehensive and transparent approach, whether in resource allocation, treatment selection, or healthcare policy formulation. Its application in healthcare enhances decision quality and aligns with the increasing emphasis on patient-centered care and the optimization of limited healthcare resources. As healthcare evolves, MCDA is a valuable tool for navigating the complexities inherent in healthcare decision scenarios, ultimately contributing to improved patient care and healthcare system efficiency.

One of the popular topics around the healthcare area at the latest time was COVID-19. In the literature, it could be seen that numerous research papers were directed to this problem. Alemdar et al. focused on the accessibility of vaccination centers in COVID-19 outbreak control [14]. The Analytical Hierarchy Process (AHP) method was used to determine criteria weights based on the experience of the advisory committee. Sarwar et al. employed the MCDA to measure vaccination willingness in response to COVID-19 with the Analytical Hierarchy Process method [15]. De Nardo et al. covered the problem of prioritizing hospital admission of patients affected by COVID-19 in low-resource settings with hospital-bed shortage [16]. The Potentially All Pairwise RanKings of all possible Alternatives (PAPRIKA) method was applied for this purpose. Sarwar and Imran directed their research to prioritize infection prevention and control activities for SARS-CoV-2 with the AHP method [17]. With the outcome of the evaluation, the authors indicated that unnecessary travel, 3Cs (spaces that are closed, crowded, and involve close contact), and touching own body parts should be avoided. Moreover, wearing a mask and proper hand washing were also crucial

to reduce the spread of coronavirus. Choudhury et al. examined the preparedness of Indian states against COVID-19 pandemic risk based on the Fuzzy Analytical Hierarchy Process approach [18]. Ruggeri et al. used the MCDA methodology with Monte Carlo simulation for assessing the health innovations applied to the COVID-19 emergency [19]. Yang et al. applied the Analytical Hierarchy Process method with an Intuitionistic Linguistic multi-criteria group decision model to evaluate the health technologies [20]. The results accuracy was validated with the Keeney-Raiffa MCDA (KRM) method. Ortiz-Barrios et al. assessed hospitals' disaster preparedness with the Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Decision Making Trial and Evaluation Laboratory (FDEMATEL), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) techniques [21]. The authors indicated that *Personnel* is the most important factor when evaluating hospital preparedness, while *Flexibility* has the greatest prominence.

It could be seen that occurring uncertainties in healthcare problems lead to employing fuzzy logic to multi-criteria decision models. Chen et al. focused on the choice of makeshift hospitals with a multi-criteria approach [22]. For this purpose, the authors used the Best-Worst Method (BWM) and Data Envelopment Analysis (DEA) in the Trapezoidal Interval Type-2 Fuzzy (TrIT2F) environment. Yazdani et al. aimed to select the healthcare waste disposal locations [23]. To solve the determined problem, the authors proposed a new BWM with Interval Rough Numbers (IRN) for healthcare waste disposal location decisions and a new IRN Dombi-Bonferroni (IRNDBM) means the operator to process the rough data because of the unavailability of precise information. Ozsahin et al. evaluated the schizophrenia treatment techniques with the Fuzzy Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) method [24]. The obtained results showed that pharmacotherapy is the most preferred technique in assessed cases, while other techniques have different places in the final ranking based on the varied weights. Mishra and Rani addressed the problem of healthcare waste disposal location selection with the Fermatean Fuzzy Weighted Aggregates Sum Product Assessment (WASPAS) method, combining it with score function and entropy measure to indicate criteria weights [25]. Salimian and Mousavi evaluated the technologies for healthcare waste treatment with a group decision-making approach in an Intuitionistic Fuzzy environment [26]. The authors also performed a sensitivity analysis based on changing criteria weights values to indicate the influence of changes in the final rankings. Bharsakade et al. examined lean healthcare management with the Fuzzy Analytical Hierarchy Process method [27].

Another visible direction of developing multi-criteria models involved using different weighting methods and varied MCDA methods in the evaluation process. Németh et al. analyzed the impact of different weighting methods in MCDA models in healthcare with a focus on low and middle-income countries [28]. The results showed that more complex multi-criteria techniques are less eager to bias. Moreover, the authors indicated that the Simple Multi-Attribute Rating Technique (SMART), combined with the SWING-weighting technique and the Analytic Hierarchy Process methods, could be the most feasible approach. Devarakonda et al. performed research toward identifying drivers and triggers of infectious disease outbreaks using ensemble learning [29]. To identify the criteria relevance, the authors used Shannon's entropy technique to objectively define criteria weights based on the information measures from the decision matrix. Almahdi et al. used MCDA for developing mobile-based patient monitoring systems with the Best-Worst Method to establish criteria weights based on expert knowledge and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) to assess the considered systems [30]. Schey et al. focused on assessing the importance of criteria in treatments for rare diseases [31]. Based on the results from the Analytical Hierarchy Process method, the authors indicated that the *treatment efficacy* was the most important aspect. Beheshtinia et al. addressed the problem of selecting healthcare waste disposal center locations [32]. The authors presented the hybrid MCDA model PROMSIS, a combination of TOPSIS and PROMETHEE methods. Moreover, the AHP method was used to establish criteria weights. Adalı and Tuş examined the potential hospital sites with distance-based MCDA methods [33]. Thus, the authors selected Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Evaluation based on Distance

Table 1  
Most popular research papers included in the review in the healthcare field

Healthcare			
Citations	Methods	Problem	Reference
178	D-numbers based MCDM model	Healthcare waste management	[36]
120	Direct, SMART, AHP, CA, MACBETH, DCE, PAPRIKA	Off-patent pharmaceuticals	[28]
85	CRITIC, TOPSIS, EDAS, CODAS	Hospital site selection	[33]
78	BWM, VIKOR	Patient monitoring systems	[30]
77	IRN, BWM, Dombi-Bonferroni model	Healthcare waste disposal location	[23]

from Average Solution (EDAS), and COmbinative Distance-based ASsessment (CODAS) methods to assess alternatives. The CRiteria Importance Through Intercriteria Correlation (CRITIC) method was applied to determine criteria weights in the problem. Mustapha et al. examined the problem of breast cancer screening using supervised learning and MCDA [34]. For this purpose, the authors used the Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) method to evaluate the accuracy of the Support Vector Machine (SVM), K-Nearest Neighbor (KNN), Logistic Regression, and Random Forest Classifier, showing that the first one was the best approach. Gardas directed the research to indicate the organizational challenges that influence the adoption of Healthcare 4.0 technologies and model the mutual relationship between them using the Decision Making Trial and Evaluation Laboratory (DEMATEL) methodology [35]. The results from the study show three causal factors, namely “Lack of vision and commitment from the top management”, “Hierarchical structure”, and “Lack of skilled workforce”.

The trends in application decision models in healthcare problems showed that various assessment approaches are utilized to solve the considered healthcare problems. Xiao proposed a novel method for assessing healthcare waste treatment technologies based on D numbers [36]. The results showed that the proposed method can effectively handle the considered selection problem under complex and uncertain environments. Camilo et al. covered the problem of selecting the most appropriate triage system for the emergency care units in natal [37]. For this purpose, the FITradeoff method was used. Montibeller et al. focused on examining the prioritization of health threats with the Multi-Attribute Value analysis [38]. Lasorsa et al. directed their research into evaluating non-clinical hospital services [39]. The Potentially All Pairwise RanKings of all possible Alternatives (PAPRIKA) method was used. Gardas et al. covered the problem of healthcare surgical management [40]. The Total Interpretive Structural Modelling (TISM) methodology was used to identify the relationships among the factors and develop a hierarchical structure. Also, the Matrice d’Impacts Croisés Multiplication Appliqués à un Classement (MICMAC) approach was employed to identify the dominant factors. From the research papers directed to healthcare problems, the five most popular works were highlighted and presented in Table 1.

## 2.2. MCDA applications in energy development

Multi-Criteria Decision Analysis stands out as a crucial tool in energy development due to its ability to handle the complexity inherent in decision-making processes. In renewable energy development, decisions often involve many criteria, objectives, and constraints that require careful consideration. MCDA provides a systematic framework for evaluating and comparing various alternatives based on multiple criteria simultaneously. It is particularly beneficial in the energy field, where decisions impact diverse aspects such as economic feasibility, environmental sustainability, and social acceptance. The MCDA methods allow decision-makers to weigh these decision factors comprehensively, ensuring a more informed and balanced assessment of energy development strategies.

Moreover, the adaptability of MCDA methods makes them particularly useful in addressing the evolving challenges of energy technologies and policy problems. The renewable energy sector is dynamic, with advancements and innovations occurring rapidly. MCDA allows decision-makers to incorporate new criteria,

adjust weights, and adapt decision models to changing circumstances. This flexibility is vital to staying updated with technological developments, political changes, and emerging energy trends. By providing a structured and adaptable approach, MCDA empowers decision-makers to navigate the complexities of energy development, make informed choices aligned with sustainability goals, and contribute to a cleaner and more resilient energy future.

The performed review showed that varied approaches to solving determined multi-criteria problems were applied within the analyzed research works. Albawab et al. focused on evaluating the development of sustainability indicators for ranking energy storage technologies [41]. The multi-criteria analysis was based on extended Stepwise Weight Assessment Ratio Analysis (SWARA), and Additive Ratio Assessment (ARAS) methods. Mazzeo et al. proposed a novel energy-economic-environmental MCDA approach in optimizing a hybrid renewable system [42]. The results from the study emphasized that, for specific loads, PV, wind, and battery powers, the development of specific incentives for wind systems can help to make hybrid systems more economically competitive. Rehman et al. faced the problem of selecting wind energy power plant locations using the PROMETHEE method, which allowed for the identification of the optimal wind energy power plant location selected among the five alternatives [43]. Khorsand and Ramezanzpour focused on proposing an energy-efficient task-scheduling algorithm based on an MCDA approach in cloud computing [44]. Using the BWM and TOPSIS methods provided results that indicated that the proposed approach, in comparison with its counterparts, can effectively reduce the makespan and energy consumption. Diemuodeke et al. evaluated the problem of the optimal mapping of hybrid renewable energy systems for locations using the MCDA approach [45]. The HOMER software was used, and the TOPSIS method was applied considering technical, economic, environmental, and sociocultural criteria. Hong, Kim, and Jeong assessed the sustainability of the green hydrogen economy in Korea [46]. Hydrogen, renewables, uranium, coal, and gas were compared and evaluated in six selected dimensions including energy return on energy investment, greenhouse gas emissions, levelized cost of electricity, import dependency, long-term energy storage, and other applications.

Roy compared the performance of novel biomass-based hybrid energy systems such as downdraft type biomass gasifier, solid oxide fuel cell (SOFC), externally fired gas turbine (EFGT), and Stirling engine (SE) [47]. To assess the considered decision variants, the entropy method was used to determine criteria weights, and the VIKOR method was used to calculate the final ranking. Singh et al. addressed the problem of selecting optimal distributed energy resources mix in distribution networks [48]. The authors proposed a novel mix with the TOPSIS method, which was used compared to the proposed and existing methods on the standard 33-bus distribution system. McKenna et al. directed their research toward combining local preferences with the MCDA approach and linear optimization to develop feasible energy concepts in small communities in Germany [49]. The authors used the Multi-Attribute Value Theory (MAVT) method with sensitivity analysis of modeling interval weights to determine the final rankings. Murrant and Radcliffe addressed the problem of assessing energy storage technology options using a framework based on a multi-criteria approach [50]. The Multi-Attribute Value Theory method was applied for this purpose, and the authors emphasized that it can lead to important insights for the development of energy systems.

Many applications utilize fuzzy logic to handle uncertainties occurring in multi-criteria decision problems in energy management. Chatterjee and Kar focused on an MCDA evaluation of renewable energy selection in an uncertain environment with both subjective and objective criteria weights. The authors proposed COPRAS-Z methodology, where Z-number model fuzzy numbers helped with reliability degree representing the imprecise judgment of decision-makers in evaluating the weights of criteria and assessment of renewable energy alternatives [51]. Ke et al. developed a framework for a comprehensive evaluation of plan selection of urban integrated energy systems based on a BWM-CRITIC-VIKOR framework under an intuitionistic fuzzy environment [52]. The authors indicated that the initial investment, the utilization rate of renewable energy, and the comprehensive utilization rate have the most significant influence. Zhou et al.

utilized a hybrid fuzzy MCDA approach for performance analysis and evaluation of park-level integrated energy systems [53]. For this purpose, the objective weighting method of entropy was used to calculate criteria weights, and the schemes are evaluated based on the extended TODIM (an acronym in Portuguese for interactive and multi-criteria decision-making).

Ren constructed the MCDA model to prioritize energy systems under uncertainties after life cycle sustainability assessment [54]. The criteria weights were identified with a fuzzy two-stage logarithmic goal programming, and the Interval Grey Relational Analysis (GRA) was used to rank the analyzed alternatives, while the results were validated with the Interval TOPSIS method. Mrówczyńska et al. covered the problem of examining scenarios as a tool supporting decisions in urban energy policy using fuzzy logic, multi-criteria analysis and GIS tools [55]. Different criteria weights scenarios have identified factors affecting the implementation of renewable energy sources evaluations. Zhong et al. analyzed the investment strategies for renewable energies with Interval Type-2 (IT2) Fuzzy Sets, hesitant IT2 Fuzzy DEMATEL, TOPSIS, and VIKOR methods [56]. The authors recommend performing a detailed analysis to identify the risk in renewable energy investment projects that could be done with sensitivity analysis approaches. Noorollahi et al. proposed a framework for GIS-based site selection of photovoltaic solar farms [57]. For this purpose, the Fuzzy-Boolean logic and Analytical Hierarchy Process method were applied, showing that 25.78% of the examined province's area is best suited for the solar farm. Wang et al. directed their research to renewable energy plants location selection in Vietnam under a fuzzy environment [58]. The uncertainties were modeled with Fuzzy AHP and TOPSIS methods.

On the other hand, it could be seen that applying the Analytical Hierarchy Process method is a popular direction, despite the visible shortcomings of this method. Shaaban et al. directed their research to the sustainability assessment of electricity generation technologies in Egypt with AHP and WSM methods [59]. The authors indicated that the performed study emphasized the importance of a multi-dimensional evaluation of the technologies while considering the stakeholders' preferences to achieve a reliable and sustainable future energy supply. Mahdy and Bahaj focused on using MCDA to evaluate offshore wind energy potential in Egypt [60]. The authors used the Analytical Hierarchy Process and Pairwise Comparison methods to link the obtained criteria weights to site spatial assessment in a Geographical Information System. Okokpuije et al. covered the problem of selecting suitable material for developing horizontal wind turbine blades [61]. The AHP and TOPSIS methods were used to evaluate considered decision variants. Ruiz et al. focused on the MCDA assessment for selecting the optimal location of solar energy plants in Indonesia [62]. To identify the relevance of considered decision factors, the AHP method was applied. Vinhoza and Schaeffer assessed Brazil's offshore wind energy potential using a Spatial MCDA approach in which the AHP method was used to identify criteria weights considered in the determined problem [63]. Nzotcha, Kenfack, and Manjia focused on selecting a site for a pumped hydro-energy storage plant using the AHP method for weights identification and the ELimination and Choice Expressing Reality (ELECTRE) II method used for the evaluation purposes [64].

Selected applications contained complex decision models determined with many multi-criteria decision methods. Ullah et al. used the MCDA approach for optimal planning of on/off grid hybrid solar, wind, hydro, and biomass clean electricity supply [65]. Fuzzy AHP, TOPSIS, Evaluation based on Distance from Average Solution (EDAS), and Multi-Objective Optimization Method by Ratio Analysis (MOORA) methods were used to determine the decision model. Criteria such as cost, reliability, emission, social, and topographical were considered simultaneously. Saraswat and Digalwar evaluated energy alternatives of the energy sector in India by integrating Shannon's entropy and Fuzzy AHP with six Fuzzy MCDA methods, namely TOPSIS, VIKOR, PROMETHEE II, WSM, WPM, and WASPAS [66]. Ehteram, Karami, and Farzin faced the challenge of reservoir optimization for energy production with a new evolutionary algorithm based on the MCDA model [67]. All examined evolutionary algorithms were evaluated by Complex Proportional Assessment (COPRAS), TOPSIS, modified TOPSIS, Weighted Aggregated Sum



Table 2  
Most popular research papers included in the review in the energy development field

Energy development			
Citations	Methods	Problem	Reference
175	AHP, WLC	Offshore wind energy potential	[60]
119	TOPSIS	Hybrid RES locations	[45]
92	IT2 fuzzy DEMATEL, TOPSIS, VIKOR	RES investment strategies	[56]
86	AHP	Solar energy plants location	[62]
86	Fuzzy AHP, TOPSIS	RES plants location	[58]

Product Assessment (WASPAS), and BORDA. The presented research works indicated that a variety of problems connected to energy management and development are currently addressed in the literature. Moreover, Table 2 presents the most popular works from this field, showing the number of citations, used methods, solved problems, and the reference to the paper.

### 2.3. MCDA applications in supplier selection

Multi-Criteria Decision Analysis serves as a valuable and robust methodology in the supplier selection area. The process of choosing suppliers involves considering a multitude of criteria, ranging from cost and quality to reliability and environmental sustainability. MCDA allows for simultaneously evaluating and comparing suppliers based on these diverse criteria. This comprehensive approach ensures that decision-makers can make well-informed choices that align with the organization’s strategic goals. In supplier selection, where decisions have far-reaching implications on a business’s efficiency and competitiveness, MCDA helps prioritize criteria based on their relative importance, thereby facilitating a more rational and objective decision-making process.

The flexibility of MCDA methods is particularly advantageous in supplier selection, where market conditions, supplier capabilities, and organizational priorities can change over time. The adaptability of MCDA allows decision-makers to adjust decision models to reflect the evolving dynamics of the business environment. It is crucial for maintaining the relevance and effectiveness of supplier selection processes in the face of changing market conditions and organizational requirements. By providing a structured and dynamic approach, MCDA empowers organizations to navigate the complexities of supplier selection, optimize decision outcomes, and enhance overall supply chain performance.

Since supplier selection problems could be considered in many industries, research works directed to this field addressed varied approaches for selecting the most rational decision variant among the considered alternatives. Xue et al. used a multi-stage MCDA approach for evaluating the supplier performance of high-speed trains [68]. The authors included six criteria in the problem, namely physical quality, delivery performance, which belongs to quantitative criteria, and service, price, quality management system, and environmental safety, which belong to qualitative criteria. Mishra et al. addressed the problem of medical equipment supplier selection with dual probabilistic linguistic Full Consistency ARAS model [69]. Chakraborty et al. combined D numbers with Measurement Alternatives and Ranking According to Compromise Solution (MARCOS) method to select the best-performing supplier in a leading Indian iron and steel-making industry based on seven selective evaluation criteria and opinions of three decision-makers [70]. Liu, Deng, and Chan used the ANP and entropy method to determine criteria weights, and then the DEMATEL method combined with Game Theory was applied for evidential supplier selection [71]. Kaya and Yet determined Bayesian networks based on the DEMATEL method for solving the problem of supplier selection, and knowledge elicited from multiple experts was used to build the decision model [72]. Chen proposed a hybrid MCDA model approach based on ANP-Entropy TOPSIS for building materials supplier selection [73]. Zakeri et al. directed their research toward supplier selection and proposed a new weighting method called the Win, Loss, Draw (WLD) method [74]. As the practical problem, a real case

study of domestic cheese brands was considered, and the proposed methodology was used to select the best cheese supplier for an Iranian hypermarket.

Many works included handling uncertainties in the defined problems by introducing fuzzy logic and combining it with multi-criteria calculations. Güneri and Deveci covered the problem of assessment of supplier selection in the defense industry using q-rung orthopair fuzzy set based EDAS approach [75]. Đalić et al. proposed a novel integrated Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (PIPRECIA) and Interval Rough Simple Additive Weighting (SAW) methods to assess green supplier [76]. The authors considered seven criteria and four alternatives in the problem space. Wu, Lin, and Barnes focused on sustainable supplier selection in the chemical industry with an integrated decision-making approach using Fuzzy Grey Relational Analysis (FGRA), Failure Mode and Effects Analysis (FMEA), and cloud computing-entropy weight method (EWM) to analyze the economic, social, and environmental dimensions [77]. Moreover, the authors evaluated considered alternatives using the Decision-making Trial and Evaluation Laboratory. Hendiani et al. applied Interval Type-2 Fuzzy preference relations to propose a novel MCDA model for sustainable supplier selection problems in which the weights of criteria and performance ratings are expressed as Interval Type-2 Trapezoidal Fuzzy Sets [78]. Gupta, Soni, and Kumar focused on the problem of supplier selection in the automotive industry with an MCDA approach under a fuzzy environment and used Fuzzy AHP for criteria weight calculation and three popular multi-criteria techniques, namely TOPSIS, MABAC, and WASPAS [79].

Furthermore, Memari et al. used the Intuitionistic Fuzzy TOPSIS method to evaluate the automotive spare parts manufacturer problem that concerns nine criteria and thirty sub-criteria [80]. Liu et al. directed their research toward an extended multi-criteria group decision-making method applied in emergency medical supplier selection [81]. The authors used an extended IT-2FSs assessment method and a novel ISM-BWM-Cosine Similarity-Max Deviation Method (IBCSMDM) to determine criteria weights and the TODIM method to evaluate the decision variants. Hendiani, Mahmoudi, and Liao adopted the Fuzzy Best-Worst method to obtain corresponding weights, while the supplier selection problem was directed at finding the most sustainable supplier for procuring Tubes for Shell & Tube Heat Exchanger equipment in the south of Iran [82]. Wei and Zhou proposed an MCDA framework for electric vehicle supplier selection of government agencies and public bodies in China, where BWM and fuzzy VIKOR method were applied [83]. Yildizbasi and Arioz integrated big data analytics and a hybrid fuzzy MCDA with fuzzy AHP-TOPSIS methods to evaluate green supplier selection considering selected aspects of sustainable development [84]. Ecer used the Interval Type-2 Fuzzy AHP method to examine home appliance manufacturers and applied sensitivity analysis to verify the consistency and stability of the proposed model [85].

Some approaches considered employing multiple MCDA methods to solve supplier selection problems, examining the robustness of the obtained results. Stojić et al. propose a novel rough WASPAS approach for supplier selection in a company manufacturing PVC carpentry products [86]. For this purpose, the AHP, Simple Additive Weighting (SAW), rough EDAS, rough MultiAttributive Border Approximation area Comparison (MABAC), rough VIKOR, rough Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA), and rough Multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA), while the obtained results were compared with Spearman correlation coefficient. Badi and Pamucar addressed the problem of supplier selection for steelmaking companies by using combined Grey-MARCOS methods and compared the obtained results with CODAS, TOPSIS, and VIKOR methods [87]. Petrović et al. used three Fuzzy MCDA methods to evaluate suppliers of procurement of THK Linear motion guide components in the “Lagerton” company in Serbia, namely Fuzzy TOPSIS, WASPAS, and ARAS [88]. Moreover, criteria weights were determined by the Fuzzy SWARA method. Stević et al. developed a novel MCDA model with the FUCOM method and the Interval Rough SAW method to solve the supplier selection problem regarding the sustainable assumptions [89]. Moreover, the authors performed a sensitivity analysis with changing criteria weights and modeling the dynamic

Table 3  
Most popular research papers included in the review in the supplier selection field

Supplier selection			
Citations	Methods	Problem	Reference
478	Intuitionistic Fuzzy TOPSIS	Automotive spare parts	[80]
222	ANP, ENTROPY, DEMATEL	Cam operated rotary switches	[71]
197	Fuzzy AHP, TOPSIS, MABAC, WASPAS	Indian automotive industry	[79]
186	Deng entropy, DS-VIKOR	Manufacturing enterprise	[92]
157	IT2 Fuzzy AHP	Home appliance manufacturer	[85]

decision matrices. Leong, Wong, and Wong directed their research toward determining the robustness of the supplier selection evaluation with GRA-BWM-TOPSIS methods under seven criteria, namely quality, lead time, cost, flexibility, visibility, responsiveness, and financial stability, and five domain experts were engaged in the evaluation process [90]. Phochanikorn and Tan developed a new extension to determine the MCDA model for sustainable supplier selection under an Intuitionistic Fuzzy Environment [91]. The authors used ANP, DEMATEL, and VIKOR methods to assess the area of the palm oil industry. Fei, Deng, and Hu covered the problem of supplier selection problem by proposing a combination of Dempster-Shafer evidence theory with the VIKOR method [92]. Within the evaluation, domain experts were engaged to determine the relevance of the given criteria: product quality, difficulty in establishing cooperation, service performance, risk factor, and price/cost. The presented research approaches showed that many uncertainties could occur in evaluating suppliers, and the fuzzy sets could be effectively used to model the decision process more reliably. Moreover, applying multiple MCDA techniques allowed for verifying results robustness. The most popular research works directed toward supplier selection field included in the review were presented in Table 3.

#### 2.4. MCDA applications in transport

The Multi-Criteria Decision Analysis methods have extensive application in the transport field due to the apparent complexity and many factors involved in decision-making processes. Transportation systems are multifaceted, involving cost, environmental impact, safety, and efficiency. MCDA provides a structured and systematic approach to evaluating and prioritizing transportation alternatives based on diverse criteria. In the transport field, where decisions influence urban planning, environmental sustainability, and public prosperity, MCDA enables decision-makers to assess the trade-offs and make informed choices comprehensively.

The dynamic nature of the transport industry, with evolving technologies, changing societal needs, and environmental concerns, necessitates a flexible decision-making framework. MCDA allows for incorporating evolving criteria and changing priorities, ensuring that decision models remain relevant over time. Whether selecting the optimal public transportation system, evaluating infrastructure projects, or making policy decisions, Multi-Criteria Decision Analysis methods assist in considering the multifaceted impacts of each alternative. By accounting for diverse criteria simultaneously, MCDA facilitates a holistic understanding of the consequences of transport decisions, contributing to the development of sustainable and effective transportation systems.

In the performed review, the authors utilized various MCDA techniques to evaluate multi-criteria problems within the transport area. Kalifa et al. applied MCDA analysis to prioritize the public transport system in Sub-Saharan Africa [93]. For this purpose, the ANP and ELECTRE III methods were used, combined with the sensitivity analysis of modifying criteria weights. The results from the research showed that the obtained rankings are robust to modeled scenarios. Kiraci and Bakir applied the TOPSIS method to indicate the most suitable decision variant among the four aircraft types, which are the most demanded by airline companies [94]. The selection was made regarding different flight networks and different flight

destinations. Ammenberg and Dahlgren compared different bus technologies as part of the sustainable assessment of public transport with 12 criteria grouped into four main areas of evaluation [95]. Aspen and Sparrevik combined Stochastic Multicriteria Acceptability Analysis (SMAA) with the TOPSIS method to evaluate usage of biofuels, natural gas, and electricity on Norwegian ferry crossings [96]. The obtained results showed that all-electric propulsion is preferable, and plug-in hybrid solutions with natural gas also gave a robust performance. Manzolli, Trovão, and Antunes directed their research toward evaluating rapid transit systems implementation in an urban context with PROMETHEE method [97]. The authors modeled four assessment scenarios, namely baseline, environmental, economic, and economic-environmental. Ali et al. directed their research toward direct reductions in carbon emission levels in the Lahore Metropolitan Area (LMA) of Pakistan with the MCDA approach combined with the Bilan Carbone model [98]. Three assessment scenarios were included, namely the current situation and two variants of the future (usual and low carbon scenarios). Hasan, Chapman, and Frame focused on indicating the acceptability of transport emissions reduction policies in New Zealand by 2030 [99]. The analysis was performed with the Simple Additive Weighting method, and the obtained results were then verified with a sensitivity analysis approach concerning generated weights scenarios.

Furthermore, many developed multi-criteria decision models were determined based on applying the AHP method. Singh, Singh, and Sandhu addressed the modern problem of green scooter selection with the MCDA approach, for which the authors combined the AHP and TOPSIS methods [100]. Güner combined the AHP and TOPSIS methods to measure the service quality and rank the bus transit routes, showing the opportunity to monitor and improve the quality of bus transit service [101]. Liaqat et al. directed their research toward evaluating portable energy storage technologies for electric vehicles with the AHP method [102]. Lee focused on prioritizing advanced public transport modes considering urban types in Korea, for which the AHP method was used [103]. Jahanshahi et al. covered the problem of evaluation and relocating bicycle sharing stations in Mashhad city [104]. For this purpose, the authors identified seven decision criteria, which were evaluated by the AHP method, and the obtained weights were used to rank alternatives with the VIKOR method. Petrović and Kankaraš determined the decision model based on the DEMATEL-AHP methods whose purpose was to evaluate criteria for selecting an aircraft for the protection of air traffic [105]. The study included gathering assessments from 45 respondents. Hamurcu and Eren assessed electric buses regarding green transportation conditions with the AHP-TOPSIS method [106]. Six potential electric buses were evaluated under seven criteria, and the criteria weights were modeled with sensitivity analysis to examine the results stability. Nalmapantis et al. faced the challenge of evaluating innovative ideas for public transport proposed by citizens [107]. The AHP method was used to evaluate the importance of criteria weights, with 97 completed questionnaires.

On the other hand, while uncertainties were found in the defined problem, researchers applied various extensions of fuzzy logic to handle the decision-making calculations. Deveci et al. developed a Fuzzy Einstein-based Decision Support System for public transportation management during the COVID-19 pandemic [108]. The dimension of the considered problem was defined as four public transportation management alternatives and 13 criteria, grouped into four main aspects. The logarithmic additive function was used to determine criteria weights, and the Combined Compromise Solution (CoCoSo) method combined with the Einstein T-norm and T-conorm was used to evaluate alternatives. Stević, Subotić, and Softić used Improved Fuzzy Step-Wise Weight Assessment Ratio Analysis to determine criteria weights and EDAS method to evaluate the alternatives within the problem of safety road sections [109]. Sałabun, Palczewski, and Wątróbski focused on assessing the transport evaluation with MCDA approach under incomplete knowledge [110]. The authors evaluated electric bikes with the Characteristic Objects Method (COMET), which uses Triangular Fuzzy Numbers (TFN) within the calculations. Tian et al. proposed a Decision Support System (DSS) for electric vehicle selection [111]. The DSS was developed based on indicating criteria weights by transforming the sentiment analysis results of online auto reviews into

Table 4  
Most popular research papers included in the review in the transport field

Transport			
Citations	Methods	Problem	Reference
98	AHP, Fuzzy AHP, TOPSIS, PROMETHEE	Transport infrastructure projects	[117]
82	AHP	Public transport innovative ideas	[107]
73	AHP, TOPSIS	Quality of public transport systems	[101]
69	AHP, TOPSIS	Electric bus selection	[106]
63	AHP, Fuzzy AHP, TOPSIS, Fuzzy TOPSIS, PROMETHEE	Safe route planner	[116]

Hesitant Intuitionistic Fuzzy Elements, while the evaluation was done by the Organisation, rangement et Synthèse de données relationnelles (ORESTE) method with Hesitant Intuitionistic Fuzzy Chebyshev distance. Ziemba proposed an approach that combines different types of uncertainty in decision-making by developing a New Easy Approach To Fuzzy PROMETHEE (NEAT-PROMETHEE) method, combined with the Monte Carlo method and elements of the Stochastic Multicriteria Acceptability Analysis method to assess electric vehicles [112]. Alkharabsheh et al. integrated the MCDA approach with Grey Theory to evaluate urban public transportation systems with the Grey-AHP method in the real-world problem using the public transport system’s supply quality in Amman, Jordan [113]. Feng et al. proposed a novel MCDA method for selecting the site of electric vehicle charging stations under sustainable perspectives. [114]. The model was built based on the Linguistic Entropy Weight (LEW) method and Fuzzy Axiomatic Design (FAD). Ali et al. developed a new hybrid MCDA method for car selection based on the Full Consistency Fuzzy TOPSIS (FCF-TOPSIS) approach, with the obtained results indicating a more accurate outcome than in the case of the AHP-TOPSIS application [115].

Moreover, selected evaluation approaches considered using multiple MCDA methods within the same problem to compare the obtained results and indicate their robustness. Sarraf and McGuire focused on the problem of safe route planner [116]. For this purpose, the AHP, Fuzzy AHP, TOPSIS, Fuzzy TOPSIS, and PROMETHEE methods were applied. Broniewicz and Ogrodnik applied the AHP, Fuzzy AHP, TOPSIS, and PROMETHEE methods to solve the problem of evaluating transport infrastructure projects [117]. These four techniques were used to select the variant of the expressway section in north-eastern Poland. Erdogan et al. focused on applying the MCDA approach to optimal planning of workplace charging stations by adapting the WASPAS model with Dombi Bonferroni functions for flexibility [118]. Moreover, the obtained results were compared with MABAC, MAIRCA, and CoCoSo methods to verify the robustness of the rankings. The presented applications and trends showed that despite visible shortcomings, the AHP method is highly popular in developing decision models dedicated to transport areas. Moreover, the concept of fuzzy logic and its varied extensions is popular in modeling the occurring uncertainties. Based on the presented approaches directed to solve the problems in transportation, Table 4 presents the most popular research works.

*2.5. MCDA applications in sustainable development*

MCDA is also effective in sustainable development because it can handle complex decision problems involving multiple, often conflicting, objectives. Sustainable development requires balancing economic, social, and environmental considerations, making it multi-dimensional. In sustainable development, where decisions have long-term repercussions on ecological systems, social equity, and economic prosperity, MCDA enables a comprehensive assessment of alternatives. It assists in integrating diverse stakeholder perspectives, aligning with the participatory nature of sustainable development. By concurrently considering environmental impact, social integration, economic viability, and other relevant criteria, MCDA ensures a more precise understanding of the consequences of various decisions. Additionally, the flexibility of

multi-criteria techniques allows for adapting to evolving sustainability goals and shifting societal priorities, making it well-suited for the dynamic and evolving nature of the field.

Moreover, the transparency offered by MCDA aids in building consensus among stakeholders by providing a clear rationale for decision outcomes. It is crucial in sustainable development, where decisions often involve complex trade-offs, and stakeholder engagement is vital for successful implementation. MCDA significantly advances sustainable development goals by facilitating informed, inclusive, and balanced decision-making processes.

Since sustainable development covers various areas of operation, researchers addressed their research works in various directions and proposed many approaches to improve making decisions under different circumstances. Aksoy and San combined GIS and MCDA approaches to select sustainable landfill sites considering dynamic data source [119]. The AHP method was used to identify criteria importance. Gharizadeh et al. integrated the MCDA approach to assessing insurance companies regarding sustainability performance [120]. The AHP method was combined with Principal Component Analysis (PCA) and Data Envelopment Analysis to provide a combined subjective and objective evaluation approach. Erdogan, Šaparauskas, and Turskis determined the MCDA model to indicate the most rational solution for sustainable construction management [121]. Seven criteria (technical experience, record of performance, financial stability, the qualifications of the employees and the management, capacity, safety record, and equipment and operation) were evaluated with the AHP method. Das and Mukhopadhyay used the MCDA approach to assess the groundwater potential zones focusing on Birbhum district (West Bengal) in India [122]. By combining the AHP and GIS techniques, the authors indicated that 212.27 km<sup>2</sup> has a very high potential. Omran et al. focused on the sustainability assessment of wastewater treatment techniques in urban areas of Iraq, employing 52 specialists to gather expert knowledge [123]. The Weighted Sum Model (WSM) was used to validate the results, while 31 factors grouped into four areas (environmental, social, economical, and technical) were considered. Manupati, Ramkumar, and Samanta faced the challenge of evaluating the urban renewal process in Southern India [124]. The determined framework consisted of seven criteria, and the decision variants were assessed by the Decision Making Trial and Evaluation Laboratory based Analytic Network Process (DANP) method.

Furthermore, Almeida focused on developing a tool to build indicators and localize Sustainable Development Goal (SDG) 11 in Brazilian municipalities [125]. To this end, the Multi-Actor MultiCriteria Analysis (MAMCA) approach was used with the AHP method to determine criteria relevance. Pagone, Salonitis, and Jolly proposed an approach for automatically weighted high-resolution mapping for sustainable manufacturing systems [126]. For this purpose, the entropy weighting method was used to determine criteria relevance objectively, and the TOPSIS method was used to evaluate decision variants. The authors indicated that the proposed methodology can be applied to sustainable manufacturing in general. Roszkowska and Filipowicz-Chomko measured sustainable development in the education area with the extended TOPSIS method [127]. The authors considered eight indicators from SDG4 to evaluate the 28 European countries. Ma et al. used the Life Cycle Assessment (LCA) to select sustainable material in the automotive industry [128]. The authors used the entropy weighting method combined with the TOPSIS technique to evaluate 16 alternatives. Talukder, Hipel, and vanLoon directed their research toward assessing the sustainability of agricultural systems regarding selected indicators (productivity, stability, efficiency, durability, compatibility, and equity) [129]. Chen and Zhang assessed the sustainability of cities in Liaoning province in China and considered 21 decision factors grouped into three areas, namely economic, social, and environmental [130]. The obtained results were then verified with selected criteria weighting approaches, namely entropy weights, equal weights, and Coefficient-Variation Method (CVM). Invidiata, Lavagna, and Ghisi addressed the problem of selecting design strategies to improve the sustainability of buildings in Milan [131]. The authors indicated that there will be an average increase of 53% in the cooling energy demand, while the heating energy demand in 2080 will decrease by 49%, compared to the consumption in 2017.

To handle incomplete knowledge in the challenged problems regarding sustainable development, many fuzzy extensions were applied to handle the decision process. Boral et al. proposed a novel hybrid group MCDA methodology for failure mode and effect analysis for sustainable manufacturing [132]. For this purpose, the Interval Type-2 Fuzzy DEMATEL and Modified Fuzzy MAIRCA methods were used to evaluate the process plant gearbox. Ezbakhe and Pérez-Foguet handled the problem of renewable energy planning under uncertain conditions [133]. For this purpose, the authors used a modified ELECTRE III model and represented the uncertainty in the performance scores as lower/upper bounds added to the model's discrimination thresholds. The evaluation of renewable energy resources for Turkey (hydro, wind, geothermal, solar, and biomass) was performed under five main criteria (technological, technical, economic, environmental, and socio-politic). Nguyen, Lin, and Dang applied the Fuzzy MCDA approach for evaluating online food delivery in Vietnam [134]. For this purpose, the Fuzzy AHP method was integrated with the WASPAS technique to assess considered food companies. Raj, Kumar, and Verma used big data analytics to facilitate the challenges of a sustainable manufacturing supply chain with the AHP method combined with Grey Relational Analysis [135]. Eleven criteria grouped into five fields (financial, quality, operation, technical, and logistics) were considered in the decision process. Wang and Peng proposed a Fuzzy MCDA framework for assessing urban sustainable development using the Fuzzy Delphi method and adopting the Extent Analysis Method on Fuzzy AHP (EFAHP) method to aggregate experts comments on empirical evaluation [136]. Yıldızbaşı et al. evaluated the sustainable supply chain indicator with the Fuzzy MCDA approach [137]. The Fuzzy AHP and Fuzzy TOPSIS methods were used to obtain results, which indicated the situation regarding the social sustainability of the automotive industry companies in Turkey.

On the other hand, selected approaches were directed toward assessing the robustness of the obtained rankings by comparing the performance of different MCDA methods. Ture, Dogan, and Kocak evaluated the EURO 2020 strategy with the VIKOR and TOPSIS methods [138]. Taking into account 22 indicators and assessing 27 European Union (EU) countries, the authors indicated that new EU member countries such as Slovenia and Romania have attained higher scores than many of the 15 EU countries. Mijajlović et al. addressed the problem of determining the competitiveness of Spa centers to achieve assumed sustainable goals [139]. Due to uncertainty in the problem, FUCOM was used to determine criteria weights, and the Fuzzy MARCOS method was used to assess decision variants. The results were verified with the Fuzzy SAW, WASPAS, MABAC, ARAS, and TOPSIS methods, while the sensitivity analysis of criteria weights scenarios was used to verify the impact of different criteria relevance. Bączkiewicz and Kizielewicz addressed the problem of sustainable energy consumption in Europe for the industrial sector [140]. Based on the European Statistical Office (EUROSTAT) data, the TOPSIS, VIKOR, COMET, and PROMETHEE II methods were used to evaluate European countries. Moghtadernejad, Chouinard, and Mirza provided a methodology for the preliminary design of sustainable facades, which has a crucial impact on building energy performance [141]. The authors used three selected MCDA methods, namely AHP, Choquet integrals, and TOPSIS while considering eight decision criteria: aesthetics, weight, fire resistance, acoustics, environmental impacts, ease of construction, durability, and initial costs. Suganthi focused on evaluating sectoral investments for sustainable development with integrated Fuzzy AHP, VIKOR/DEA methodology [142]. Yang et al. addressed the problem of sustainable sports tourism with a proposition of framework determined based on a hybrid MCDA model [143]. The aim was to explore potential sports tourism attractions in Taiwan. For this purpose, the Bayesian Best Worst Method (Bayesian BWM) was used to integrate multiple experts' judgments to generate the group optimal criteria weights, and the VIKOR method was used to assess decision variants. The sensitivity analysis of criteria weights was performed, and the results were verified with the SAW, TOPSIS, PROMETHEE, and WASPAS methods. From the provided description, it could be seen that the authors addressed various problems, important to increase the quality of decision-making in sustainable development areas. Problems of fulfilling Sustainable

Table 5  
Most popular research papers included in the review in the sustainable development field

Sustainable development			
Citations	Methods	Problem	Reference
152	AHP, VIKOR, DEA	Sectoral investments evaluation	[142]
125	AHP, COPRAS	Buildings life cycle analysis	[131]
96	AHP	Construction management	[121]
85	AHP	Landfill site selection	[119]
85	AHP, Choquet integrals, TOPSIS	Facades preliminary design	[141]

Development Goals is a common challenge. Moreover, new approaches to handling uncertainties allowed to evaluate decision variants more effectively. Based on the presented research works, the highlight of the five most popular papers included in the review from the field on sustainable development were presented in Table 5.

### 2.6. MCDA applications in other fields

Multi-criteria methods find applications across diverse fields beyond healthcare, energy management, transport, supplier selection, and sustainable development. In areas such as finance, MCDA can aid in investment decisions by simultaneously considering multiple factors like risk, return, and market conditions. In marketing, it can assist in product launch decisions by evaluating various criteria like market demand, competition, and cost-effectiveness. The versatility of MCDA extends to human resources, helping in recruitment processes by weighing qualifications, experience, and cultural fit. Urban planning can be utilized to assess different development proposals, considering factors like environmental impact, public opinion, and infrastructure needs. In each of the mentioned fields, MCDA's strength lies in its ability to handle complexity, accommodate diverse criteria, and provide a structured framework for decision-making, promoting more informed and well-explained choices.

Since the MCDA approach could be adjusted to any practical application and field in which multiple opposite criteria are considered, researchers aim to develop new methodologies for solving the given problem with multi-criteria techniques. Askarifar, Motaffef, and Aazaami proposed an investment development framework in Iran's seashores using TOPSIS and Best-Worst Method [144]. Rezaei et al. covered the problem of the product-package design in a food supply chain [145]. The authors used the BWM method to evaluate three selected products of the Kraft Heinz Company and examined the results' stability by applying sensitivity analysis of weights scenarios. Bampa et al. covered the problem of harvesting European knowledge on soil functions and land management with the Decision EXpert (DEX) methodology to evaluate knowledge and needs [146]. Rani et al. proposed a multi-criteria food waste treatment method selection using a Single-Valued Neutrosophic (SVN) CRITIC Multi-Objective Optimization based on Ratio Analysis with the full multiplicative form (MULTIMOORA) framework [147]. The CRITIC method was used to determine criteria weights, while the MULTIMOORA allowed for alternatives' evaluation. Grover, Chopra, and Krejci directed their research towards the public distribution system of food grains in Indian Punjab to indicate the approaches for decentralized food policies in developing countries [148]. The MAVT method was used to assess analyzed decision variants. Vavrek analyzed the effectiveness of MCDA methods in athlete evaluation, directing the assessment to National Hockey League (NHL) attackers [149]. The TOPSIS method was used, and the results were verified by comparing different criteria weighting methods. Iacovidou and Voulvoulis proposed a framework for development and application in comparing two food waste management options using a UK region [150]. The DEFINITE decision support software was employed to assess considered decision variants, allowing the evaluation of the performance of criteria/sub-criteria using a range of analytical methods. Moreover, the authors conducted uncertainty and sensitivity analyses related to the criteria/sub-criteria weighting variations. Kondratenko, Kondratenko,



and Sidenko applied the MCDA approach to select a rational Internet of Things (IoT) platform based on the Linear Convolution Method (LCM), which allows to bring the multi-criteria problem to one-criterion [151].

In the reviewed papers, it could be seen that the Analytical Hierarchy Process method is still highly popular, despite the development of newer techniques aiming to improve the process of determining criteria weights. Everest combined the GIS and MCDA approaches to select a suitable site for pistachio (*Pistacia vera*) in Turkey [152]. The AHP method was used to determine criteria relevance. Haroun et al. challenged the problem of evaluating the adaptive reuse of heritage buildings using the case of Aziza Fahmy Palace (Alexandria) in Egypt [153]. The authors used the AHP method to determine the decision model. Maleki et al. focused on the social sustainability assessment of high-rise residential buildings [154]. The authors developed an MCDA tool to assess sustainability using the Integrated Value Model for Sustainability Assessment (MIVES) built on the AHP method. Mantogiannis and Katsigiannis used the Analytical Hierarchy Process model to evaluate four real estate investment alternatives from the UK private rented market. The authors validated the volatility of the financial performance indicators through Monte Carlo simulation runs [155]. März evaluated the fuel poverty vulnerability of urban neighborhoods for the German city of Oberhausen [156]. For this purpose, the GIS-MCDA approach was used with the AHP methods applied to identify criteria weights. Pham et al. integrated deep learning and the MCDA approach to perform a flood risk assessment [157]. The authors used one of the popular Deep Neural Networks (DNN) algorithms to generate flood susceptibility maps while the Analytic Hierarchy Process was used to generate the hazard, exposure, and vulnerability maps.

The authors handled selected practical applications to MCDA problems by introducing extensions of fuzzy logic to the considered problem space to model the uncertainties effectively. Deveci et al. focused on prioritizing zero-emission zone logistics [158]. For this purpose, the authors applied the Defining Interrelationships Between Ranked criteria (DIBR) method to gather the experts' opinions and compute the weights, while a novel approach that integrates Combined Compromise Solution (CoCoSo) with the context of type-2 neutrosophic numbers was used to evaluate alternatives. Sahin et al. applied the Fuzzy TOPSIS method with vertex distance to select the dry bulk carrier [159]. Gireesha et al. developed an improved Interval-Valued Intuitionistic Fuzzy Sets Weighted Aggregate Sum and Product Assessment (IIVIFS-WASPAS) to select cloud service providers for the identification of trustworthy solutions [160]. The sensitivity analysis of the impact of the change in coefficient characteristic for the proposed methodology was verified, and the feasibility of the Rank Reversal phenomenon was also evaluated. Kizielewicz and Dobryakova applied the COMET method to model the uncertain knowledge in the problem of basketball players' assessment [161]. Sharma, Gupta, and Acharya focused on prioritizing the critical factors of cloud computing adoption, engaging experts from 13 organizations in the assessment process [162]. The AHP and Fuzzy AHP methods were applied for this purpose. Simon et al. proposed a methodology for the mass customization model in the food industry using industry 4.0 standard [163]. The authors used the Fuzzy AHP method to determine criteria weights. Urbaniak, Wątróbski, and Sařabun focused on evaluating the performance of e-sports players in the Counter-Strike: Global Offensive (CS:GO) with the COMET method [164]. Vazifehdan and Darestani addressed the problem of green logistics outsourcing by employing MCDA and Quality Function Deployment (QFD) in the petrochemical industry [165]. The authors used Fuzzy ANP, Fuzzy DEMATEL, and Superiority and Inferiority Ranking (SIR) methods.

Researchers also addressed the problem of examining the robustness of the MCDA methods since different techniques could produce unequivocal results. Pamucar et al. developed a new Logarithm Methodology of Additive Weights (LMAW) method to solve multi-criteria problems and verified it in the logistics area to evaluate service providers in India [166]. The results were verified with selected MCDA techniques, namely TOPSIS, VIKOR, Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval (RAFSI), COPRAS, and MABAC. Rutten-van Mólken et al. directed their research toward strengthening the evidence base of integrated care for people with multi-morbidity

Table 6  
Most popular research papers included in the review in the rest of the problems

Rest of the problems			
Citations	Methods	Problem	Reference
174	IRN, BWM, WASPAS, MABAC	Third-party logistics provider assessment	[170]
154	MACBETH, TOPSIS, ANP, AHP, MAUT, PROMETHEE, ELECTRE	Real estate and land management	[168]
126	LMAW, RAFSI, COPRAS, TOPSIS, VIKOR, MABAC	Logistic service provider	[166]
116	AHP, TOPSIS, SAW, PROMETHEE	Employee placement	[173]
88	AHP, Fuzzy AHP	Cloud computing	[162]

in Europe [167]. The authors applied the Discrete Choice Experiment (DCE), Swing Weighting, and Simple Multi-Attribute Rating Techniques Exploiting Ranks (SMARTER) to evaluate criteria relevance and performed a sensitivity analysis by comparing selected methods and excluding certain criteria in the problem. Moreover, the proposed approach modeled the parameter uncertainty in the performance scores and the criteria weights simultaneously in a probabilistic sensitivity analysis using Monte Carlo simulation. Guarini, Battisti, and Chiovitti determined a methodology for site selection in real estate and land management processes [168]. For this purpose, the performance of selected MCDA methods was compared, namely Measuring Attractiveness by a Categorical Based Evaluation (MACBETH), TOPSIS, ANP, AHP, Multi-Attribute Utility Theory (MAUT), PROMETHEE, and ELECTRE. Vakilipour et al. evaluated the quality of life at different spatial levels [169]. The authors compared the performance of selected MCDA methods, namely TOPSIS, VIKOR, SAW, and ELECTRE, and assessed alternatives within three spatial levels: socioeconomic, environmental, and accessibility. Pamucar, Chatterjee, and Zavadskas assessed third-party logistics providers [170]. The authors proposed a novel BWM-WASPAS-MABAC model based on interval rough numbers. The sensitivity analysis of different weighting scenarios was applied to verify the results' stability. Puška, Beganović, and Šadić developed an investment model based on the MCDA approach by applying the SAW, TOPSIS, and VIKOR methods [171]. Tsakalerou, Efthymiadis, and Abilez proposed an intelligent methodology for offshore construction evaluation [172]. To assess decision variants, the Stable Preference Ordering Towards Ideal Solution (SPOTIS) method was applied. Moreover, the authors used the COMET method to handle uncertainties in the problem. Widianta et al. applied AHP, TOPSIS, SAW, and PROMETHEE methods to evaluate employee placement [173]. The results showed that each method's ranking and accuracy levels differed depending on the different scaling and weighting processes in the examined methods. Based on the presented works included in the review, it could be seen that varied practical problems were addressed in the literature recently. Besides five mainly distinguished fields (healthcare, energy management, transport, supplier selection, and sustainable development), the authors covered the areas of sport management, logistics, and cloud computing, among others. Table 6 presents the most popular research works dedicated to fields other than five main fields identified in the review.

### 3. Discussion

The provided review gives a comprehensive overview of the recent trends and applications of Multi-Criteria Decision Analysis methods in diverse fields such as healthcare, energy management, transport, supplier selection, sustainable development, and other fields. By synthesizing and presenting a wide range of research studies, the review gives an insightful overview of the current trends, methodologies, and challenges in the application of MCDA. This facilitates a deeper understanding of the specific problems addressed within each domain and allows for identifying commonalities and differences in the approaches employed in recent works.

The review makes a significant contribution to the field of MCDA, highlighting the versatility and adaptability of different MCDA methods in different contexts. The analysis of healthcare applications highlights the crucial role of MCDA in dealing with complex issues such as resource allocation during health crises such as the COVID-19 pandemic. The study of fuzzy logic integration in healthcare decision-making demonstrates the effectiveness of multi-criteria methods in dealing with the uncertainty inherent in real-world problems. In the field of energy management, the review demonstrates the utility of MCDA in evaluating renewable energy sources, optimizing energy systems, and making informed decisions about energy technologies. The emphasis on sustainability criteria and considering uncertainty through fuzzy logic align with the growing importance of sustainable practices and the need for robust decision-making tools in the energy sector. The descriptions of supplier selection presented the challenges and complexities involved in selecting the most appropriate suppliers. The inclusion of fuzzy logic in many studies reflects a recognition of the inherent imprecision and subjectivity of supplier selection criteria. Exploring multiple MCDA methods in supplier selection broadens the methodological background and addresses the need for robustness and sensitivity analysis in decision-making processes.

Furthermore, the review of the transport sector sheds light on the role of MCDA in optimizing public transport systems, evaluating different transport technologies, and assessing the environmental impact of transport-related decisions. This highlights the usefulness of MCDA in addressing complex urban transport challenges. The application of MCDA techniques such as the Analytic Network Process, ELECTRE III, TOPSIS, and others have played an important role in prioritizing public transport systems, selecting aircraft types, evaluating bus technologies, and assessing energy sources for ferry crossings. These applications highlight the versatility of MCDA in solving complex transport decision-making problems. Furthermore, the widespread use of the Analytic Hierarchical Process in evaluating the selection of eco-scooters, measuring the quality of service on bus transit routes, and evaluating portable energy storage technologies for electric vehicles highlights the popularity of the method in decision-making processes related to sustainable transport.

Researchers have incorporated extensions of fuzzy logic into the MCDA framework in dealing with uncertainty. The proposed approaches and introduced novel methodologies demonstrated the effectiveness of fuzzy logic in handling imprecise and incomplete information. In addition, some studies have employed multiple MCDA methods within the same problem, aiming to compare results and ensure the robustness of decision models. For instance, the integration of AHP, Fuzzy AHP, TOPSIS, Fuzzy TOPSIS, and PROMETHEE in the evaluation of safe route planners and transport infrastructure projects illustrates the efforts to enhance the reliability of decision outcomes.

In sustainable development, MCDA has been applied to address diverse challenges, including site selection for sustainable landfill sites, assessing insurance companies' sustainability performance, and evaluating urban renewal processes. The integration of MCDA with other methodologies, such as Principal Component Analysis, Data Envelopment Analysis, and Life Cycle Assessment, demonstrated its adaptability to different sustainability assessment contexts. Researchers have also explored the use of MCDA in sectors beyond the five main fields identified in the review. This includes applications in sports management, logistics, cloud computing, real estate, and land management. The comparison of various MCDA methods in these diverse fields highlights the need for dedicated approaches based on the specific characteristics of each decision problem.

The review emphasizes the ongoing efforts to develop and improve MCDA methodologies, with researchers proposing new frameworks and extensions to address the complexities and uncertainties in decision-making processes. Overall, the extensive range of applications and the integration of diverse methods highlight the versatility and evolving nature of MCDA in contributing to decision science across different domains. The review serves as a benchmark for researchers and practitioners, offering a comprehensive understanding of the state-of-the-art in MCDA applications. It provides insights that can guide

future research directions, encourages the development of hybrid models, and promotes using MCDA as a decision-support tool in increasingly complex and uncertain real-world scenarios.

Based on the performed review and the analysis of the included research paper, the main findings about the recent trends and applications of Multi-Criteria Decision Analysis in practical problems are listed as follows:

- **Multifaceted Applicability:** The reviewed literature showcases the multifaceted applicability of MCDA across diverse fields, including healthcare, energy management, transport, supplier selection, sustainable development, and others. This versatility underscores MCDA's role as a robust decision-making tool in addressing complex challenges across selected domains.
- **Methodological Diversity:** Researchers have employed various MCDA methods to address specific decision challenges. Analytical Hierarchy Process is prominent, especially in healthcare and sustainable development, while other methods like TOPSIS, PROMETHEE, and various fuzzy logic extensions contribute to methodological diversity, reflecting a dedicated approach to specific problem contexts.
- **Effective Handling of Uncertainty:** The integration of fuzzy logic extensions in various fields, such as healthcare, supplier selection, and sustainable development, demonstrates MCDA's effectiveness in handling uncertainties. Fuzzy logic allows decision-makers to model imprecise information and incomplete knowledge, enhancing the robustness of decision outcomes.
- **Robust Decision Models:** The trend of using multiple MCA methods within the same problem, as observed in healthcare, transport, and supplier selection, emphasizes a need to determine robust decision models. Integrating AHP, Fuzzy AHP, TOPSIS, and PROMETHEE, among others, aims to compare and validate results, ensuring more reliable and informed decision outcomes.
- **Integration with Advanced Technologies:** The reviewed literature reveals a visible integration of MCDA with advanced technologies such as GIS, deep learning, and big data analytics. For instance, the combination of GIS and MCDA in site selection, the integration of deep learning in flood risk assessment, and the use of big data analytics in sustainable manufacturing supply chain decisions indicate a synergy between MCDA and the latest technologies for enhanced decision support.

These findings comprehensively highlight the improving popularity of MCDA research, emphasizing its adaptability, methodological diversity, capacity to handle uncertainties, commitment to robust decision-making, and integration with advanced technologies across diverse research domains.

#### **4. Conclusions**

In conclusion, the trends and applications of MCDA methods across diverse fields indicate their adaptability and effectiveness in addressing complex decision-making scenarios. The combination of MCDA with fuzzy logic, artificial intelligence, and data analytics reflects the dynamic nature of the decision support area, offering valuable insights for researchers and practitioners in these domains. The study on the applications of Multi-Criteria Decision Analysis across various domains draws several important conclusions that contribute to both academic research and practical decision-making processes: 1) it shows diverse applications and approaches used in practical problems, 2) it emphasizes the effective handling of uncertainty in modeling real-world scenarios, 3) it shows the growing popularity of examining the results robustness and sensitivity analysis, 4) it highlights the trend of determining hybrid models for enhanced decision support, 5) it provides guidance for future research. The study confirms the significance of the MCDA techniques as a valuable approach for tackling complex decision-making challenges in various domains. It sheds light on the evolving space of MCDA applications, offering insights that can inform both academic research and practical decision-making processes in an era characterized by increasing complexity and uncertainty.

While the review provides valuable insights into the applications and trends of Multi-Criteria Decision Analysis across selected domains, it's essential to acknowledge several limitations:

- **Scope and Selection Bias:** The study might have a scope limitation due to the vastness of the field. The inclusion and exclusion criteria for selecting research papers might introduce some bias. If certain areas or applications of MCDA are underrepresented, the findings may not fully represent the entire spectrum of multi-criteria model applications.
- **Depth of Analysis:** Due to the wide nature of the review, the depth of analysis for each application area may be limited. In-depth exploration of specific applications or comparisons between different MCDA methods within a domain could provide more complex insights.
- **Incomplete Representation of Emerging Areas:** The review might not fully cover possible areas of MCDA application. However, due to the characteristics and flexibility of MCDA, it could be applied to any practical problem with conflicting criteria, making it challenging to address all application fields.

Despite these limitations, the review provides a comprehensive overview of the recent trends and applications of MCDA, offering valuable insights into trends, challenges, and the diverse range of decision problems. Future research can build upon these findings to address some limitations and delve deeper into specific areas of interest.

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## References

- [1] Aruldoss M, Lakshmi TM, Venkatesan VP. A survey on multi criteria decision making methods and its applications. *American Journal of Information Systems*. 2013; 1(1): 31-43.
- [2] Sriram S, Ramachandran M, Chinnasamy S, Mathivanan G. A review on multi-criteria decision-making and its application. *REST Journal on Emerging trends in Modelling and Manufacturing*. 2022; 7(4): 101-107.
- [3] Roszkowska E. Multi-criteria decision making models by applying the TOPSIS method to crisp and interval data. *Multiple Criteria Decision Making/University of Economics in Katowice*. 2011; 6(1): 200-230.
- [4] Garcia S, Cintra Y, Rita de Cássia S, Lima FG. Corporate sustainability management: a proposed multi-criteria model to support balanced decision-making. *Journal of cleaner production*. 2016; 136: 181-196.
- [5] Marttunen M, Lienert J, Belton V. Structuring problems for Multi-Criteria Decision Analysis in practice: A literature review of method combinations. *European journal of operational research*. 2017; 263(1): 1-17.
- [6] Razmak J, Aouni B. Decision support system and multi-criteria decision aid: a state of the art and perspectives. *Journal of Multi-Criteria Decision Analysis*. 2015; 22(1-2): 101-117.
- [7] Odu G. Weighting methods for multi-criteria decision making technique. *Journal of Applied Sciences and Environmental Management*. 2019; 23(8): 1449-1457.
- [8] Huang IB, Keisler J, Linkov I. Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Science of the total environment*. 2011; 409(19): 3578-3594.
- [9] Marsh K, Lanitis T, Neasham D, Orfanos P, Caro J. Assessing the value of healthcare interventions using multi-criteria decision analysis: a review of the literature. *Pharmacoeconomics*. 2014; 32(4): 345-365.
- [10] Ho W, Xu X, Dey PK. Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Journal of operational research*. 2010; 202(1): 16-24.
- [11] Macharis C, Bernardini A. Reviewing the use of Multi-Criteria Decision Analysis for the evaluation of transport projects: Time for a multi-actor approach. *Transport policy*. 2015; 37: 177-186.
- [12] Dadelo S, Turskis Z, Zavadskas EK, Dadeliene R. Multi-criteria assessment and ranking system of sport team formation based on objective-measured values of criteria set. *Expert Systems with Applications*. 2014; 41(14): 6106-6113.
- [13] Kumar A, Sah B, Singh AR, Deng Y, He X, Kumar P, et al. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renewable and Sustainable Energy Reviews*. 2017; 69: 596-609.
- [14] Alemdar KD, Kaya Ö, Çodur MY, Campisi T, Tesoriere G. Accessibility of vaccination centers in COVID-19 outbreak control: A gis-based multi-criteria decision making approach. *ISPRS International Journal of Geo-Information*. 2021; 10(10): 708.

- [15] Sarwar A, Nazar N, Qadir A. Measuring vaccination willingness in response to COVID-19 using a multi-criteria-decision making method. *Human Vaccines & Immunotherapeutics*. 2021; 17(12): 4865-4872.
- [16] De Nardo P, Gentilotti E, Mazzaferri F, Cremonini E, Hansen P, Goossens H, et al. Multi-Criteria Decision Analysis to prioritize hospital admission of patients affected by COVID-19 in low-resource settings with hospital-bed shortage. *International Journal of Infectious Diseases*. 2020; 98: 494-500.
- [17] Sarwar A, Imran M. Prioritizing infection prevention and control activities for SARS-CoV-2 (COVID-19): a multi-criteria decision-analysis method. *Journal of healthcare leadership*. 2021; p. 77-84.
- [18] Choudhury S, Majumdar A, Saha AK, Majumdar P. Evaluating the preparedness of indian states against COVID-19 pandemic risk: A fuzzy multi-criteria decision-making approach. *Risk Analysis*. 2022; 42(1): 85-96.
- [19] Ruggeri M, Cadeddu C, Roazzi P, Mandolini D, Grigioni M, Marchetti M. Multi-criteria-decision-analysis (MCDA) for the horizon scanning of health innovations an application to COVID 19 emergency. *International Journal of Environmental Research and Public Health*. 2020; 17(21): 7823.
- [20] Yang C, Wang Y, Hu X, Chen Y, Qian L, Li F, et al. Improving hospital based medical procurement decisions with health technology assessment and multi-criteria decision analysis. *INQUIRY: The Journal of Health Care Organization, Provision, and Financing*. 2021; 58: 00469580211022911.
- [21] Ortiz-Barrios M, Gul M, López-Meza P, Yucesan M, Navarro-Jiménez E. Evaluation of hospital disaster preparedness by a multi-criteria decision making approach: The case of Turkish hospitals. *International journal of disaster risk reduction*. 2020; 49: 101748.
- [22] Chen ZH, Wan SP, Dong JY. An efficiency-based interval type-2 fuzzy multi-criteria group decision making for makeshift hospital selection. *Applied Soft Computing*. 2022; 115: 108243.
- [23] Yazdani M, Tavana M, Pamučar D, Chatterjee P. A rough based multi-criteria evaluation method for healthcare waste disposal location decisions. *Computers & Industrial Engineering*. 2020; 143: 106394.
- [24] Ozsahin I, Abebe ST, Mok G. A multi-criteria decision-making approach for schizophrenia treatment techniques. *Arch Psychiatry Psychother*. 2020; 2: 52-61.
- [25] Mishra AR, Rani P. Multi-criteria healthcare waste disposal location selection based on Fermatean fuzzy WASPAS method. *Complex & Intelligent Systems*. 2021; 7(5): 2469-2484.
- [26] Salimian S, Mousavi SM. The selection of healthcare waste treatment technologies by a multi-criteria group decision-making method with intuitionistic fuzzy sets. *Journal of Industrial and Systems Engineering*. 2022; 14(1): 205-220.
- [27] Bharsakade RS, Acharya P, Ganapathy L, Tiwari MK. A lean approach to healthcare management using multi criteria decision making. *Opsearch*. 2021; pp. 1-26.
- [28] Németh B, Molnár A, Bozóki S, Wijaya K, Inotai A, Campbell JD, et al. Comparison of weighting methods used in multicriteria decision analysis frameworks in healthcare with focus on low-and middle-income countries. *Journal of comparative effectiveness research*. 2019; 8(4): 195-204.
- [29] Devarakonda P, Sadasivuni R, Nobrega RA, Wu J. Application of spatial multicriteria decision analysis in healthcare: Identifying drivers and triggers of infectious disease outbreaks using ensemble learning. *Journal of Multi-Criteria Decision Analysis*. 2022; 29(1-2): 23-36.
- [30] Almahdi E, Zaidan A, Zaidan B, Alsalem M, Albahri OS, Albahri AS. Mobile-based patient monitoring systems: A prioritisation framework using multi-criteria decision-making techniques. *Journal of medical systems*. 2019; 43: 1-19.
- [31] Schey C, Postma MJ, Krabbe PF, Topachevskyi O, Volovyk A, Connolly M. Assessing the preferences for criteria in multi-criteria decision analysis in treatments for rare diseases. *Frontiers in public health*. 2020; 8: 162.
- [32] Beheshtinia MA, Bahrami F, Fathi M, Asadi S. Evaluating and prioritizing the healthcare waste disposal center locations using a hybrid multi-criteria decision-making method. *Scientific Reports*. 2023; 13(1): 15130.
- [33] Adalı EA, Tuş A. Hospital site selection with distance-based multi-criteria decision-making methods. *International Journal of Healthcare Management*. 2021; 14(2): 534-544.
- [34] Mustapha MT, Ozsahin DU, Ozsahin I, Uzun B. Breast cancer screening based on supervised learning and multi-criteria decision-making. *Diagnostics*. 2022; 12(6): 1326.
- [35] Gardas BB. Organizational hindrances to Healthcare 4.0 Adoption: An multi-criteria decision analysis framework. *Journal of Multi-Criteria Decision Analysis*. 2022; 29(1-2): 186-195.
- [36] Xiao F. A novel multi-criteria decision making method for assessing health-care waste treatment technologies based on D numbers. *Engineering Applications of Artificial Intelligence*. 2018; 71: 216-225.
- [37] Camilo DGG, de Souza RP, Frazão TDC, da Costa Junior JF. Multi-criteria analysis in the health area: selection of the most appropriate triage system for the emergency care units in natal. *BMC Medical Informatics and Decision Making*. 2020; 20: 1-16.
- [38] Montibeller G, Patel P, del Rio Vilas VJ. A critical analysis of multi-criteria models for the prioritisation of health threats. *European Journal of Operational Research*. 2020; 281(1): 87-99.
- [39] Lasorsa I, Padoano E, Marceglia S, Accardo A. Multi-criteria decision analysis for the assessment of non-clinical hospital services: Methodology and case study. *Operations Research for Health Care*. 2019; 23: 100171.
- [40] Gardas BB, Ghongade NP, Jagtap AH. Application of multi-criteria decision-making approach in healthcare surgical management. *Journal of Multi-Criteria Decision Analysis*. 2022; 29(1-2): 92-109.

- [41] Albawab M, Ghenai C, Bettayeb M, Janajreh I. Sustainability performance index for ranking energy storage technologies using multi-criteria decision-making model and hybrid computational method. *Journal of Energy Storage*. 2020; 32: 101820.
- [42] Mazzeo D, Baglivo C, Matera N, Congedo PM, Oliveti G. A novel energy-economic-environmental multi-criteria decision-making in the optimization of a hybrid renewable system. *Sustainable Cities and Society*. 2020; 52: 101780.
- [43] Rehman AU, Abidi MH, Umer U, Usmani YS. Multi-criteria decision-making approach for selecting wind energy power plant locations. *Sustainability*. 2019; 11(21): 6112.
- [44] Khorsand R, Ramezanpour M. An energy-efficient task-scheduling algorithm based on a multi-criteria decision-making method in cloud computing. *International Journal of Communication Systems*. 2020; 33(9): e4379.
- [45] Diemuodeke E, Addo A, Oko C, Mulugetta Y, Ojapah M. Optimal mapping of hybrid renewable energy systems for locations using multi-criteria decision-making algorithm. *Renewable Energy*. 2019; 134: 461-477.
- [46] Hong S, Kim E, Jeong S. Evaluating the sustainability of the hydrogen economy using multi-criteria decision-making analysis in Korea. *Renewable Energy*. 2023; 204: 485-492.
- [47] Roy D. Performance evaluation of a novel biomass-based hybrid energy system employing optimisation and multi-criteria decision-making techniques. *Sustainable Energy Technologies and Assessments*. 2020; 42: 100861.
- [48] Singh P, Meena NK, Yang J, Vega-Fuentes E, Bishnoi SK. Multi-criteria decision making monarch butterfly optimization for optimal distributed energy resources mix in distribution networks. *Applied Energy*. 2020; 278: 115723.
- [49] McKenna R, Bertsch V, Mainzer K, Fichtner W. Combining local preferences with multi-criteria decision analysis and linear optimization to develop feasible energy concepts in small communities. *European journal of operational research*. 2018; 268(3): 1092-1110.
- [50] Murrant D, Radcliffe J. Assessing energy storage technology options using a multi-criteria decision analysis-based framework. *Applied Energy*. 2018; 231: 788-802.
- [51] Chatterjee K, Kar S. A multi-criteria decision making for renewable energy selection using Z-numbers in uncertain environment. *Technological and economic development of economy*. 2018; 24(2): 739-764.
- [52] Ke Y, Liu J, Meng J, Fang S, Zhuang S. Comprehensive evaluation for plan selection of urban integrated energy systems: A novel multi-criteria decision-making framework. *Sustainable Cities and Society*. 2022; 81: 103837.
- [53] Zhou J, Wu Y, Wu C, Deng Z, Xu C, Hu Y. A hybrid fuzzy multi-criteria decision-making approach for performance analysis and evaluation of park-level integrated energy system. *Energy Conversion and Management*. 2019; 201: 112134.
- [54] Ren J. Multi-criteria decision making for the prioritization of energy systems under uncertainties after life cycle sustainability assessment. *Sustainable Production and Consumption*. 2018; 16: 45-57.
- [55] Mrówczyńska M, Skiba M, Sztubecka M, Bazan-Krzywoszańska A, Kazak J, Gajownik P. Scenarios as a tool supporting decisions in urban energy policy: The analysis using fuzzy logic, multi-criteria analysis and GIS tools. *Renewable and Sustainable Energy Reviews*. 2021; 137: 110598.
- [56] Zhong J, Hu X, Yüksel S, Dinçer H, Ubay GG. Analyzing the investments strategies for renewable energies based on multi-criteria decision model. *IEEE Access*. 2020; 8: 118818-118840.
- [57] Noorollahi Y, Senani AG, Fadaei A, Simaee M, Moltames R. A framework for GIS-based site selection and technical potential evaluation of PV solar farm using Fuzzy-Boolean logic and AHP multi-criteria decision-making approach. *Renewable Energy*. 2022; 186: 89-104.
- [58] Wang CN, Huang YF, Chai YC, Nguyen VT. A multi-criteria decision making (MCDM) for renewable energy plants location selection in Vietnam under a fuzzy environment. *Applied Sciences*. 2018; 8(11): 2069.
- [59] Shaaban M, Scheffran J, Böhner J, Elsobki MS. Sustainability assessment of electricity generation technologies in Egypt using multi-criteria decision analysis. *Energies*. 2018; 11(5): 1117.
- [60] Mahdy M, Bahaj AS. Multi criteria decision analysis for offshore wind energy potential in Egypt. *Renewable energy*. 2018; 118: 278-289.
- [61] Okokpuije I, Okonkwo U, Bolu C, Ohunakin O, Agboola M, Atayero A. Implementation of multi-criteria decision method for selection of suitable material for development of horizontal wind turbine blade for sustainable energy generation. *Heliyon*. 2020; 6(1).
- [62] Ruiz H, Sunarso A, Ibrahim-Bathis K, Murti S, Budiarto I. GIS-AHP Multi Criteria Decision Analysis for the optimal location of solar energy plants at Indonesia. *Energy Reports*. 2020; 6: 3249-3263.
- [63] Vinhoza A, Schaeffer R. Brazil's offshore wind energy potential assessment based on a Spatial Multi-Criteria Decision Analysis. *Renewable and Sustainable Energy Reviews*. 2021; 146: 111185.
- [64] Nzotcha U, Kenfack J, Manjia MB. Integrated multi-criteria decision making methodology for pumped hydro-energy storage plant site selection from a sustainable development perspective with an application. *Renewable and Sustainable Energy Reviews*. 2019; 112: 930-947.
- [65] Ullah Z, Elkadeem M, Kotb KM, Taha IB, Wang S. Multi-criteria decision-making model for optimal planning of on/off grid hybrid solar, wind, hydro, biomass clean electricity supply. *Renewable Energy*. 2021; 179: 885-910.
- [66] Saraswat S, Digalwar AK. Evaluation of energy alternatives for sustainable development of energy sector in India: An integrated Shannon's entropy fuzzy multi-criteria decision approach. *Renewable Energy*. 2021; 171: 58-74.
- [67] Ehteram M, Karami H, Farzin S. Reservoir optimization for energy production using a new evolutionary algorithm based on multi-criteria decision-making models. *Water resources management*. 2018; 32: 2539-2560.
- [68] Xue M, Fu C, Feng NP, Lu GY, Chang WJ, Yang SL. Evaluation of supplier performance of high-speed train based on

- multi-stage multi-criteria decision-making method. *Knowledge-Based Systems*. 2018; 162: 238-251.
- [69] Mishra AR, Rani P, Hezam IM, Deveci M. Dual Probabilistic Linguistic Full Consistency Additive Ratio Assessment Model for Medical Equipment Supplier Selection. *International Journal of Fuzzy Systems*. 2023; pp. 1-17.
- [70] Chakraborty S, Chattopadhyay R, Chakraborty S. An integrated D-MARCOS method for supplier selection in an iron and steel industry. *Decision Making: Applications in Management and Engineering*. 2020; 3(2): 49-69.
- [71] Liu T, Deng Y, Chan F. Evidential supplier selection based on DEMATEL and game theory. *International Journal of Fuzzy Systems*. 2018; 20: 1321-1333.
- [72] Kaya R, Yet B. Building Bayesian networks based on DEMATEL for multiple criteria decision problems: A supplier selection case study. *Expert Systems with Applications*. 2019; 134: 234-248.
- [73] Chen CH. A hybrid multi-criteria decision-making approach based on ANP-entropy TOPSIS for building materials supplier selection. *Entropy*. 2021; 23(12): 1597.
- [74] Zakeri S, Chatterjee P, Cheikhrouhou N, Konstantas D. Ranking based on optimal points and win-loss-draw multi-criteria decision-making with application to supplier evaluation problem. *Expert Systems with Applications*. 2022; 191: 116258.
- [75] Güneri B, Deveci M. Evaluation of supplier selection in the defense industry using q-rung orthopair fuzzy set based EDAS approach. *Expert Systems with Applications*. 2023; 222: 119846.
- [76] Đalić I, Stević Ž, Karamasa C, Puška A. A novel integrated fuzzy PIPRECIA-interval rough SAW model: Green supplier selection. *Decision Making: Applications in Management and Engineering*. 2020; 3(1): 126-145.
- [77] Wu C, Lin Y, Barnes D. An integrated decision-making approach for sustainable supplier selection in the chemical industry. *Expert Systems with Applications*. 2021; 184: 115553.
- [78] Hendiani S, Liao H, Ren R, Lev B. A likelihood-based multi-criteria sustainable supplier selection approach with complex preference information. *Information Sciences*. 2020; 536: 135-155.
- [79] Gupta S, Soni U, Kumar G. Green supplier selection using multi-criterion decision making under fuzzy environment: A case study in automotive industry. *Computers & Industrial Engineering*. 2019; 136: 663-680.
- [80] Memari A, Dargi A, Jokar MRA, Ahmad R, Rahim ARA. Sustainable supplier selection: A multi-criteria intuitionistic fuzzy TOPSIS method. *Journal of manufacturing systems*. 2019; 50: 9-24.
- [81] Liu S, He X, Chan FT, Wang Z. An extended multi-criteria group decision-making method with psychological factors and bidirectional influence relation for emergency medical supplier selection. *Expert Systems with Applications*. 2022; 202: 117414.
- [82] Hendiani S, Mahmoudi A, Liao H. A multi-stage multi-criteria hierarchical decision-making approach for sustainable supplier selection. *Applied Soft Computing*. 2020; 94: 106456.
- [83] Wei Q, Zhou C. A multi-criteria decision-making framework for electric vehicle supplier selection of government agencies and public bodies in China. *Environmental Science and Pollution Research*. 2023; 30(4): 10540-10559.
- [84] Yildizbasi A, Arioz Y. Green supplier selection in new era for sustainability: a novel method for integrating big data analytics and a hybrid fuzzy multi-criteria decision making. *Soft Computing*. 2022; 26: 253-270.
- [85] Ecer F. Multi-criteria decision making for green supplier selection using interval type-2 fuzzy AHP: a case study of a home appliance manufacturer. *Operational Research*. 2022; 22(1): 199-233.
- [86] Stojić G, Stević Ž, Antuchevičienė J, Pamučar D, Vasiljević M. A novel rough WASPAS approach for supplier selection in a company manufacturing PVC carpentry products. *Information*. 2018; 9(5): 121.
- [87] Badi I, Pamucar D. Supplier selection for steelmaking company by using combined Grey-MARCOS methods. *Decision Making: Applications in Management and Engineering*. 2020; 3(2): 37-48.
- [88] Petrović G, Mihajlović J, Čojbašić Ž, Madić M, Marinković D. Comparison of three fuzzy MCDM methods for solving the supplier selection problem. *Facta Universitatis, Series: Mechanical Engineering*. 2019; 17(3): 455-469.
- [89] Stević Ž, Durmić E, Gajić M, Pamučar D, Puška A. A novel multi-criteria decision-making model: interval rough SAW method for sustainable supplier selection. *Information*. 2019; 10(10): 292.
- [90] Leong WY, Wong KY, Wong WP. A new integrated multi-criteria decision-making model for resilient supplier selection. *Applied System Innovation*. 2022; 5(1): 8.
- [91] Phochanikorn P, Tan C. A new extension to a multi-criteria decision-making model for sustainable supplier selection under an intuitionistic fuzzy environment. *Sustainability*. 2019; 11(19): 5413.
- [92] Fei L, Deng Y, Hu Y. DS-VIKOR: A new multi-criteria decision-making method for supplier selection. *International Journal of Fuzzy Systems*. 2019; 21: 157-175.
- [93] Kalifa M, Özdemir A, Özkan A, Banar M. Application of Multi-Criteria Decision analysis including sustainable indicators for prioritization of public transport system. *Integrated Environmental Assessment and Management*. 2022; 18(1): 25-38.
- [94] Kiraci K, Bakır M. Using the multi criteria decision making methods in aircraft selection problems and an application. *Journal of Transportation and Logistics*. 2018; 3(1): 13-24.
- [95] Ammenberg J, Dahlgren S. Sustainability assessment of public transport, part i – a multi-criteria assessment method to compare different bus technologies. *Sustainability*. 2021; 13(2): 825.
- [96] Aspen DM, Sparrevik M. Evaluating alternative energy carriers in ferry transportation using a stochastic multi-criteria decision analysis approach. *Transportation Research Part D: Transport and Environment*. 2020; 86: 102383.
- [97] Manzolli JA, Trovão JP, Antunes CH. Scenario-Based Multi-criteria decision analysis for rapid transit systems implementation in an urban context. *ETransportation*. 2021; 7: 100101.
- [98] Ali G, Abbas S, Pan Y, Chen Z, Hussain J, Sajjad M, et al. Urban environment dynamics and low carbon society:



- multi-criteria decision analysis modeling for policy makers. *Sustainable Cities and Society*. 2019; 51: 101763.
- [99] Hasan M, Chapman R, Frame D. Acceptability of transport emissions reduction policies: A multi-criteria analysis. *Renewable and Sustainable Energy Reviews*. 2020; 133: 110298.
- [100] Singh J, Singh H, Sandhu AS. Gearless Scooter Selection Using Multi-Criteria Decision Making. *IUP Journal of Operations Management*. 2018; 17(3): 21-41.
- [101] Güner S. Measuring the quality of public transportation systems and ranking the bus transit routes using multi-criteria decision making techniques. *Case Studies on Transport Policy*. 2018; 6(2): 214-224.
- [102] Liaqat M, Ghadi YY, Adnan M, Fazal MR. Multicriteria evaluation of portable energy storage technologies for electric vehicles. *IEEE Access*. 2022; 10: 64890-64903.
- [103] Lee DJ. A multi-criteria approach for prioritizing advanced public transport modes (APTMs) considering urban types in Korea. *Transportation Research Part A: Policy and Practice*. 2018; 111: 148-161.
- [104] Jahanshahi D, Minaei M, Kharazmi OA, Minaei F. Evaluation and relocating bicycle sharing stations in mashhad city using multi-criteria analysis. *International Journal of Transportation Engineering*. 2019; 6(3): 265-283.
- [105] Petrović I, Kankaraš M. DEMATEL-AHP multi-criteria decision making model for the selection and evaluation of criteria for selecting an aircraft for the protection of air traffic. *Decision Making: Applications in Management and Engineering*. 2018; 1(2): 93-110.
- [106] Hamurcu M, Eren T. Electric bus selection with multicriteria decision analysis for green transportation. *Sustainability*. 2020; 12(7): 2777.
- [107] Nalmpantis D, Roukouni A, Genitsaris E, Stamelou A, Naniopoulos A. Evaluation of innovative ideas for Public Transport proposed by citizens using Multi-Criteria Decision Analysis (MCDA). *European Transport Research Review*. 2019; 11(1): 1-16.
- [108] Deveci M, Pamucar D, Gokasar I, Delen D, Martínez L. A fuzzy Einstein-based decision support system for public transportation management at times of pandemic. *Knowledge-Based Systems*. 2022; 252: 109414.
- [109] Stević Ž, Subotić M, Softić E, Božić B. Multi-criteria decision-making model for evaluating safety of road sections. *J Intell Manag Decis*. 2022; 1(2): 78-87.
- [110] Sałabun W, Palczewski K, Wątróbski J. Multicriteria approach to sustainable transport evaluation under incomplete knowledge: Electric bikes case study. *Sustainability*. 2019; 11(12): 3314.
- [111] Tian ZP, Liang HĀ, Nie RX, Wang XK, Wang JQ. Data-driven multi-criteria decision support method for electric vehicle selection. *Computers & Industrial Engineering*. 2023; 177: 109061.
- [112] Ziembra P. Multi-criteria approach to stochastic and fuzzy uncertainty in the selection of electric vehicles with high social acceptance. *Expert Systems with Applications*. 2021; 173: 114686.
- [113] Alkharabsheh A, Moslem S, Oubahman L, Duleba S. An integrated approach of multi-criteria decision-making and grey theory for evaluating urban public transportation systems. *Sustainability*. 2021; 13(5): 2740.
- [114] Feng J, Xu SX, Li M. A novel multi-criteria decision-making method for selecting the site of an electric-vehicle charging station from a sustainable perspective. *Sustainable Cities and Society*. 2021; 65: 102623.
- [115] Ali Y, Mehmood B, Huzaifa M, Yasir U, Khan AU. Development of a new hybrid multi criteria decision-making method for a car selection scenario. *Facta Universitatis, Series: Mechanical Engineering*. 2020; 18(3): 357-373.
- [116] Sarraf R, McGuire MP. Integration and comparison of multi-criteria decision making methods in safe route planner. *Expert Systems with Applications*. 2020; 154: 113399.
- [117] Broniewicz E, Ogrodnik K. Multi-criteria analysis of transport infrastructure projects. *Transportation research part D: transport and environment*. 2020; 83: 102351.
- [118] Erdogan N, Pamucar D, Kucuksari S, Deveci M. An integrated multi-objective optimization and multi-criteria decision-making model for optimal planning of workplace charging stations. *Applied Energy*. 2021; 304: 117866.
- [119] Aksoy E, San BT. Geographical information systems (GIS) and multi-criteria decision analysis (MCDA) integration for sustainable landfill site selection considering dynamic data source. *Bulletin of Engineering Geology and the Environment*. 2019; 78: 779-791.
- [120] Gharizadeh Beiragh R, Alizadeh R, Shafiei Kaleibari S, Cavallaro F, Zolfani SH, Bausys R, et al. An integrated multi-criteria decision making model for sustainability performance assessment for insurance companies. *Sustainability*. 2020; 12(3): 789.
- [121] Erdogan SA, Šaparauskas J, Turskis Z. A multi-criteria decision-making model to choose the best option for sustainable construction management. *Sustainability*. 2019; 11(8): 2239.
- [122] Das N, Mukhopadhyay S. Application of multi-criteria decision making technique for the assessment of groundwater potential zones: a study on Birbhum district, West Bengal, India. *Environment, Development and Sustainability*. 2020; 22: 931-955.
- [123] Omran II, Al-Saati NH, Al-Saati HH, Hashim KS, Al-Saati ZN. Sustainability assessment of wastewater treatment techniques in urban areas of Iraq using multi-criteria decision analysis (MCDA). *Water Practice & Technology*. 2021; 16(2): 648-660.
- [124] Manupati VK, Ramkumar M, Samanta D. A multi-criteria decision making approach for the urban renewal in Southern India. *Sustainable Cities and Society*. 2018; 42: 471-481.
- [125] Almeida AC. Multi actor multi criteria analysis (MAMCA) as a tool to build indicators and localize sustainable development goal 11 in Brazilian municipalities. *Heliyon*. 2019; 5(8).

- [126] Pagone E, Salonitis K, Jolly M. Automatically weighted high-resolution mapping of multi-criteria decision analysis for sustainable manufacturing systems. *Journal of Cleaner Production*. 2020; 257: 120272.
- [127] Roszkowska E, Filipowicz-Chomko M. Measuring sustainable development in the education area using multi-criteria methods: a case study. *Central European Journal of Operations Research*. 2020; 28(4): 1219-1241.
- [128] Ma F, Zhao Y, Pu Y, Li J. A comprehensive multi-criteria decision making model for sustainable material selection considering life cycle assessment method. *IEEE Access*. 2018; 6: 58338-58354.
- [129] Talukder B, Hipel KW, vanLoon GW. Using multi-criteria decision analysis for assessing sustainability of agricultural systems. *Sustainable Development*. 2018; 26(6): 781-799.
- [130] Chen Y, Zhang D. Evaluation of city sustainability using multi-criteria decision-making considering interaction among criteria in Liaoning province China. *Sustainable Cities and Society*. 2020; 59: 102211.
- [131] Invidiata A, Lavagna M, Ghisi E. Selecting design strategies using multi-criteria decision making to improve the sustainability of buildings. *Building and Environment*. 2018; 139: 58-68.
- [132] Boral S, Howard I, Chaturvedi SK, McKee K, Naikan V. A novel hybrid multi-criteria group decision making approach for failure mode and effect analysis: An essential requirement for sustainable manufacturing. *Sustainable Production and Consumption*. 2020; 21: 14-32.
- [133] Ezbakhe F, Pérez-Foguet A. Decision analysis for sustainable development: The case of renewable energy planning under uncertainty. *European Journal of Operational Research*. 2021; 291(2): 601-613.
- [134] Nguyen NBT, Lin GH, Dang TT. Fuzzy multi-criteria decision-making approach for online food delivery (OFD) companies evaluation and selection: A case study in Vietnam. *Processes*. 2021; 9(8): 1274.
- [135] Raj R, Kumar V, Verma P. Big data analytics in mitigating challenges of sustainable manufacturing supply chain. *Operations Management Research*. 2023; pp. 1-15.
- [136] Wang WM, Peng HH. A fuzzy multi-criteria evaluation framework for urban sustainable development. *Mathematics*. 2020; 8(3): 330.
- [137] Yıldızbaşı A, Öztürk C, Efendioğlu D, Bulkan S. Assessing the social sustainable supply chain indicators using an integrated fuzzy multi-criteria decision-making methods: A case study of Turkey. *Environment, Development and Sustainability*. 2021; 23: 4285-4320.
- [138] Ture H, Dogan S, Kocak D. Assessing Euro 2020 strategy using multi-criteria decision making methods: VIKOR and TOPSIS. *Social Indicators Research*. 2019; 142: 645-665.
- [139] Mijajlović M, Puška A, Stević Ž, Marinković D, Doljanica D, Jovanović SV, et al. Determining the competitiveness of spa-centers in order to achieve sustainability using a fuzzy multi-criteria decision-making model. *Sustainability*. 2020; 12(20): 8584.
- [140] Bączkiewicz A, Kizielewicz B. Towards sustainable energy consumption evaluation in Europe for industrial sector based on MCDA methods. *Procedia Computer Science*. 2021; 192: 1334-1346.
- [141] Moghtadernejad S, Chouinard LE, Mirza MS. Multi-criteria decision-making methods for preliminary design of sustainable facades. *Journal of Building Engineering*. 2018; 19: 181-190.
- [142] Suganthi L. Multi expert and multi criteria evaluation of sectoral investments for sustainable development: An integrated fuzzy AHP, VIKOR/DEA methodology. *Sustainable Cities and Society*. 2018; 43: 144-156.
- [143] Yang JJ, Lo HW, Chao CS, Shen CC, Yang CC. Establishing a sustainable sports tourism evaluation framework with a hybrid multi-criteria decision-making model to explore potential sports tourism attractions in Taiwan. *Sustainability*. 2020; 12(4): 1673.
- [144] Askarifar K, Motaffef Z, Azaami S. An investment development framework in Iran's seashores using TOPSIS and best-worst multi-criteria decision making methods. *Decision Science Letters*. 2018; 7(1): 55-64.
- [145] Rezaei J, Papakonstantinou A, Tavasszy L, Pesch U, Kana A. Sustainable product-package design in a food supply chain: A multi-criteria life cycle approach. *Packaging Technology and Science*. 2019; 32(2): 85-101.
- [146] Bampa F, O'Sullivan L, Madena K, Sandén T, Spiegel H, Henriksen CB, et al. Harvesting European knowledge on soil functions and land management using multi-criteria decision analysis. *Soil Use and Management*. 2019; 35(1): 6-20.
- [147] Rani P, Mishra AR, Krishankumar R, Ravichandran K, Kar S. Multi-criteria food waste treatment method selection using single-valued neutrosophic-CRITIC-MULTIMOORA framework. *Applied Soft Computing*. 2021; 111: 107657.
- [148] Grover AK, Chopra S, Krejci CC. A multi-criteria decision analysis for the public distribution system of food grains in Indian Punjab: Towards decentralized food policies in developing countries. *Journal of Multi-Criteria Decision Analysis*. 2020; 27(3-4): 236-251.
- [149] Vavrek R. An Analysis of Usage of a Multi-Criteria Approach in an Athlete Evaluation: An Evidence of NHL Attackers. *Mathematics*. 2021; 9(12): 1399.
- [150] Iacovidou E, Voulvoulis N. A multi-criteria sustainability assessment framework: development and application in comparing two food waste management options using a UK region as a case study. *Environmental Science and Pollution Research*. 2018; 25: 35821-35834.
- [151] Kondratenko Y, Kondratenko G, Sidenko I. Multi-criteria decision making for selecting a rational IoT platform. In: 2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies (DESSERT). IEEE; 2018. pp. 147-152.
- [152] Everest T. Suitable site selection for pistachio (*Pistacia vera*) by using GIS and multi-criteria decision analyses (a case study in Turkey). *Environment, Development and Sustainability*. 2021; 23(5): 7686-7705.

- [153] Haroun HAAF, Bakr AF, Hasan AES. Multi-criteria decision making for adaptive reuse of heritage buildings: Aziza Fahmy Palace, Alexandria, Egypt. *Alexandria engineering journal*. 2019; 58(2): 467-478.
- [154] Maleki B, Rubio MdMC, Hosseini SMA, De La Fuente Antequera A. Multi-criteria decision making in the social sustainability assessment of high-rise residential buildings. In: *IOP Conference Series: Earth and Environmental Science*. vol. 290, IOP Publishing; 2019. pp. 012054.
- [155] Mantogiannis VA, Katsigiannis FA. Assessing real estate investment alternatives: a multi-criteria and multi-stakeholder decision aid tool. *International Journal of the Analytic Hierarchy Process*. 2020; 12(1).
- [156] März S. Assessing the fuel poverty vulnerability of urban neighbourhoods using a spatial multi-criteria decision analysis for the German city of Oberhausen. *Renewable and Sustainable Energy Reviews*. 2018; 82: 1701-1711.
- [157] Pham BT, Luu C, Van Dao D, Van Phong T, Nguyen HD, Van Le H, et al. Flood risk assessment using deep learning integrated with multi-criteria decision analysis. *Knowledge-based systems*. 2021; 219: 106899.
- [158] Deveci M, Pamucar D, Gokasar I, Delen D, Wu Q, Simic V. An analytics approach to decision alternative prioritization for zero-emission zone logistics. *Journal of Business Research*. 2022; 146: 554-570.
- [159] Sahin B, Yip TL, Tseng PH, Kabak M, Soylu A. An application of a fuzzy TOPSIS multi-criteria decision analysis algorithm for dry bulk carrier selection. *Information*. 2020; 11(5): 251.
- [160] Gireesha O, Somu N, Krithivasan K, VS SS. IIVIFS-WASPAS: an integrated multi-criteria decision-making perspective for cloud service provider selection. *Future Generation Computer Systems*. 2020; 103: 91-110.
- [161] Kizielewicz B, Dobryakova L. MCDA based approach to sports players' evaluation under incomplete knowledge. *Procedia Computer Science*. 2020; 176: 3524-3535.
- [162] Sharma M, Gupta R, Acharya P. Prioritizing the critical factors of cloud computing adoption using multi-criteria decision-making techniques. *Global Business Review*. 2020; 21(1): 142-161.
- [163] Simon J, Trojanova M, Zbihlej J, Sarosi J. Mass customization model in food industry using industry 4.0 standard with fuzzy-based multi-criteria decision making methodology. *Advances in Mechanical Engineering*. 2018; 10(3): 1687814018766776.
- [164] Urbaniak K, Wątróbski J, Sałabun W. Identification of players ranking in e-sport. *Applied Sciences*. 2020; 10(19): 6768.
- [165] Vazifehdan MN, Darestani SA. Green logistics outsourcing employing multi criteria decision making and quality function deployment in the petrochemical industry. *The Asian Journal of Shipping and Logistics*. 2019; 35(4): 243-254.
- [166] Pamucar D, Žižović M, Biswas S, Božanić D. A new logarithm methodology of additive weights (LMAW) for multi-criteria decision-making: Application in logistics. 2021.
- [167] Rutten-van Mölken M, Leijten F, Hoedemakers M, Tsiachristas A, Verbeek N, Karimi M, et al. Strengthening the evidence-base of integrated care for people with multi-morbidity in Europe using Multi-Criteria Decision Analysis (MCDA). *BMC health services research*. 2018; 18: 1-18.
- [168] Guarini MR, Battisti F, Chiovitti A. A methodology for the selection of multi-criteria decision analysis methods in real estate and land management processes. *Sustainability*. 2018; 10(2): 507.
- [169] Vakiliipour S, Sadeghi-Niaraki A, Ghodousi M, Choi SM. Comparison between multi-criteria decision-making methods and evaluating the quality of life at different spatial levels. *Sustainability*. 2021; 13(7): 4067.
- [170] Pamucar D, Chatterjee K, Zavadskas EK. Assessment of third-party logistics provider using multi-criteria decision-making approach based on interval rough numbers. *Computers & Industrial Engineering*. 2019; 127: 383-407.
- [171] Puška A, Beganović AI, Šadić S. Model for investment decision making by applying the multi-criteria analysis method. *Serbian Journal of management*. 2018; 13(1): 7-28.
- [172] Tsakalerou M, Efthymiadis D, Abilez A. An intelligent methodology for the use of multi-criteria decision analysis in impact assessment: The case of real-world offshore construction. *Scientific Reports*. 2022; 12(1): 15137.
- [173] Widianta M, Rizaldi T, Setyohadi D, Riskiawan H. Comparison of multi-criteria decision support methods (AHP, TOPSIS, SAW & PROMENTHEE) for employee placement. In: *Journal of Physics: Conference Series*. vol. 953, IOP Publishing; 2018. pp. 012116.