




Review

# Application of MCDM Methods in Sustainability Engineering: A Literature Review 2008–2018

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**Abstract:** Sustainability is one of the main challenges of the recent decades. In this regard, several prior studies have used different techniques and approaches for solving this problem in the field of sustainability engineering. Multiple criteria decision making (MCDM) is an important technique that presents a systematic approach for helping decisionmakers in this field. The main goal of this paper is to review the literature concerning the application of MCDM methods in the field of sustainable engineering. The Web of Science (WoS) Core Collection Database was chosen to identify 108 papers in the period of 2008–2018. The selected papers were classified into five categories, including construction and infrastructure, supply chains, transport and logistics, energy, and other. In addition, the articles were classified based on author, year, application area, study objective and problem, applied methods, number of published papers, and name of the journal. The results of this paper show that sustainable engineering is an area that is quite suitable for the use of MCDM. It can be concluded that most of the methods used in sustainable engineering are based on traditional approaches with a noticeable trend towards applying the theory of uncertainty, such as fuzzy, grey, rough, and neutrosophic theory.

**Keywords:** sustainability; engineering; multi-criteria decision-making

## 1. Introduction

The emergence of the concept of sustainability has been motivated by natural catastrophes, environmental contamination, depletion of natural resources, and other incidents. According to *Our Common Future* (Brundtland Report) adopted by the World Commission on Environment and Development in 1987 [1], sustainability implies an integrative concept that includes environmental, economic, and social aspects. These three aspects are often referred to as the three pillars of sustainability. In this way, sustainability has become a modern principle that explains the long-term relationship between the present and future generations [2]. At the same time, the term “sustainable development” has emerged, which implies “meet[ing] the needs of the present generation without compromising the ability of future generations to meet their own needs” [3]. Although there are many definitions of sustainable development [4], this is one of the most frequently quoted. In order to

achieve the balance between the three pillars of sustainability, it is necessary to define the links and interactions between them, i.e., it is necessary to know how they influence each other [5].

In order to achieve sustainability, sustainable engineering is proposed as a potential solution that implies the application of different methods. Examples may include the construction of facilities made of materials that provide energy efficiency, finding energy forms that do not release carbon dioxide into the atmosphere, designing electric vehicles, etc. According to some authors, sustainable engineering implies significantly more serious considerations of environmental and social aspects [6]. Sustainable engineering thereby observes the system as part of a global ecosystem. According to Abraham [7], the following basic principles of sustainable engineering can be set out:

- Using system analysis and integrating environmental impact assessment tools;
- Improving natural ecosystems;
- Using life cycle thinking;
- Using only material and energy inputs and outputs that are clean and safe;
- Minimizing the depletion of the natural resources;
- Preventing waste;
- Applying engineering solutions having in mind geographic area, culture, and aspirations;
- Creating innovation-based solutions;
- Involving all stakeholders and community in the process of developing solutions.

Engineering is the application of scientific and mathematical principles for practical objectives, such as the processes, manufacture, design, and operation of products, while accounting for constraints invoked by environmental, economic, and social factors. There are various factors needing to be considered in order to address engineering sustainability, which is critical for the overall sustainability of human development and activity. In recent decades, decision-making theory has been a subject of intense research activity [8], due to its wide applications in different areas, such as sustainable engineering and environmental sustainability. The decision-making theory approach has become an important means of providing real-time solutions to uncertainty problems, especially for sustainable engineering and environmental sustainability problems in engineering processes. In the recent decades, several techniques and methods have been used for solving problems in the areas of environmental sustainability and sustainable engineering. Multiple criteria decision making (MCDM) is an important method that has been applied in various areas of sustainable engineering. Several prior studies have employed MCDM techniques in different areas of sustainable engineering [9–18]. In addition, several prior papers have reviewed the application MCDM and fuzzy sets theory in different areas of engineering and sustainability [11,19–26].

The main goal of the paper is to review the literature regarding the application of MCDM methods in the field of sustainable engineering. Another goal is to synthesize different areas of engineering and show effective ways of solving various problems in the field by applying various MCDM methods in various forms of uncertainty. Moreover, this review can be very useful for other studies in various areas of sustainable engineering by showing how MCDM methods can be adequate tools for decision-making processes in sustainable engineering. Furthermore, this paper highlights new, important information for all the participants in MCDM processes in sustainable engineering. In addition, this paper, to the authors' knowledge, is the first review of the literature in the area of sustainable engineering from the perspective of the application of MCDM methods.

The remainder of the paper is structured as follows. Section 2 presents the methodology, in which our algorithm for collecting and processing the articles is presented and explained in detail. Section 3 discusses the primary results of the review, i.e., the total number of MCDM articles in the field of science and technology, with an emphasis on the field of sustainable engineering. The results have been presented by various areas and the structure of the published articles has been presented by journal. Section 4 provides a detailed review of various engineering fields including, construction and

infrastructure, supply chains, transport and logistics, energy, and other. In this section, the application of MCDM methods in each of the above areas is explained in detail. Section 5 presents our conclusions.

## 2. Methodology

This paper reviews the collected literature on the topic of MCDM methods in sustainable engineering. In addition to searching in the Web of Science (WoS) Core Collection Database, articles were searched in online journal databases, using Google Scholar and the Google search engine using the following keywords: MCDM, sustainability, and sustainable engineering. Their combinations were also used when searching as follows: MCDM + sustainability + engineering, MCDM + sustainable engineering, MCDM + sustainability, and MCDM + engineering. All the collected articles were published in the period of 2008–2018. The research methodology is shown in Figure 1.

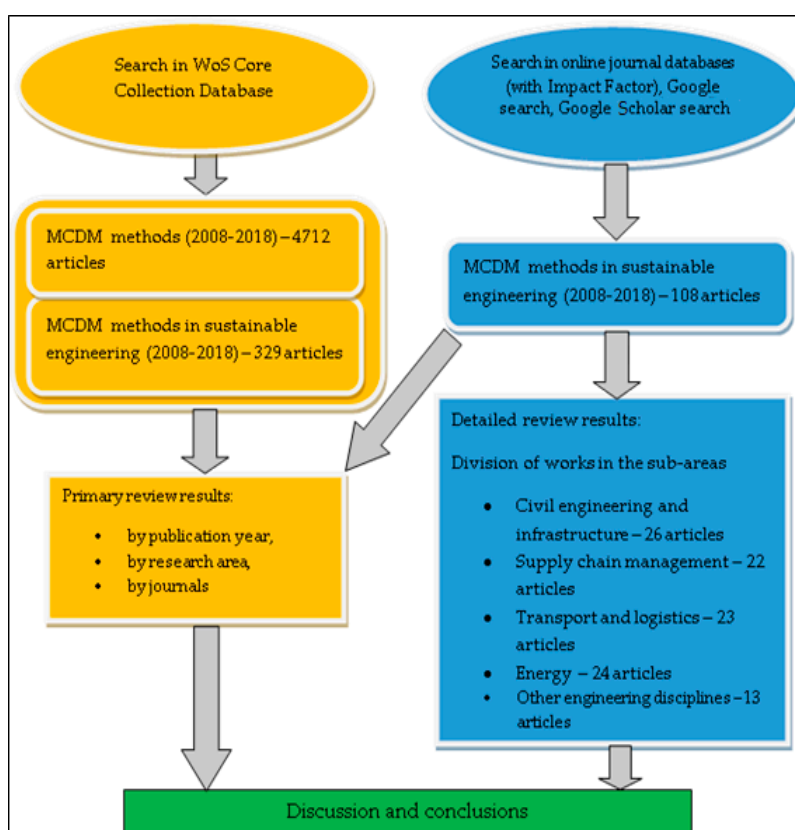
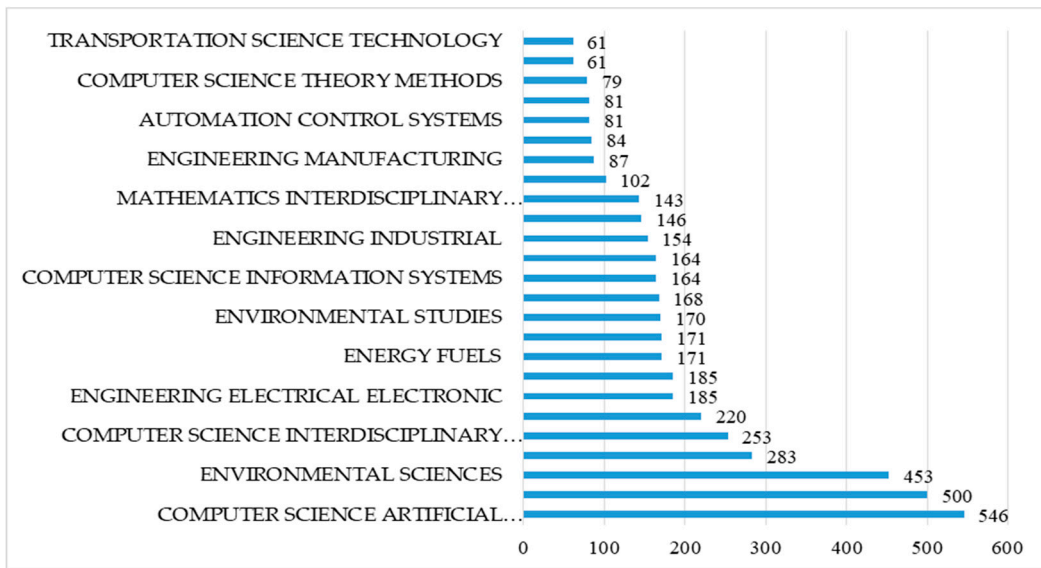


Figure 1. Brief research procedure.

By searching the WoS Core Collection Database, 4712 articles related to the application of MCDM methods in various fields of science and technology have been identified, of which 329 articles deal with the application of MCDM methods in sustainable engineering. In parallel, in the search of online journal databases with impact factors, 108 articles were found, and they were divided into five sub-areas. Based on this, the results of the primary review of articles (by publication year, by area, and by journal) are provided, while a detailed analysis and review of these articles are presented in Section 4.

## 3. Primary Review Results

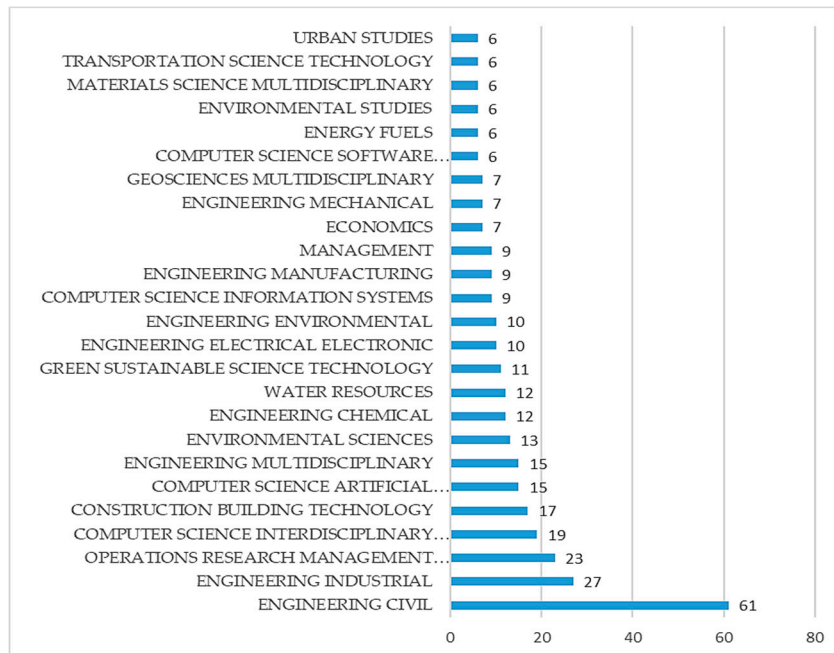
By searching the Web of Science Core Collection database, 4712 articles (November 2018) dealing with the application of MCDM methods in various fields of science and technology were found, as shown in Figure 2.



**Figure 2.** Number of articles on the application of multiple criteria decision making (MCDM) methods in various fields of science and technology.

Figure 2 shows the top 25 areas in which studies applying MCDM methods can be categorized, indicating the number of articles for each area. It appears that the largest number of articles belong to the field of computer science and artificial intelligence (546 articles), while the application of MCDM methods in operational research occupies the second position (500 articles). The smallest number of articles has been published in the field of transport technology (61). It can be concluded that these areas are currently up to date.

In terms of the articles on the application of MCDM methods in sustainable engineering, the Web of Science Core Collection database contains 329 articles, as shown in Figure 3.



**Figure 3.** Number of articles on the application of MCDM methods in sustainable engineering.

Figure 3 shows the top 25 areas in which studies applying MCDM methods in sustainable engineering can be categorized. The largest number of articles belongs to the field of civil engineering

(61), and the smallest number belongs to the fields of urban studies (6). It can be observed that the field of transportation science technology, materials science multidisciplinary, environmental studies, energy fuels and computer science software are also at the lower end. In the second position is the area of industrial engineering, followed by operational research, etc.

Figure 4 provides a review of the collected articles by publication years. There is an evident increase in the number of articles in the last few years, because environmental protection, waste minimization, renewable energy sources, energy efficiency, and the concept of sustainability in general have become increasingly frequent and significant subjects of research in many studies in the 21st century [27,28]. In addition, it appears that in 2008, there was not a single published article related to the application of MCDM methods in sustainable engineering.

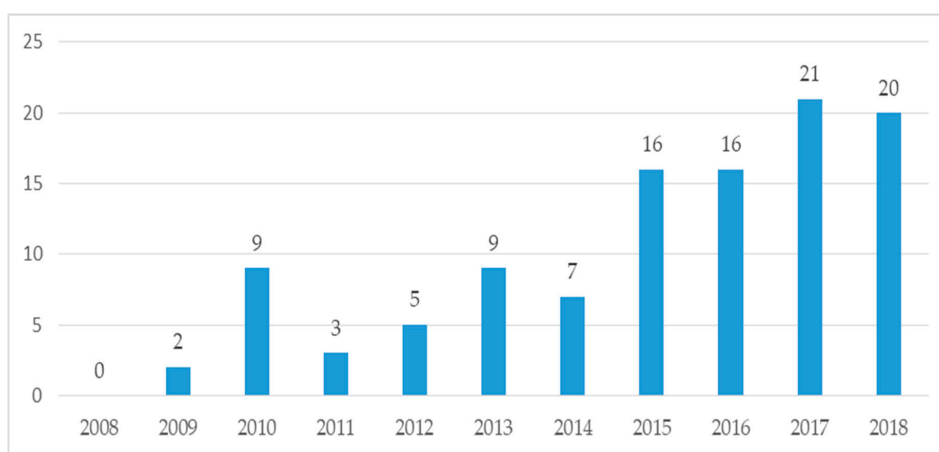


Figure 4. Number of published (collected) articles on MCDM in sustainable engineering by years.

Table 1 provides an overview of the number of articles collected by particular journals.

Table 1. Number of articles by journals.

Title of the Journal	Number of Articles	Percent
<i>Sustainability</i>	14	12.96
<i>Journal of Cleaner Production</i>	10	9.26
<i>Energy</i>	9	8.33
<i>Transport</i>	5	4.63
<i>Journal of Civil Engineering and Management</i>	5	4.63
<i>Applied Energy</i>	5	4.63
<i>International Journal of Production Research</i>	4	3.70
<i>Energies</i>	4	3.70
<i>Construction and Building Materials</i>	4	3.70
<i>Clean Technologies and Environmental Policy</i>	4	3.70
<i>Energy Policy</i>	3	2.78
<i>Transportation Research Part D: Transport and Environment</i>	2	1.85
<i>Renewable and Sustainable Energy Reviews</i>	2	1.85
<i>Land Use Policy</i>	2	1.85
<i>International Journal of Information Technology &amp; Decision Making</i>	2	1.85
<i>Ecological Economics</i>	2	1.85
<i>Water Resources Management</i>	1	0.93
<i>Water</i>	1	0.93
<i>Tunnelling and Underground Space Technology</i>	1	0.93
<i>Transportation Research Part A: Policy and Practice</i>	1	0.93
<i>Transportation Planning and Technology</i>	1	0.93
<i>The International Journal of Advanced Manufacturing Technology</i>	1	0.93
<i>Technological Forecasting and Social Change</i>	1	0.93
<i>Sustainable cities and society</i>	1	0.93
<i>Science of the Total Environment</i>	1	0.93

Table 1. Cont.

Title of the Journal	Number of Articles	Percent
<i>Journal of Manufacturing Systems</i>	1	0.93
<i>Journal of Infrastructure Systems</i>	1	0.93
<i>Journal of Environmental Planning and Management</i>	1	0.93
<i>International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems</i>	1	0.93
<i>International Journal of Sustainable Transportation</i>	1	0.93
<i>International Journal of Production Economics</i>	1	0.93
<i>Expert systems with Applications</i>	1	0.93
<i>European Journal of Operational Research</i>	1	0.93
<i>European Journal of Environmental and Civil Engineering</i>	1	0.93
<i>Environmental Modelling &amp; Software</i>	1	0.93
<i>Economic Research</i>	1	0.93
<i>Decision support systems</i>	1	0.93
<i>Computers &amp; Structures</i>	1	0.93
<i>Computers &amp; Industrial Engineering</i>	1	0.93
<i>Computer-Aided Civil and Infrastructure Engineering</i>	1	0.93
<i>Civil Engineering and Environmental Systems</i>	1	0.93
<i>Cities</i>	1	0.93
<i>Building and environment</i>	1	0.93
<i>Automation in Construction</i>	1	0.93
<i>Applied Sciences</i>	1	0.93
<i>Applied Mathematical Modelling</i>	1	0.93
<i>AICHE Journal</i>	1	0.93

Based on Table 1, it can be concluded that most of the collected articles have been published in the journal *Sustainability* (14 articles), which represents 12.96% of the total number. The *Journal of Cleaner Production* can be ranked second with 10 articles or 9.26% of the total articles. Out of a total of 47 journals, 31 have published one article related to MCDM methods in sustainable engineering. It is important to note that all these journals have impact factors.

#### 4. Detailed Review Results

All the collected articles (108 articles) on the topic of applications of MCDM methods in sustainability engineering have been classified into 5 categories: construction and infrastructure, supply chains, transport and logistics, energy, and other. It is important to mention that some areas of engineering, such as mechanical engineering, have not been taken into consideration because of the lack of articles regarding such topics. For each of the above categories, a detailed analysis of the aim and importance of the application of the individual MCDM method has been provided, and the results of the review have also been given in a table. Figure 5 shows the subdivision into the 5 subcategories with the number of articles in each subcategory.

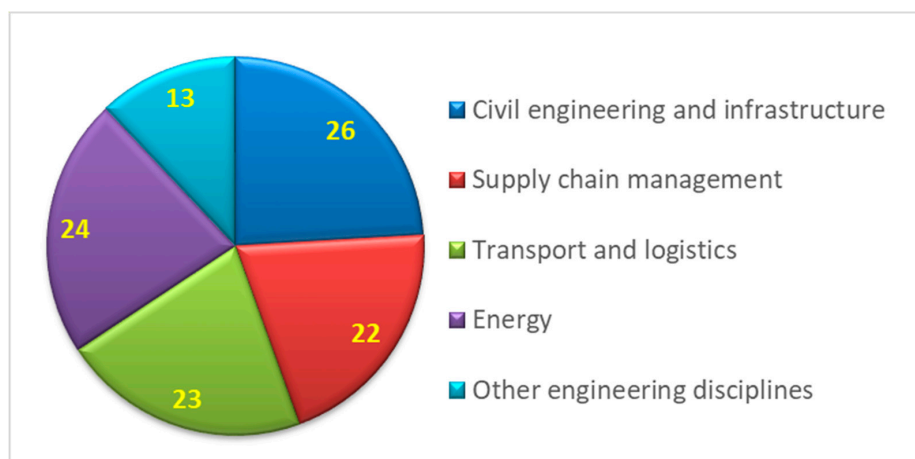


Figure 5. Division of research subjects into five sub-areas.

#### 4.1. Civil Engineering and Infrastructure

In the domain of architecture and construction, increasing attention is being paid to energy efficiency and smart buildings, and therefore, it is necessary to go towards sustainability in the design and construction of facilities and infrastructure. Consequently, it is required to select adequate materials as well. In this section, a detailed analysis of the 26 collected articles in the field of construction and infrastructure is presented.

In their work, Birgani and Yazdandoost [29] provided a framework for a new approach to addressing flood problems in urban areas. In many cases, due to unforeseen and abundant precipitation, the existing drainage network cannot receive large amounts of precipitation. For this reason, for the selection between several alternatives of the sewer system, an integrated approach that implies the sustainability and application of multi-criteria decision-making methods, i.e. the adaptive analytical hierarchy process (AHP), entropy and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was proposed. The framework was applied to the case study for a part of the city of Tehran, Iran. The problem of floods in urban areas due to abundant precipitation was also discussed in [30]. Based on the sustainability criteria, using the AHP method for determining the weights and the Preference Ranking Organization Method for the Enrichment of Evaluations II (PROMETHEE II) for the final ranking of the alternatives, a framework for the selection of an optimum drainage system was proposed. The implementation of the framework was carried out using the example of Buraydah City, Qassim, Saudi Arabia.

Construction is an area that interacts enormously with the natural environment. A large percentage of raw materials are obtained from the earth, and in their treatment and processing and the construction of buildings, certain environmental pollution is inevitable. Lombera and Rojo [31] use the Spanish MIVES (Integrated Value Model for Sustainable Assessment) methodology to define the criteria for the sustainability of industrial buildings and to select the optimum solution with regards to them. Generally speaking, the MIVES methodology combines multi-criteria decision-making and multi-attribute utility theory (MAUT), including a value function concept and weight assignment by the AHP method [32]. A similar study was presented in a study by del Cano et al. [33], in which authors also used the MIVES method but in combination with Monte Carlo simulation in order to assess the sustainability of concrete structures. For the same purpose, de la Fuente et al. [34] applied fuzzy-MIVES. Moreover, de la Fuente et al. [34] also applied the MIVES methodology together with the AHP method in order to reduce the subjective human impact on the selection of sewage pipe material. Akhtar et al. [35] solved the same problem using only the AHP method. The MIVES methodology was also used in a study by de la Fuente et al. [36], assessing the sustainability of alternatives—the types of concrete and their reinforcement for their application in tunnels, depending on environmental, social, and economic criteria. The case study was carried out for the city of Barcelona. Pons and de la Fuente [37] used MIVES to select the most suitable concrete pillars as structural components of buildings, while Pujadas et al. [32] constructed a framework for the evaluation of heterogeneous public investments using this methodology, which is a step towards sustainable urban planning. Different economic, environmental, and social aspects were considered, with five criteria and eight indicators.

The problem of monitoring, repairing, and the returning to function of steel bridge structures is a major challenge for engineers, especially because it is necessary to make key decisions, and wrongly made decisions can be very costly. In order to exclude subjectivity in selecting alternatives in this case, Rashidi et al. [38] presented the decision support system (DSS), in which the simplified AHP (S-AHP) method is used. S-AHP combines the simple multi-attribute rating technique (SMART) and the AHP method. The aim is to help engineers in planning the safety, functionality, and sustainability of steel bridge structures. Jia et al. [39] presented a framework for the selection of bridge construction between the accelerated bridge construction (ABC) method and conventional alternatives, using TOPSIS and fuzzy TOPSIS methods.

In their work, Formisano and Mazzolani [40] presented a new procedure for the selection of the optimum solution for seismic retrofitting of existing reinforced concrete (RC) buildings, as well as

optimum solutions for vertical upgrading of existing masonry constructions. The procedure involved the application of three MCDM methods, namely TOPSIS, elimination and choice expressing reality (ELECTRE), and VIseKriterijumska Optimizacija i Kompromisno Rešenje (VIKOR). In two case studies, these methods showed the same results. In their work, Terracciano et al. [41] selected cold-formed, thin-walled steel structures for vertical reinforcement and energy retrofitting systems of existing masonry constructions. The TOPSIS method for selecting alternatives based on structural, economic, environmental, and energy criteria was used.

Improving traditional buildings into modern ones must comply with technical regulations, energy requirements, comfort requirements, and the preservation of existing architecture. Siozinyte et al. [42] applied the AHP and TOPSIS grey MCDM methods to select the optimum solution for modernizing traditional buildings.

Khoshnava et al. [43] applied MCDM methods to select energy efficient, ecological, recyclable materials for building with respect to the three pillars of sustainability. In order to evaluate 23 criteria in the selection of materials, they used the decision-making trial and evaluation laboratory (DEMATEL) hybrid MCDM method together with the fuzzy analytic network process (FANP). Akadiri et al. [44] used fuzzy extended AHP (FEAHP) in order to select sustainable building materials.

In a study by Ozcan-Deniz and Zhu [45], the analytic network process (ANP) method was used to select the most environmentally friendly method for the construction of a highway, because such construction can have a great impact on the environment. Possible alternatives included different types of materials, operations, and project conditions. Constructing traffic infrastructure can greatly increase the level of safety for participants, but also reduce traffic jams. In their work, Stevic et al. [46] selected the locations for the construction of roundabouts using the rough best–worst method (BWM) and the rough weighted aggregated sum product assessment (WASPAS) approach based on the New Rough Hamy Aggregator.

In their work, Rashid et al. [47] used MCDM methods to select sustainable concrete, which implies a mixture of conventional coarse aggregate and ceramic waste aggregate. The AHP and TOPSIS methods were used to select the best performing concrete in terms of the pressure it can endure and its impact on the environment.

During and even after the construction of facilities, a large amount of natural resources is used, which adversely affects the environment. Most systems for evaluating the sustainability of facilities take into account only the environmental aspect and the environmental impact. However, it is necessary to take into account all three basic principles of sustainability, and thus Raslanas et al. [48], in their work, developed a system for evaluating the sustainability of recreational facilities, using the AHP method. Because so-called “green buildings” are environmentally friendly, attention is increasingly being given to the selection of methods for their construction. Taking into account that this is a very complex task, the application of MCDM methods is indispensable, and in the study by Tsai et al. [49], DEMATEL, ANP, and zero–one goal programming (ZOGP) methods were applied.

The selection of construction project managers plays a key role for the entire construction process. Zavadskas et al. [50] used the MCDM approach to this problem and applied AHP and additive ratio assessment (ARAS) methods. The alternatives were selected based on the criteria of education, experience, and personal abilities and skills.

When building larger facilities, i.e., implementing capital projects, it is very important to select a proper transport route for the procurement of raw materials and materials. Marzouk and Elmestekawi [51] selected the best alternative for the construction of a power plant using the SMART method.

Because the number of vehicles on the roads is increasing every day, the number of parking spaces can hardly follow this trend. Using the MCDM method, Palevicius et al. [52] indicated the worst parking conditions in Vilnius, Lithuania, with all three aspects of sustainability, using simple additive weighting (SAW), TOPSIS, complex proportional assessment (COPRAS), and AHP method. Table 2 summarizes the applied MCDM methods in the sub-area of civil engineering and infrastructure.



**Table 2.** MCDM methods in the sub-area of civil engineering and infrastructure.

A Problem that Is Solved Using the MCDM Method	Applied Methods	Reference
Evaluating urban drainage plans in terms of their sustainability and resilience	Adaptive AHP, Entropy, TOPSIS	[29]
Assessment of sustainability criteria of industrial buildings	AHP, MIVES	[31]
Assessing sustainability adopted by the Spanish Structural Concrete Code (EHE)	AHP, MIVES	[33]
Assessing sustainability adopted by the Spanish Structural Concrete Code (EHE)	Fuzzy MIVES	[34]
Sustainability analysis of different constituent materials for sewerage pipes	AHP, MIVES	[34]
Evaluating and comparing of four typical sewer pipe materials and identifying a sustainable solution	AHP	[35]
Analyzing the sustainability of different concrete and reinforcement configurations for segmental linings	AHP, MIVES	[36]
Evaluating different stormwater drainage options for urban areas of arid regions	AHP, PROMETHEE II	[30]
Developing the decision support system for the asset management of steel bridges	S-AHP (SMART, AHP)	[38]
Estimating the components of the total cost of ABC versus conventional construction methods	TOPSIS, Fuzzy TOPSIS	[39]
Selection of the optimum solution for the seismic retrofitting of existing RC buildings and for the super-elevation of existing masonry constructions	TOPSIS, ELECTRE, VIKOR	[40]
Establishing a cost–benefit approach for the most suitable vertical addition solution	TOPSIS	[41]
Finding the best compromise solution for effective vernacular architecture change	AHP, TOPSIS Grey	[42]
Developing a methodological and systematic approach for building material selection	DEMATEL, FANP	[43]
Selection of sustainable materials for building projects	FEAHP	[44]
Selecting the most feasible highway construction method	ANP	[45]
Location selection for roundabout construction	Rough BWM, Rough WASPAS	[46]
Sustainability assessment tool for analyzing reinforced concrete structural columns of residential buildings	MIVES	[37]
Finding strategies for the prioritization and selection of heterogeneous investments projects	MIVES	[32]
Assessment of properties of a fresh and hardened concrete by incorporating various amounts of ceramic waste.	AHP, TOPSIS	[47]
Creating a recreational building sustainability assessment model	AHP	[48]
Building an effective evaluation model for green building construction methods	DEMATEL, ANP, ZOGP	[49]
Development of the methodology that serves as a decision support aid in assessing project managers	AHP, ARAS	[50]
Selecting the most efficient procurement/delivery system for multiple contracts power plants	SMART	[51]
Indicating the worst passenger car parking conditions in residential areas	SAW, TOPSIS, COPRAS, AHP	[52]

Based on Table 2, it can be concluded that the AHP method is one of the most frequently applied. In addition, it appears that AHP, as well as other methods, can be synthesized with other MCDM methods, but also with other theories such as fuzzy and grey numbers.

#### 4.2. Supply Chain Management

Supply chains present a very complex field involving many participants. The aim of the complete supply chain is to find an optimum from the perspective of all the participants, which is a rather complex task [53–55].

Supply chain management in terms of sustainability in a number of industries is an increasingly frequent topic of research. Therefore, this section provides an analysis of 22 articles on this topic. In the review by Seuring [56], MCDM, and particularly AHP, was listed as one of the quantitative methods for improving the supply chain management. Additionally, based on the review, it can be concluded that the social component of sustainability is paid the least attention. In their review paper, Zimmer et al. [57] analyzed the use of various models to support decision-making on sustainable supplier selection. The models that were stated as the most commonly used were the mathematical/analytic ones, which include MCDM. Significantly, the biggest percentage of application belongs to the AHP method, followed by ANP, etc. The selection of suppliers, according to many authors, is one of the most demanding problems of sustainable supply chain management. Therefore, numerous methods for ranking suppliers have been developed to date, and Fallahpour et al. [58] used the fuzzy modifications of the AHP and TOPSIS methods. The abovementioned authors used the fuzzy preferences programming (FPP) method to reach the relative weights of criteria, while the fuzzy TOPSIS method was used to rank suppliers. In order to validate the methods, a case study was conducted on a real system. The fuzzy approach in combination with the TOPSIS MCDM method was

used by Govindan et al. [59] to assess the sustainable performance of suppliers. In order to perform the selection of suppliers in terms of sustainability and at the same time to take into account the business goals of the company, Dai and Blackhurst [60] presented an integrated approach based on AHP and the quality function deployment (QFD) method with four hierarchical phases. Rezaei et al. [61] presented a new methodology for the selection of suppliers consisting of three phases, where the central phase is the application of the BWM method of multi-criteria decision-making. The methodology presented can be particularly useful for companies that are looking for new markets. For the selection of suppliers, Azadnia et al. [62] proposed an integrated approach that, in addition to the fuzzy AHP method (FAHP), is based on multi-objective mathematical programming, as well as on rule-based weighted fuzzy method. According to Su et al. [63], the assessment of sustainable supply chain management and the selection of suppliers are performed using grey theory in combination with the DEMATEL method. Luthra et al. [64] presented an integrated approach to selecting suppliers consisting of a combination of AHP and VIKOR methods based on 22 criteria for all three aspects of sustainability. Because thermal power plants are the main source of electricity in China, it is necessary to make a selection of sustainable suppliers of raw materials in order to achieve sustainable development of the company. According to Zhao and Guo [65], an integrated approach is based on the fuzzy entropy–TOPSIS method. MCDM methods can be used to assess the degree of organizational sustainability of a company, as presented in [66]. Hsu et al. [67] presented a hybrid approach based on several MCDM methods in order to select suppliers in terms of carbon emissions. The observed framework for the selection of suppliers has been applied to the case of a hotel in Taiwan. A similar study was carried out by Kuo et al. [68] on the example of electronic industry. The evaluation of the supplier performance in the field of electronic industry in order to implement green supply chains is a topic of research in the study by Chatterjee et al. [17]. The authors used rough DEMATEL–ANP (R'AMATEL) in combination with rough multi-attribute ideal real comparative analysis (R'MAIRCA) method. Liu et al. [69] selected the suppliers of fresh products using the BWM and multi-objective optimization on the basis of the ratio analysis (MULTIMOORA) method.

Because innovation plays a very important role in sustainability, Gupta and Sarkis [70] presented a framework for ranking and selecting the criteria for sustainable innovations in supply chain management. This framework is based on the BWM method, and its applicability and efficiency were tested on several manufacturing companies in India. In their work, Validi et al. [71] dealt with the sustainability of the food supply chain. The TOPSIS method was used for the purpose of ranking the traffic routes, taking into account CO<sub>2</sub> emissions and total transport costs.

A quantitative assessment of the performance of a sustainable supply chain was presented in Erol et al. [72] with regard to all three aspects of sustainability. Due to the presence of indeterminacy, it is very difficult to estimate certain criteria, which is why the authors used fuzzy techniques in addition to MCDM. More precisely, the fuzzy entropy and fuzzy MAUT methods were used. Das and Shaw [73] proposed a methodology based on the AHP and Fuzzy TOPSIS methods for selecting a sustainable supply chain, taking into account carbon emissions and various social factors. In the study by Entezaminia et al. [74], the AHP method was used to evaluate products in the supply chain according to environmental criteria such as recyclability, biodegradability, energy consumption, and product risk.

The application of information and communication technologies in supply chains can bring numerous benefits to an organization, and among the most important is sustainability. Luthra et al. [75] proposed the application of delphi and fuzzy DEMATEL methods for identifying and evaluating the guidelines for the application of these technologies in sustainable initiatives in supply chains. In Padhi et al. [76], a framework that identifies sustainable processes in supply chains for individual industries in India was presented. The ranking of industry branches was carried out using six fuzzy MCDM methods. Table 3 provides a summary of the applied MCDM methods for the sub-area of supply chain management. The decision-making process requires the prior definition and fulfillment of certain factors, especially when it comes to complex areas, such as supply chain management [77].

**Table 3.** MCDM methods in the sub-area of supply chain management.

A Problem that Is Solved Using the MCDM Method	Applied Methods	Reference
Sustainable supplier selection through a questionnaire-based survey	FPP, Fuzzy TOPSIS	[58]
Investigating sustainable supply chains in manufacturing companies	BWM	[70]
Provision of optimized distribution routes based on carbon output and costs for the demand side of a dairy supply chain producing milk products	TOPSIS	[71]
Development of the sustainability-focused supplier assessment methodology that will be able to capture the ‘voice of customer’ at multiple stages in the supply chain and translate the needs of the end customer back through the supply chain	AHP-QFD	[60]
Proposing an innovative three-phase supplier selection methodology	BWM	[61]
Integrated approach of rule-based weighted fuzzy method, fuzzy analytical hierarchy process, and multi-objective mathematical programming for sustainable supplier selection	FAHP	[62]
Identifying and analyzing criteria and alternatives in incomplete information	Grey-DEMATEL	[63]
Evaluating the sustainable supplier selection	AHP, VIKOR	[64]
Selecting the proper green supplier of thermal power equipment	Fuzzy Entropy-TOPSIS	[65]
Classification of the degree of sustainability of organizations that work in providing supplies to the oil and gas industry	ELECTRE TRI	[66]
Evaluating the carbon and energy management performance of suppliers by using multiple-criteria decision-making	Fuzzy Delphi, DEMATEL, DEMATEL-ANP (DANP), VIKOR	[67]
Novel hybrid multiple-criteria decision-making method for evaluating green suppliers in an electronics company	DANP, DEMATEL, VIKOR	[68]
Evaluating the performance of suppliers in the electronics industry	R’AMATEL, R’MAIRCA	[17]
Novel two-stage fuzzy integrated MCDM method for the selection of suitable suppliers	BWM, MULTIMOORA	[69]
Evaluating the sustainability performance of a supplier	Fuzzy TOPSIS	[59]
Evaluating the sustainability performance of a supply chain	Fuzzy MAUT	[72]
Proposing an uncertain supply chain network design (SCND) model by considering various carbon emissions and social factors	AHP, Fuzzy TOPSIS	[73]
Development of a new comprehensive multi-objective aggregate production planning model in a green supply chain considering a reverse logistic network to be used in many industries	AHP	[74]
Identification and evaluation of key drivers relevant to information and communication technologies for sustainability initiatives in a supply chain	Delphi, Fuzzy DEMATEL	[75]
Identifying the significance of various sustainable supply chain processes on firm performance	Fuzzy TOPSIS, Fuzzy ELECTRE, Fuzzy AHP, Fuzzy Multiplicative AHP, Fuzzy SMART, Fuzzy VIKOR	[76]

In the sub-area of supply chain management, based on the table, it is apparent that most authors apply the AHP and TOPSIS methods. As mentioned in the previous section, their applications can be combined with other methods.

#### 4.3. Transport and Logistics

As in other engineering disciplines, MCDM methods are also applied in the field of transport and logistics. This section provides a review of 23 articles dealing with the above issues. In Mardani et al. [78], a review of the methods used to solve problems in transport systems was provided. The articles were systematically categorized into 10 groups, one of which was sustainability. The authors stated that according to the number of articles published on MCDM in combination with sustainability, this category could be ranked sixth.

In Jeon et al. [79], the application of MCDM methods in selecting sustainable transport plans based on the sustainability index is examined. The weighted sum model (WSM) method was used. In their work, Cadena and Magro [80] presented a new methodology for assigning weight coefficients to sustainability criteria in transport projects. In order to solve the problem of inaccuracy and subjectivity, the REMBRANDT and Delphi methods were applied.

Because the traffic system is the lifeblood of every country and one of the basis for its economic development, Baric et al. [81] proposed the application of the AHP method in selecting the best road section design in urban conditions. The tested model on the real system showed reliable results. One of the disadvantages of the AHP method is that it requires a large number of inputs. In order to solve this problem, Inti and Tandon [82] presented a modified AHP method with the characteristics of the additive transitivity of fuzzy relations. The model was tested in the selection of contractors for the construction of transport infrastructure.

In order to improve transport sustainability, one of the solutions is the application of various alternative fuels and vehicle drives. Mitropoulos and Prevedouros [83], in this way, assessed the

characteristics of vehicles using the sustainability index. The identified indicators were classified into five categories of sustainability—environment, technology, energy, economy, and users—followed by the application of the WSM method for their aggregation. Additionally, Mohamadabadi et al. [84] selected the type of fuel for vehicles based on three basic aspects of sustainability. The PROMETHEE method was used for the ranking of alternatives based on five criteria. Intermodal transport can greatly improve the sustainability of the transport system. It is necessary to select the optimum location of terminals in terms of different requirements of different participants in a transport process. Therefore, Zecevic et al. [85] proposed a new hybrid MCDM model for the location selection. Sustainable transport systems have become necessary nowadays, primarily in large cities due to various adverse environmental impacts. An approach to selecting the best alternative of transport systems based on 24 criteria, classified into three categories, was defined in a study by Awasthi et al. [86]. The approach consists of three steps, and the TOPSIS method is applied in combination with fuzzy theory in order to evaluate the criteria and the selection of an alternative. Castillo and Pitfield [87] proposed the evaluative and logical approach to sustainable transport indicator compilation (ELASTIC) framework for selecting the sustainability indicators of the transport system using the AHP and SAW methods. Although, in recent years, improvements have been evidently made to methods of transport planning, according to Lopez and Monzon [88], it is necessary to apply a multidisciplinary approach based on Geographic Information System (GIS) in order to increase the level of sustainability in transport. In addition, it is necessary to integrate multi-criteria decision-making methods within the proposed approach. In his work, Simongati [89] presented a model for the selection of FREIGHT INTEGRATOR with MCDM methods and sustainability indicators. The aforementioned term represents a provider of door-to-door transport services, using different modes of transport in an efficient and sustainable way. The selection of alternatives is based on SAW and PROMETHEE methods. The assessment of transport system sustainability of some European countries based on selected economic, environmental, and social indicators is presented in the work of Bojkovic et al. [90]. The ELECTRE I method has been used together with its modification based on the absolute significance threshold (AST). A framework for the selection of sustainable transport projects in urban areas of developing countries was proposed in the work of Jones et al. [91].

The selection of alternatives is based on the localized sustainability score index using the AHP method. In addition to the AHP method, in order to assess the sustainability of various transport solutions, such as mode sharing, multimodal transport, and intelligent transport systems, Awasthi and Chauhan [92] used the Dempster–Shafer theory in the proposed hybrid approach. While the AHP method serves primarily to rank the criteria based on the weights, the Dempster–Shafer theory allows the synthesis of multiple sources of information. Dimić et al. [93] developed a model for strategic transport management based on Strengths, Weakness, Opportunities, Treats (SWOT) analysis, fuzzy Delphi, and DEMATEL–ANP methods.

Sustainability is a very important concept in logistics, and reverse logistics as one of its subgroups can greatly improve efficiency and the environmental aspect of business. Wang et al. [94] presented a method for identifying the collection mode for used components. A hybrid approach based on AHP and entropy weight (AHP–EW) method was used to estimate the weights of particular criteria, while the multi-attributive border approximation area comparison (MABAC) method was used to rank the alternatives. Different initiatives for city logistics (e.g., the proper location of distribution centers) can significantly contribute to raising the level of sustainability in the city. That is precisely the subject of research in Awasthi and Chauhan [95]. The MCDM methods used in the work were AHP and Fuzzy TOPSIS. Mavi et al. [96], using the fuzzy step-wise weight assessment ratio analysis (SWARA) and fuzzy MOORA methods, selected a third-party provider of reverse logistics service in the plastics industry.

One of the most current problems in logistics and supply chains is the selection of the location of the logistics center in terms of sustainability. Rao et al. [97] used the fuzzy multi-attribute group decision-making (MAGDM) approach to address the problem. Turskis and Zavadskas [98] approached

the problem of selecting the location of the logistics center with the fuzzy ARAS (ARAS-F) method, while Pamucar et al. [99] used the DEMATEL–MAIRCA method for the same purpose.

Logistics are closely linked to the processing industry. Therefore, it is necessary to identify the factors that influence their interaction. For this purpose, Jiang et al. [100] applied the grey DEMATEL-based ANP method (DANP). Table 4 provides a summary of the applied MCDM methods for the sub-area of transport and logistics.

**Table 4.** MCDM methods in the sub-area of transport and logistics.

A Problem that Is Solved Using the MCDM Method	Applied Methods	Reference
Selecting sustainable transport plans based on the sustainability index	WSM	[79]
Assigning weight coefficients to the sustainability criteria in transport projects	REMBRANDT, Delphi	[80]
Evaluating road section design in an urban environment	AHP	[81]
Selection of the contractor for the construction of transport infrastructure	AHP, FAHP	[82]
Assessment of transportation vehicle characteristics.	WSM	[83]
Ranking different renewable- and non-renewable-fuel-based vehicles	PROMETHEE	[84]
Selection of the intermodal transport terminal location	Fuzzy Delphi, Fuzzy Delphi ANP, Fuzzy Delphi VIKOR	[85]
Evaluation and selection of sustainable transportation systems under uncertain (fuzzy) environments	Fuzzy TOPSIS	[86]
Identifying and selecting a small subset of sustainable transport indicators	AHP, SAW	[87]
Assessment model for transport infrastructure plans	REMBRANDT	[88]
Valuation and comparison model adjusted to the decision-making tasks of the freight integrator	SAW, PROMETHEE	[89]
Evaluation of transport–sustainability performance in some European countries.	ELECTRE I, Modified ELECTRE I	[90]
Screening urban transport projects in developing countries to reflect locally derived sustainability criteria	AHP	[91]
Evaluating the impact of environmentally friendly transport measures on city sustainability	AHP	[92]
Developing the model for strategic transport management	Fuzzy Delphi, DEMATEL–ANP	[93]
Identifying the best collection mode for used components	AHP–EW, MABAC	[94]
Hybrid approach for evaluating city logistics initiatives	AHP, Fuzzy TOPSIS	[95]
Evaluation of third-party reverse logistic provider considering sustainability and risk factors	Fuzzy SWARA, Fuzzy MOORA	[96]
Location selection of a city logistics center from a sustainability perspective	Fuzzy MAGDM	[97]
Selecting the most suitable site for a logistics center among a set of alternatives	Fuzzy ARAS, AHP	[98]
Sustainable selection of a location for the development of a multimodal logistics center	DEMATEL–MAIRCA	[99]
Identifying interactions between manufacturing and logistics industries	Grey DANP	[100]

Table 4 indicates which MCDM methods are used in the field of transport and logistics. In this case, the AHP method is also the most applied MCDM method.

#### 4.4. Energy

This section provides a review of the application of MCDM methods in the field of energy. 24 articles were analyzed, and the results have been given in textual and tabular formats. Developing renewable energy sources is a growing trend in the world on a day-to-day basis, especially when it comes to solar energy. The selection of an optimum location for the installation of photovoltaic systems is of great importance, because it can reduce the cost of the project and also ensure the maximum production of electricity. It sufficiently proves the high sustainability of such sources. Al Garni and Awasthi [101] selected the location of solar systems based on MCDM methods and GIS. The AHP method was used to evaluate the weights of feasibility criteria that directly affect the performance of the solar system. A similar study was also presented in the work of Diaz-Cuevas et al. [102], where spatial information instead of GIS was provided with the PostgreSQL-PostGIS database, which was based on Structured Query Language (SQL). The AHP method is used to determine the weights of the criteria. GIS is also necessary in selecting the location of wind farms that are also a very significant alternative source of energy. According to Sanchez-Lozano et al. [103], fuzzy MCDM methods are used to determine the weights of the criteria and the selection of an optimum alternative in solving this problem.

The selection of the optimum type of renewable energy sources using MCDM methods based on the hesitant fuzzy linguistic (HFL) term set was presented in the work of Buyukozkan and

Karabulut [104]. The proposed methodology was tested using the example of the selection between several alternatives in the territory of Turkey. A similar study was presented in the work of Wu et al. [105], where a case study for China was conducted. Based on the AHP and TOPSIS methods, it was found that solar systems are the best solution. Yazdani et al. [18] presented a new hybrid approach for the selection of renewable energy technology, using DEMATEL, ANP, COPRAS, and WASPAS methods. Zhang et al. [106] used the improved MCDM method based on fuzzy measure and integral to select the “pure” form of energy between several alternatives. In their research, Troldborg et al. [107] dealt with the same issue and applied the PROMETHEE method. In their work, Klein and Whalley [108] selected between 13 renewable and non-renewable energy sources based on eight criteria. According to Tsoutsos et al. [109], the selection of an optimum renewable energy source in Crete, Greece was carried out with the PROMETHEE I and PROMETHEE II methods. Countries rich in fossil fuels are forced to seek alternative energy sources in order to reduce CO<sub>2</sub> emissions. Pamucar et al. [110] applied the linguistic neutrosophic numbers pairwise-combinative distance-based assessment (LNN PW-CODAS) to select the optimum energy production technology in Libya. In Pamucar et al. [111], a model for the selection of a location for the construction of wind farms based on GIS in combination with two MCDM methods, BWM and MAIRCA, was presented.

Generated electricity planning is of great importance for the electric power system of a country. Mirjat et al. [112] proposed the application of the AHP method for assessing the sustainability of four types of energy models. A case study was carried out for Pakistan. The European Union is developing its energy plans, and MCDM methods find their application in the ranking of plans. According to Balezentis and Streimikiene [113], for this purpose, WASPAS, ARAS, and TOPSIS methods should be used. The selection of the best energy project between several alternatives, using MCDM methods, was considered in the work of Buyukozkan and Karabulut [104].

Because electric vehicles are becoming increasingly common on roads in the world, it is necessary to provide stations for charging them at optimum locations. Zhao and Li [114] presented a methodology based on MCDM methods. The criteria of the expanded concept of sustainability, which in addition to the traditional three aspects also includes technology, were selected based on fuzzy delphi, while the selection of the best alternative was performed using the fuzzy grey relation analysis (GRA)-VIKOR method. Guo and Zhao [115] dealt with the same issues. In order to eliminate subjectivity when selecting the location of charging stations, in addition to the basic criteria of sustainability, 11 sub-criteria were defined, in which the weights were determined on the basis of literature research, opinion of experts, and feasibility studies. The specific location selection was completed using the fuzzy TOPSIS method.

Nuclear energy implies low values of CO<sub>2</sub> emissions into the atmosphere, which is necessary in terms of the concept of sustainability. Gao et al. [116] presented a framework for selecting the best option for a nuclear fuel cycle at a plant. In order to determine the weights of the criteria, fuzzy AHP and criteria importance through intercriteria correlation (CRITIC) were used, and the selection of alternatives was performed using the TOPSIS and PROMETHEE II methods. The selection of the optimum energy option for a thermal power plant was the subject of research in the work of Skobalj et al. [117]. The selection between seven alternatives, including revitalization and additional production by alternative energy sources, was performed on the basis of the sustainability index, which was determined by the analysis and synthesis of parameters under information deficiency (ASPID) method. The application of MCDM methods in order to select a sustainable energy solution has not been omitted even when it comes to hydroelectric power plants in the work of Vucijak et al. [118]. According to Streimikiene et al. [119], the selection between several alternative technologies for the sustainable production of electricity can be performed with the MULTIMOORA and TOPSIS methods (Barros et al. [120]). Maxim [121] also deals with the same issues in his work. He used a modified SWING method for ranking technologies. Energy is the key to the economic and social development of a particular area. In their work, Jovanovic et al. [122] proposed a new approach based on the predictions of different energy scenarios in urban areas and the application of MCDM methods for

evaluating them. Biomass implies a multitude of resources, such as plant waste, animal waste, food waste, etc. Ioannou et al. [123] used MCDM methods in their research to select the location of a biomass power plant. Table 5 provides a summary of the applied MCDM methods for the sub-area of energy.

**Table 5.** MCDM methods in the sub-area of energy.

A Problem that Is Solved Using the MCDM Method	Applied Methods	Reference
Evaluating and selecting the best location for utility-scale solar photovoltaic (PV) projects	AHP	[101]
Identifying optimum locations for solar plants	AHP	[102]
Approach for the evaluation of available sites to implant onshore wind farms	FAHP, Fuzzy TOPSIS	[103]
Numerical decision support method for identifying the most suitable renewable energy source	HFL-AHP, HFL-COPRAS	[104]
Evaluating the renewable energy sources and selecting the most appropriate one from the perspective of public investors	AHP, TOPSIS	[105]
Multi-criteria assessment of renewable energy systems	DEMATEL, ANP, COPRAS, WASPAS	[18]
Multi-criteria analysis for a national-scale sustainability assessment and ranking of renewable energy technologies in Scotland	PROMETHEE	[107]
Comparing a wide range of conventional and alternative electricity generation technologies across several criteria	Weighted sum method	[108]
Assessing the performance of different renewable energy source alternatives	PROMETHEE I, PROMETHEE II	[109]
Selection of power-generation technology using a linguistic neutrosophic CODAS Method	LNN PW-CODAS	[110]
Location selection for wind farms	Rough BWM, Rough MAIRCA	[111]
Sustainability assessment of energy modeling results for long-term electricity planning	AHP	[112]
Ranking energy development scenarios for the EU by employing MCDM techniques.	WASPAS, ARAS, TOPSIS	[113]
Novel method with a sustainability perspective for selecting energy projects	AHP, VIKOR	[104]
Multi-criteria decision-making framework to address the issue of electric vehicle charging stations siting	Fuzzy Delphi, GRA-VIKOR	[114]
Employing various MCDM techniques to select the optimum electric vehicle charging station	Fuzzy TOPSIS	[115]
Evaluation of decision-making for China's future nuclear fuel cycle options from a sustainability perspective	AHP, CRITIC, TOPSIS, PROMETHEE II	[116]
Estimating the quality of the considered thermal power plant "Kolubara"-A Unit No. 2	ASPID	[117]
Assessing applicability potentials of a specific multi-criteria decision support method to sustainable hydropower design	VIKOR	[118]
Multi-criteria decision support framework for choosing the most sustainable electricity production technologies	MULTIMOORA, TOPSIS	[117]
Comprehensively ranking a large number of electricity-generation technologies	SWING	[121]
Measurement the sustainability of an urban energy system	ASPID	[122]

As can be seen from Table 5, in the field of energy, MCDM methods are mainly used to solve problems of selecting the optimum type of renewable and non-renewable energy sources. In most cases, the AHP method is applied.

#### 4.5. Other Engineering Disciplines

In addition to four previously analyzed areas of the application of MCDM methods in sustainable engineering, uncategorized works are discussed in this section. This includes 13 articles from various fields of engineering, and their detailed analysis is given below. Creating a sustainable environmental management system is of great importance for reducing environmental pollution. Khalili and Duecker [124] created a system for selecting the best solution using the ELECTRE III method. In their research, Egilmez et al. [125] applied the intuitionistic fuzzy decision making (IFDM) approach, which is the integration of fuzzy logic and MCDM theory, in order to rank and select a city (in the US and Canada) with the highest degree of environmental sustainability. According to Alwaer and Clements-Croome [126], the model for the assessment of smart household sustainability includes the application of the AHP method. The level of sustainability of temporary housing units for the accommodation of persons after natural disasters can be assessed using the MIVES method according to Hosseini et al. [127]. A review of the MCDM methods used in assessing the sustainability of the system is shown in Diaz-Balteiro et al. [128], and it can be concluded that the AHP method takes the leading position in a number of applications. In Rosen et al. [129], a new method for assessing the sustainability of renewed contaminated surfaces was developed. The proposed sustainable choice of remediation (SCORE) method is a tool for selecting between several alternatives for possible

land remediation. Ren et al. [130] developed a generic framework for the selection of sustainable technology for the treatment of sewage sludge in urban areas, using three MCDM methods: sum weighted method (SWM), digraph model, and TOPSIS. Using a MCDM method, Ren et al. [131] selected industrial systems from the aspect of sustainability. Because fossil fuel reserves are limited and atmospheric pollution is increasing, it is necessary to stimulate bio-diesel consumption. Sivaraja and Sakthivel [132] applied FAHP–TOPSIS, FAHP–VIKOR, and FAHP–ELECTRE to select the best blend of the specified fuel. In their research, Zavadskas et al. [133] selected the site for the incineration of waste, taking into account all the sustainability criteria using the new extension of the WASPAS method, the WASPAS single-valued neutrosophic Set (WASPAS–SVNS). It is known that the global population is growing each year, and it is necessary to provide an adequate amount of food. For this reason, Debnath et al. [134] selected the project portfolio for agricultural production by applying grey DEMATEL and MABAC methods. Huang et al. [135] presented a hybrid MCDM approach for the selection of materials for the production of particulate matter sensors. In their paper, Zhang et al. [136] dealt with the problem of evaluating the supply of rare minerals. For this purpose, fuzzy AHP and PROMETHEE methods were used. The application of the MCDM method within the decision support system can be of great importance to assist in emergency situations such as forest fires. The development of such a system is described in Ioannou et al. [137]. Table 6 provides a summary of the applied MCDM methods for the sub-area of other engineering disciplines.

**Table 6.** MCDM methods in the sub-area of other engineering disciplines.

A Problem that Is Solved Using the MCDM Method	Applied Methods	Reference
Proposing the design of the sustainable environmental management system	ELECTRE III	[124]
Sustainability performance assessment of 27 US and Canada metropolises	IFDM	[125]
Measuring the level of sustainability for sustainable intelligent buildings	AHP	[126]
Assessing the sustainability of post-disaster temporary housing units Technologies	MIVES	[127]
Assessing the sustainability of contaminated land remediation	SCORE	[128]
Sustainability assessment of the technologies for the treatment of urban sewage sludge	SWM, Digraph model, TOPSIS	[130]
Sustainability prioritization of industrial systems	Fuzzy AHP, Fuzzy ANP, PROMETHEE	[131]
Selection of optimum biodiesel blend in internal combustion engines	Fuzzy AHP–TOPSIS, Fuzzy AHP–VIKOR, Fuzzy AHP–ELECTRE	[132]
Sustainable assessment of alternative sites for the construction of a waste incineration plant	WASPAS–SVNS	[133]
Strategic project portfolio selection of agricultural byproducts	DEMATEL, MABAC	[134]
Evaluation and selection of materials for particulate matter sensors	DEMATEL, VIKOR	[135]
Enrichment evaluation to assess the security performance for China’s several critical minerals	Fuzzy AHP, PROMETHEE	[136]

The application of MCDM methods in other engineering disciplines is reduced to the environmental aspect of sustainability. Problems such as environmental pollution, soil contamination, air pollution, and the selection of the best fossil fuel are just a few that are solved by applying MCDM methods, of which AHP is most frequently used, according to Table 6.

## 5. Conclusions

In this paper, representative studies that include the application of multi-criteria decision-making models in the field of sustainability engineering have been presented. A review of about 108 studies related to the application of multi-criteria decision-making methods in the field of civil engineering and infrastructure, supply chain management, transport and logistics, energy, and other engineering disciplines provides interesting conclusions that can be useful for researchers who deal with the application of MCDM models in different engineering areas.

This literature review has shown that sustainable engineering is an area that is quite suitable for the use of MCDM. It is not surprising that the number of publications related to environmental protection, waste minimization, renewable energy sources, energy efficiency, and the concept of



sustainability have tripled in the last decade. Switching to the concept of renewable energy has influenced researchers to try to exploit and improve available knowledge in decision-making.

Most of the methods used in sustainable engineering are based on traditional approaches with a noticeable trend of applying the theory of uncertainty, such as fuzzy, grey, rough, and neutrosophic theory. It can be said that the selection between existing MCDM methods is also a multi-criteria problem. Each of the methods has its advantages and disadvantages, and it is not possible to claim that any method is more suitable than others. The same applies to the selection of uncertainty theory for a considered multi-criteria problem. The choice of the method depends largely on the preferences of decision-makers and analysts. It is therefore important to consider the convenience, validity, and accessibility of methods for a problem considered. Mukhametzhanov and Pamucar [138] emphasize that the choice of method can significantly influence the decision-making process. They also emphasized that several methods should be used in a decision-making process in order to obtain a sustainable and high-quality decision. This is also an explanation of the observed trend of using a large number of methods in the literature. By analyzing the prior research presented in this review, it can be concluded that in the field of civil engineering and infrastructure, MCDM methods in most cases help to solve the problems that arise when selecting methods of building structures and roads. These problems attach great importance as objects require reinforcements in the case of seismic activities, and also, in the trend of the construction of green, ecological houses. In the sub-section of civil engineering and infrastructure there are 6 papers dealing with this topic, which amounts to 23.07% of the total. The most common method is AHP, which is used in 13 papers or 50% of the total. MCDM methods are most commonly used in this field in combination with fuzzy theory. A total of three papers (11.54%) have been analyzed that integrate fuzzy principles along with other MCDM methods. In the field of supply chain management, the selection of the supplier is the most common problem that is solved using the MCDM method. It is necessary to select the most modern supplier in terms of sustainability, but also from the point of view of the customer or user of the service. Out of the total number of analyzed papers in this field, 11 or 50% deal with this problem, and the most commonly used methods are TOPSIS and AHP with 6 papers or 27.27% each. The combination of the MCDM method with the most common fuzzy theory is represented in 8 papers or in 36.36% of the total. The analysis has shown that the selection of the location of terminals and logistics centers from the aspect of sustainability is the most important problem that is solved by MCDM methods in the field of transport and logistics. Of the total number of articles in this field, 4 or 17.39% include a subject of research that is related to the choice of location. In this case, the AHP method is the most commonly applied. More precisely, it was applied in 7 papers or 30.43% of the total number. In this field, it is often a combination of MCDM methods with fuzzy theory. It is the same number as in the previous sub-area: 8 papers or 34.78% of the total. MCDM methods in the field of energy are used to a large extent for the choice of a certain type or mode of energy production. Alternatives most often include renewable but also conventional sources of energy. In this area there are 9 such papers, or 37.50% of the total, while the number of papers in which the AHP method is applied is 8 or 33.33%. Fuzzy theory is most commonly combined with MCDM methods in this field and is present in 3 papers or 12.5% of the total. When it comes to other engineering disciplines, the application of the MCDM method is mainly to assess the sustainability of buildings, land, waste treatment technologies, and cities. Within the mentioned area, 6 papers dealing with this topic were analyzed, or 46.15% of the total number. The AHP method is also the most commonly applied in this field and is applied in 4 papers or 30.77% of the total. In addition, the application of fuzzy theory is used, along with the other methods. In this sub-area, fuzzy principles were applied in 3 papers or in 23.08% of the total.

Based on the analysis of papers and problems that are solved using the MCDM method, it can be concluded that the AHP method has the broadest application when it comes to sustainable engineering. Generally, the total number of papers involving the use of the AHP method was 38 or 35.19% of the total. Among the other theories that integrate with MCDM, fuzzy theory stands out in cases of uncertainty and imprecision with a total of 25 papers or 23.15% of the total.

It can be concluded that there has been a significant increase in the application of MCDM models in all engineering areas in the last decade. The complexity of synchronous problems forces researchers to search for more flexible and simpler methods. Therefore, it is expected that there will be a further increase in works that consider the application of existing MCDM models and the development of new models for multi-criteria decision-making. It is also expected that the validation of results using multiple methods, the development of interactive systems to support the decision-making, and the improvement of fuzzy, grey, rough, and neutrosophic theory for the consideration of uncertainty will encourage researchers in the field of sustainable engineering to expand further research towards the creation of hybrid models, upgrading the existing MCDM models.

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