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Review

An Overview of Multi-Criteria Decision-Making Methods in Dealing with Sustainable Energy Development Issues

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Abstract: The measurement of sustainability is actively used today as one of the main preventative instruments in order to reduce the decline of the environment. Sustainable decision-making in solving energy issues can be supported and contradictory effects can be evaluated by scientific achievements of multi-criteria decision-making (MCDM) techniques. The main goal of this paper is to overview the application of decision-making methods in dealing with sustainable energy development issues. In this study, 105 published papers from the Web of Science Core Collection (WSCC) database are selected and reviewed, from 2004 to 2017, related to energy sustainability issues and MCDM methods. All the selected papers were categorized into 9 fields by the application area and into 10 fields by the used method. After the categorization of the scientific articles and detailed analysis, SWOT analysis of MCDM approaches in dealing with sustainable energy development issues is provided. The widespread application and use of MCDM methods confirm that MCDM methods can help decision-makers in solving energy sustainability problems and are highly popular and used in practice.

Keywords: sustainable energy; sustainability assessment; multi-criteria decision-making; MCDM; MCDM review; renewable energy

1. Introduction

More than half of global greenhouse gas (GHG) emissions come from energy production and use, which puts the energy sector at the core of efforts to fight climate change [1]. The moving to a cleaner, more efficient energy system must be an essential policy goal of each country or region energy system. Sustainable energy development is one of the main subjects of discussion in governmental, non-governmental and scientific level, being a major focus of national and international economic, environmental and social agendas. The sustainable energy sector has a balance of energy production and consumption and has a considerably less negative impact on the environment and gives the opportunity for a country to increase the productivity of its social and economic activities [1].

Sustainable development is defined as a dynamic pattern of social, economic, technological and environmental indicators and policies which allow the countries to move toward a better wellbeing, i.e., there is not a final fix sustainable state [2]. Each generation will have more knowledge and innovative technologies; they will also perceive the different needs in sustainable development goals in their own way based on their cultures and values since there is no specific sustainability status. Therefore, issues and goals related to sustainable development must be regularly updated [3]. Authors analyzing sustainability issues argue that sustainable development is about achieving a balance between each individual system over time that requires inter-disciplinary actions in decision-making. Nowadays sustainable development has become one of the main criteria in decision-making at local, national and regional level. The energy sector plays the main role in all of the aspects of sustainable development and, now, energy issues have been a fundamental component of the conceptual and strategic discussions on sustainable development worldwide.

Since the 1980s, the planning of energy system activities has become an important tool in decision-making and in aiming to reduce the prices of increasing energy resources and the problems of resource scarcity. The rising concern for the environment and growing negative environmental impact of energy resource usage has added environmental aspects to the tasks of energy planning and decision-making. However, policymakers, scientists, companies, public figures, and other organizations are finding it increasingly difficult to combine contradicting goals and to find a compromise. In the energy sector, the conflicting goals are particularly evident. Mathematical models that are reasonably and adequately chosen make it possible to combine contradictory questions reliably and in accordance with pre-selected criteria. The measurement of sustainability is actively used today as one of the main preventative instruments in order to reduce the decline of the environment. Multi-criteria decision-making (MCDM) support instruments are particularly useful when facing the problem of determining or expressing preferences and when decisions have to be made based on several contradictory indicators of competing for importance. Meyar-Naimi, Vaez-Zadeh [2] introduced an improved Driving Force–State–Response (DSR-HNS) policy-making framework, which could be modified to present interrelations between sustainability dimensions and decision-making in the energy sector (Figure 1):

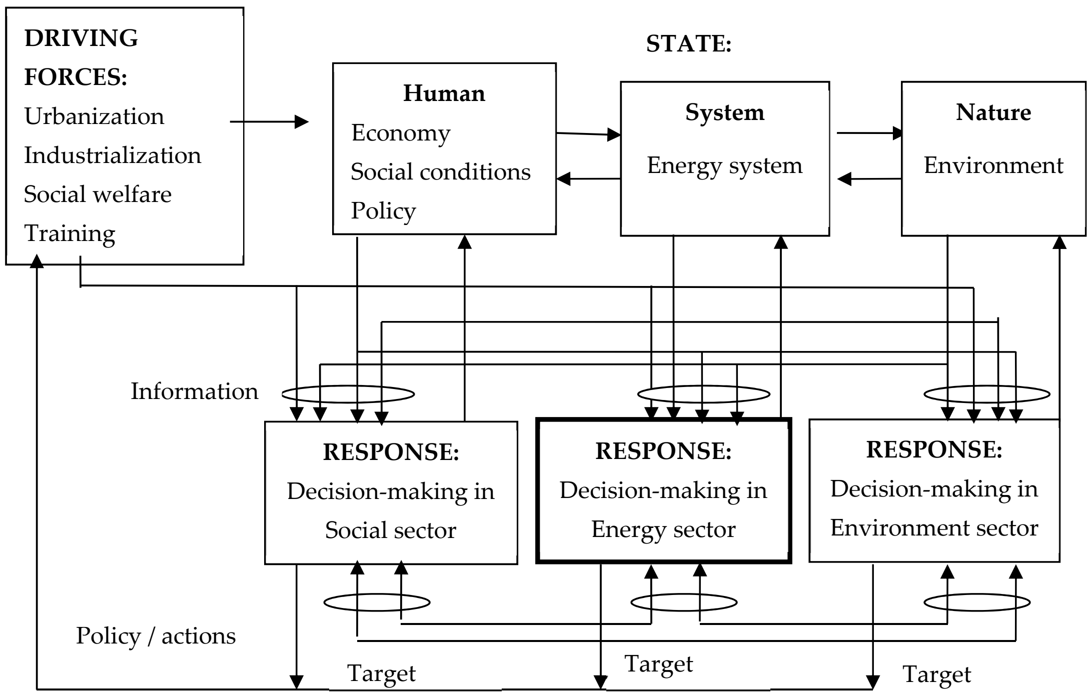

Figure 1. The interrelations between sustainability dimensions and decision-making in the energy sector (prepared according to Meyar-Naimi, Vaez-Zadeh [2]).

As can be seen in Figure 1, the decision-making and selection of appropriate methods for achieving the objectives are significant. MCDM methods help to reconcile contradictory questions, choose the best solution based on the selected criteria (target values), and combine different policies with each other. Questions that need to be solved and goals that need to be attained in the energy sector often are contradictory: reduce energy prices for end users, decrease the energy dependency, reduce the usage of fossil fuels, ensure energy security, etc. With MCDM methods, we can reconcile these contradictory questions and find the optimal solution. MCDM methods can help energy policy decision-makers to choose the best solution that is not influenced by the evaluation process. So creators of energy policies should give priority to this tool when making decisions, creating goals, and searching for the means to attain them. For this reason, MCDM methods are increasingly being used to deal with energy policy issues.

Thanks to an increased demand, the matter of solving the issues in the energy sector planning is being thoroughly explored in the scientific literature and studies of energy sustainability have become highly popular. A large number of analyses and assessment instruments, as well as systems/methodologies, have been applied in energy sustainability studies. A lot of the decision support systems are based on the application of multi-criteria analysis methods. Many methods which help to perform a multi-criteria analysis to design and assess various alternatives been created around the world. The application of modern technologies in the decision-making process makes it possible to assess and analyze numerous possible choices and scenarios and to present objective recommendations for the design and selection of the best decisions. Scientists analyze and propose various intelligent decision support systems, modify and improve them, and expand their application areas. In the scientific literature, it is possible to find articles that review the usage of MCDM methods to solve concrete energy questions. However, there is a lack of articles that summarize the main achievements of these assessment methods in solving energy sector sustainability problems. The main goal of this paper is to give an overview of the application of decision-making approaches in dealing with sustainable energy development issues.

A search of publications in the online Web of Science Core Collection (WSCC) database was made on 20 May 2018. The search was made on the topics of "sustainable energy" and "multi-criteria decision making" during the period of 1990–2017. From all the publications identified (289), 126 publications related to sustainable energy development issues were in the Energy and Fuels category, including 78 research publications and 34 review publications. A detailed analysis of the publications was made in the Energy and Fuels category. Proceedings papers were excluded from this research. The logical scheme of the research is presented in Figure 2.

In the next few paragraphs of this paper, an overview of the multi-criteria decision analysis in dealing with sustainable energy development issues is presented and a detailed analysis on the topics of "multi-criteria decision making" and "sustainable energy" from the WSCC database in the Energy Fuels category is provided.

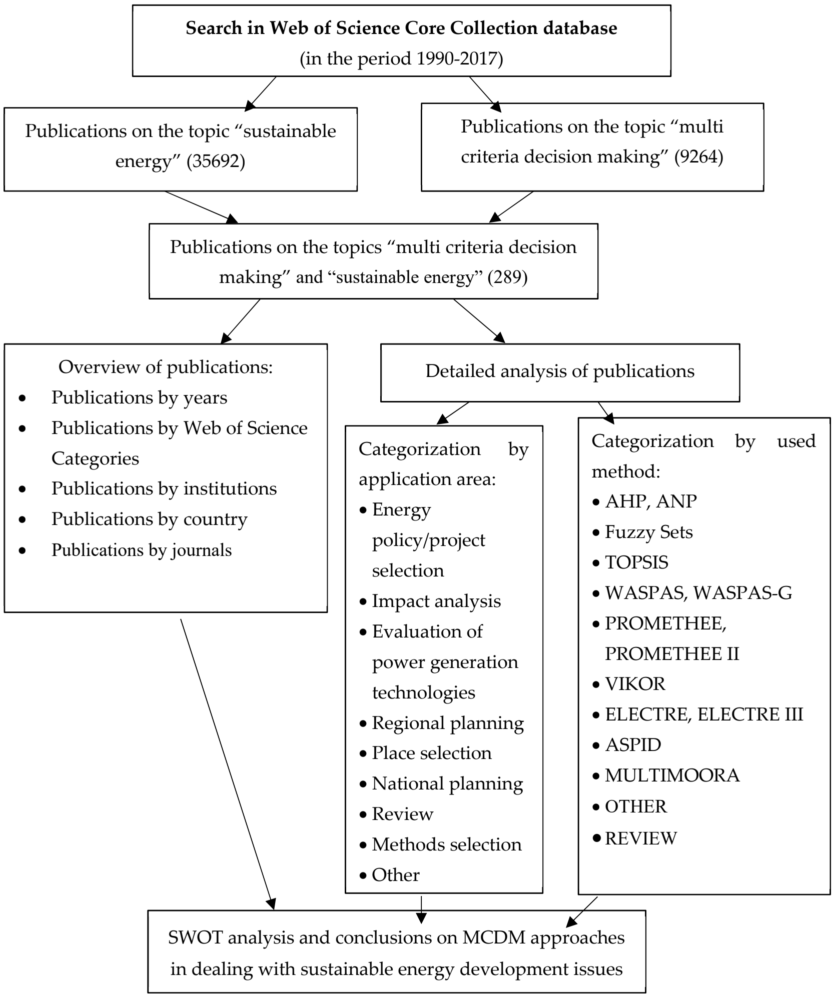

Figure 2. The logical scheme of the research.

2. MCDM in Solving Energy Sustainability Issues

Over the last three decades, a lot of articles in the WSCC database (more than 35,000) have been prepared that deal with sustainability issues in the energy sector (Figure 3). Additionally, there is a significantly increasing trend of growth each year. There are more than six thousand publications on the topic of "sustainable energy" in the WSCC database from 2017.

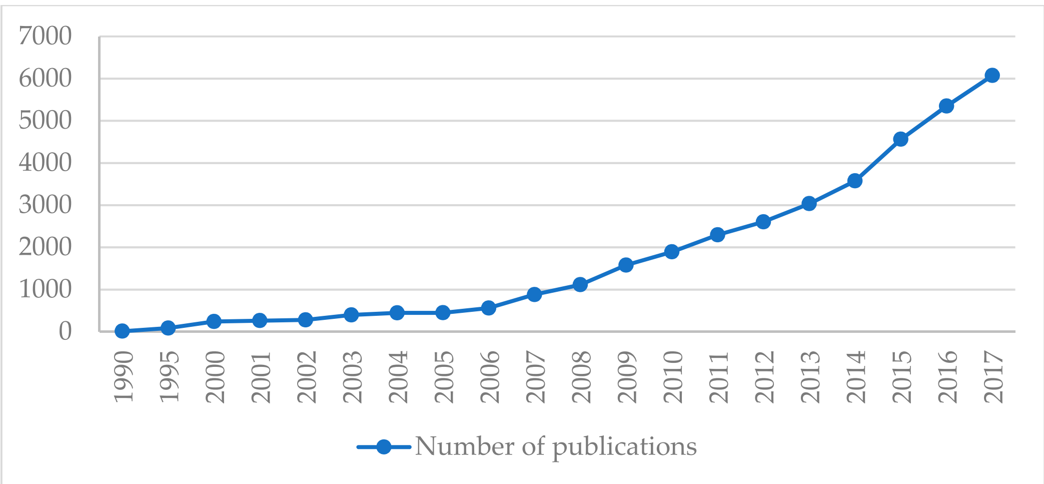

Figure 3. The publications on the topic "sustainable energy", 1990–2017.

Because of its universality and a wide selection of specific issues, the multi-criteria decision analysis is becoming more and more popular and every year the number of studies is increasing. Since 1990, more than nine thousand publications have been prepared on the topic of "multi-criteria decision making" in the WSCC database. The last four years of publications consist of more than 50 percent of all the publications on this topic (Figure 4).

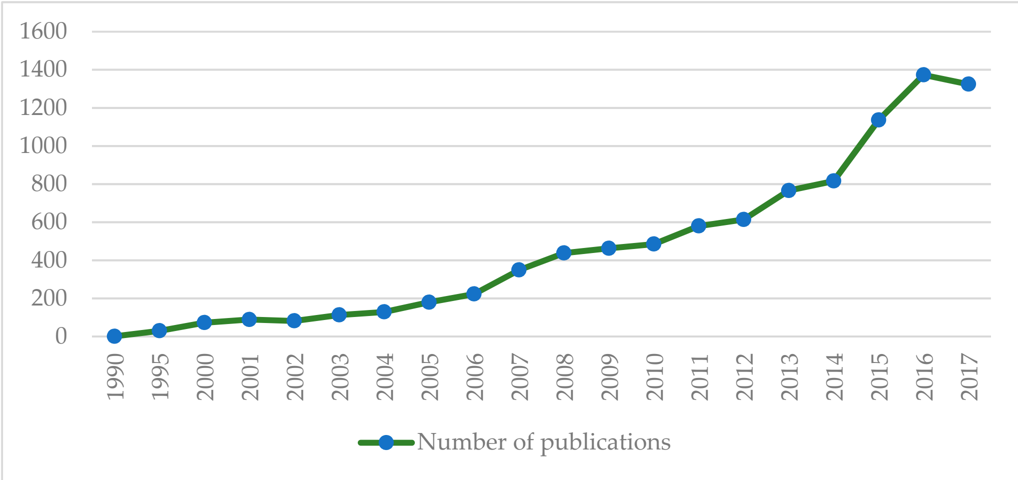

Figure 4. The publications on the topic of "multi-criteria decision making", 1990–2017.

As mentioned before, sustainable energy development is becoming more topical and an increasing number of publications related to sustainability assessment are being published each year. The continuously increasing number of publications which apply MCDM methods for sustainability assessment in the energy sector is presented in Figure 5. This justifies the importance of MCDM methods in the scientific and practical fields for solving energy sustainability issues. There are 289 publications on the topics of "multi-criteria decision making" and "sustainable energy" in the WSCC database. The last three years of publications consist of more than 57 percent of all the publications on these topics.

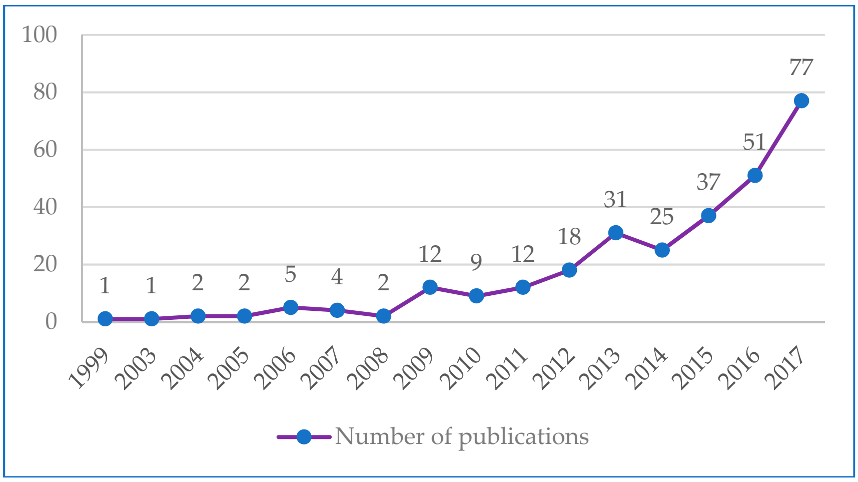

Figure 5. The publications on the topics of "multi-criteria decision making" and "sustainable energy", 1990–2017.

The largest number of publications on sustainable energy issues using the MCDM methods fall into the categories of Energy Fuels (126), Green sustainable science technology (81), and Environmental sciences (76) (Table 1). The University of Belgrade (11) and the Vilnius Gediminas Technical University (9) are the leaders in this subject, among other higher education institutions (Table 2).

Table 1. The publications by the Web of Science Categories on the topics of "multi-criteria decision making" and "sustainable energy", 1990–2017.

Web of Science Category	Number of Publications
Energy fuels	126
Green sustainable science technology	81
Environmental sciences	76
Engineering environmental	42
Environmental studies	36
Thermodynamics	25
Economics	21
Construction building technology	19
Engineering civil	17
Engineering chemical	17
Operations research management science	16
Engineering electrical electronic	11

Note: The table does not represent the Web of Science Categories, which have less than 10 publications.

Table 2. The publications by institutions on the topics of "multi-criteria decision making" and "sustainable energy", 1990–2017.

Institutions	Number of Publications
University of Belgrade	11
Vilnius Gediminas Technical University	9
Indian Institute of Technology ITT	7
Hong Kong Polytechnic University	7
North China Electric Power University	7
Universidade de Lisboa	6
National Technical University of Athens	6
University of Southern Denmark	6
Chinese Academy of Sciences	5
Ecole Polytechnique Federale de Lausanne	5
Lithuanian Institute of Agrarian Economics	5
State University System of Florida	5
University of British Columbia	5
University of Central Florida	5

Note: Institutions which have less than 5 publications are not represented in the table.

Figure 6 shows the distribution of energy-related issues which are being dealt with by different countries using MCDM methods. The vast majority of publications on this topic are published by scientists from China (36), the USA (31), and the UK (29). Renewable and Sustainable Energy Reviews (31), Energy (20), Journal of Cleaner Production (20), Energy Policy (15), and Sustainability (10) are the most popular scientific journals containing articles on this topic (Table 3).

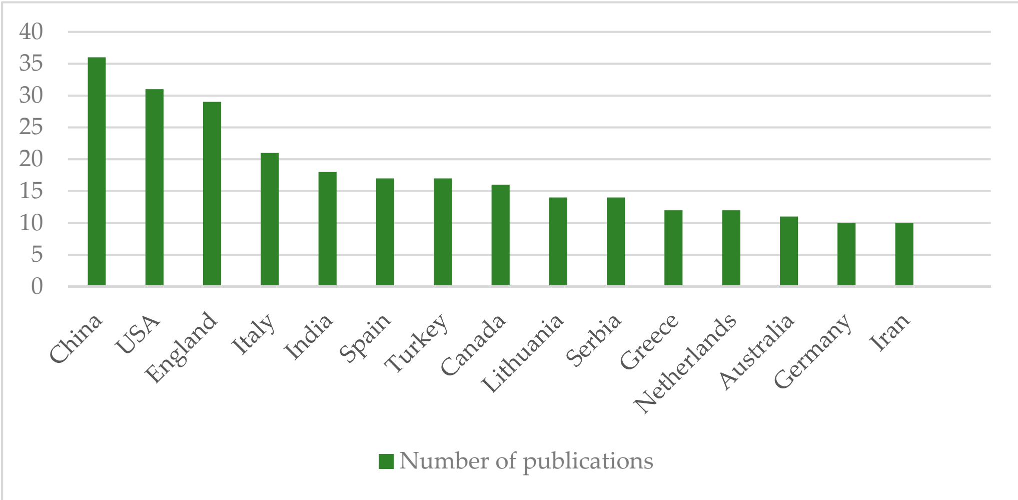

Figure 6. The publications by country on the topics of "multi-criteria decision making" and of "sustainable energy", 1990–2017. Note: The figure does not represent countries, which have less than 10 publications.

Table 3. The publications by journals on the topics of "multi-criteria decision making" and "sustainable energy", 1990–2017.

Journals	Number of Publications
Renewable and Sustainable Energy Reviews	31
Energy	20
Journal of Cleaner Production	20
Energy Policy	15
Sustainability	10
Applied Energy	5
Clean Technologies and Environmental Policy	5
Renewable Energy	5
Energies	5

Note: Journals which have less than 5 publications are not represented in the table.

The initial analysis of scientific articles has revealed that issues related to the development of the sustainable energy sector are analyzed in the Energy Fuels category, thus, a further detailed analysis of the scientific articles will be carried out in this specific category. Figure 7 presents the dynamics of the publications on the topics of "multi-criteria decision making" and "sustainable energy" in the Energy Fuels Web of Science category, which shows the increasing popularity of the MCDM methods each year, i.e., the number of publications on the aforementioned topics almost doubled in 2017 if compared to 2016 (from 17 to 32). We should notice that scientists started to use MCDM methods for the analysis of the energy sector sustainability quite late so that scientific publications in the WSCC database dates only from 2004.

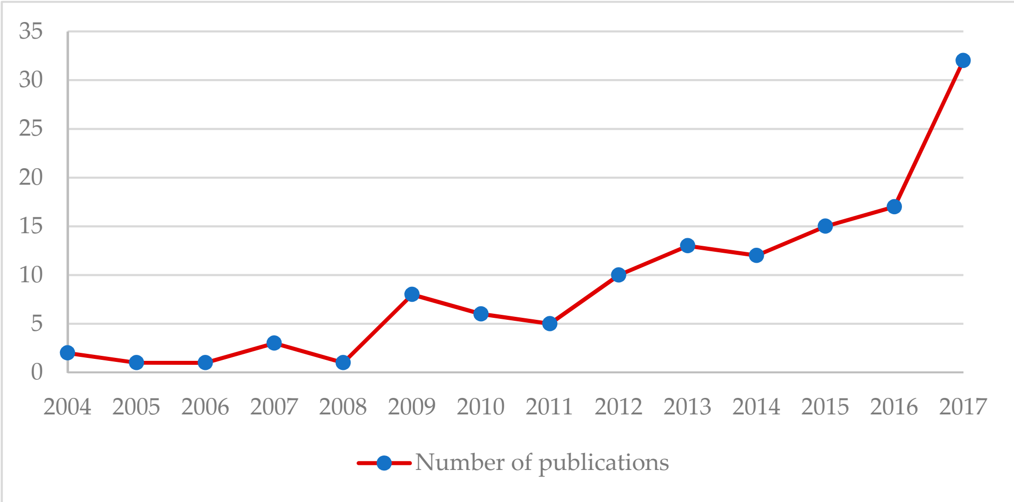

Figure 7. The publications on the topics of "multi-criteria decision making" and "sustainable energy" in the Energy Fuels Web of Science Category, 2004–2017.

3. Detailed Analysis of Articles Dealing with Sustainable Energy Development Decision-Making Issues

In the Energy Fuels Web of Science Category, there are 126 publications, but there have been only 105 articles and review papers involved in a detailed analysis. All selected papers were categorized into 9 fields by application area: energy policy/project selection papers, impact analysis papers, evaluation of power generation technologies papers, regional planning papers, place selection papers, national planning papers, review papers, methods selection papers, and other papers. After content analysis, all the selected papers were categorized into 10 fields by the used method: Analytic Hierarchy Process (AHP) [4], Analytic Network Process (ANP) [5]; Fuzzy Set Theory (Fuzzy Sets) [6]; Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) [7]; Weighted Aggregated Sum Product Assessment (WASPAS) [8] and Weighted Aggregated Sum Product Assessment with the grey attributes scores (WASPAS-G) [9]; PROMETHEE [10]; Multi-Criteria Optimization and Compromise Solution (VIKOR) [11]; Elimination and Choice Transcribing Reality (ELECTRE) [12], ELECTRE III [13]; Analysis and Synthesis of Parameters under Information Deficiency (ASPID) [14]; Full Multiplicative Form of Multi-Objective Optimization by Ratio analysis (MULTIMOORA) [15]; and other. Categorization of the research by application areas and by the used method are presented in Table 4.

Table 4. The categorization of research by the application area and by the used method, 2004–2017.

Application Area Method	Energy Policy/Project Selection	Impact Analysis	Evaluation of Power Generation Technologies	Regional Planning	Place Selection	National Planning	Review	Methods Selection Papers	OTHER
AHP, ANP	[16–21]	[21–25]	[18,19,26–34]	[19,35,36]	[17,37–40]	[22,26,31,35,36,41–43]			
Fuzzy Sets	[18,19,44]	[22,24,45–47]	[18,26,27,31,32,48–56]	[19]	[38,57,58]	[26,31]			[59]
TOPSIS	[44,60,61]	[59]	[31,32,34,49,60,62–65]	[61]	[38]	[31]			[59,66]
WASPAS, WASPAS-G	[61,67]			[61,67]		[67]			
PROMETHEE PROMETHEE II	[16,68]		[28,31,50,69–71]			[31,68]			[72]
VIKOR	[18,73]		[18,28,32]		[58]	[41]			
ELECTRE ELECTRE III	[74,75]		[74,76,77]	[76]		[76]			
ASPID		[45,78]							
MULTIMOORA	[79]		[52,62,79]	[79]		[79]			
OTHER	[61,67,80–89]	[85,90,91]	[48,92–99]	[61,67,85,100]	[57,101,102]	[43,67,86–88,103,104]			[105,106]
REVIEW	[107–109]	[110]		[107]		[107]	[1,109,111–116]	[1,112,114,116–119]	

A detailed analysis of scientific articles and the grouping of articles by methods and problem areas revealed that MCDM methods are generally used to deal with the issues related to technology selection, project selection, energy policy, and energy planning at the national level. The AHP and ANP methods have been used in 29 research articles, Fuzzy Sets in 25, TOPSIS in 14, WASPAS, WASPAS-G in 2, PROMETHEE in 9, VIKOR in 6, ELECTRE, ELECTRE III in 4, ASPID in 2, and MULTIMOORA in 3.

The percentage distribution of the method by application areas is provided in Table 5. The AHP and ANP methods are commonly used for energy policy/project selection issues. Other methods not distinguished separately in this table are also used in a large number of studies. The AHP, ANP, and Fuzzy Sets methods are mostly used for impact analysis. The Fuzzy Sets, AHP, ANP, TOPSIS, and PROMETHEE methods are commonly applied for technology evaluation. The AHP, ANP, and WASPAS methods are popular for regional planning. The AHP, ANP, and Fuzzy methods are also applied for the selection of the best place for energy production. Meanwhile, the AHP, ANP, Fuzzy, and PROMETHEE methods are commonly used for the energy sector planning at the national level. The percentage distribution of application areas by method is provided in Table 6.

Table 5. The distribution of methods by application areas, %.

Application Area Method	Energy Policy/Project Selection	Impact Analysis	Evaluation of Power Generation Technologies	Regional Planning	Place Selection	National Planning	Review	Methods Selection Papers	Other
AHP, ANP	16.67	31.25	19.64	21.43	38.46	32			
Fuzzy Sets	8.33	31.25	25	7.14	23.08	8			16.67
TOPSIS	8.33	6.25	16.07	7.14	7.69	4			33.33
WASPAS WASPAS-G	5.56			14.29		4			
PROMETHEE PROMETHEE II	5.56		10.71			8			16.67
VIKOR	5.56		5.36		7.69	4			
ELECTRE ELECTRE III	5.56		5.36	7.14		4			
ASPID		12.5							
MULTI MOORA	2.78		3.57	7.14		4			
OTHER	33.32	12.5	14.29	28.58	23.08	28			33.33
REVIEW	8.33	6.25		7.14		4	100	100	
Total	100	100	100	100	100	100	100	100	100

Table 6. The distribution of application areas by method, %.

Application Area Method	Energy Policy/Project Selection	Impact Analysis	Evaluation of Power Generation Technologies	Regional Planning	Place Selection	National Planning	Review	Methods Selection Papers	Other
AHP, ANP	15.79	13.16	28.94	7.90	13.16	21.05			
Fuzzy Sets	10.35	17.23	48.27	3.45	10.35	6.90			3.45
TOPSIS	16.66	5.56	50	5.56	5.56	5.56			11.10
WASPAS, WASPAS-G	40			40		20			
PROMETHEE PROMETHEE II	18.18		54.55			18.18			9.09
VIKOR	28.57		42.85		14.29	14.29			
ELECTRE ELECTRE III	28.57		42.85	14.29		14.29			
ASPID		100							
MULTIMOORA	20		40	20		20			
OTHER	31.59	5.26	21.05	10.53	7.89	18.42			5.26
REVIEW	14.29	4.76		4.76		4.76	38.10	33.33	

Different problems in the energy sector related to sustainability were analyzed by the application of different MCDM techniques. The application of the AHP method has led Cucchiella et al. [20] to develop a sustainability index, the aim of which is to assess sustainability of the European countries from the environmental and energy perspective. Shad et al. [21] have developed the assessment system for the selection and development of energy efficient projects in construction sector, having considered the goals of sustainable development, by giving an example of Iran and a developing system based on the AHP methodology.

Celikbilek and Tuysuz [18] have introduced a grey-based multi-criteria decision model for the evaluation of the impact of renewable energy resources on sustainable economic, social, and environmental development. The model is based on the Decision Making Trial and Evaluation Laboratory, ANP, and multi-criteria optimization and compromise solution techniques. Abdullah and Najib [19] have developed an intuitionistic fuzzy AHP method, which is designed for sustainable energy planning and selection of technologies. The proposed intuitionistic fuzzy AHP method deals with the uncertainty in the decision-making process. Ren et al. [16] have developed a model for energy development evaluation by combining linear programming and multi-criteria assessment methods, such as AHP and PROMETHEE. Using AHP methods as a basis, Supriyasilp et al. [17] have evaluated hydropower production opportunities in the Ping River Basin (Thailand). Using the fuzzy AHP method, Ligus [24] aimed to assess the contribution of low-polluting energy technologies to social welfare (the study was made using the case of Poland).

AlSabbagh el al. [25] made an integrated assessment of CO^2 reduction measures in the transport sector in Bahrain. Scientists have modified and supplemented the AHP method in their research in the following three directions: multi-AHP models, scenario packaging, and the examination of the plausibility of the results.

Claudia Roldan et al. [23] evaluated the sustainability of power plants in Mexico using the Life Cycle Assessment (LCA) and AHP methods. Having considered today's situation, the results of the study unambiguously show the benefits of wind power in the development of a sustainable energy policy in Mexico. After the analysis of the most popular methods, which are used to evaluate the environmental aspect of energy consumption, Wang et al. [22] have developed an environmental performance evaluation model. The model combines the following three evaluation techniques: AHP, fuzzy extent analysis, and membership degree analysis.

Debbarma et al. [28] studied the amounts of pollutants from different energy production technologies using the AHP method for the assessment of the weights of criteria and VIKOR and PROMETHEE II methods for the assessment of ranks of alternatives under research.

Gao et al. [31] have developed an integrated assessment system for selecting the most optimal nuclear energy production technology through the combination of the AHP, Fuzzy TOPSIS, and PROMETHEE methods.

Billig and Thraen [33] studied technical and economic aspects (99 different alternatives) of renewable methane production from biomass. The AHP method in combination with utility value analysis was adapted for that. Ozcan et al. [34] have introduced a methodology, which aims to select appropriate maintenance strategy for hydroelectric power plants. The study was introduced using the example of Turkey and integrates the AHP and TOPSIS methods. By combining the LCA and AHP methods, Von Doderer and Kleynhans [30] studied the lignocellulosic bioenergy system in South Africa and researched 37 possible alternatives of the energy production. Stein [29] has prepared a decision-making model that provides a possibility to group different energy production alternatives according to several different criteria. The model is based on the AHP method, while the criteria are grouped into the main 4 groups, which are as follows: financial, technical, environmental, and social-political. Lee et al. [27] measured the efficiency of the hydrogen energy technologies using the Hybrid Fuzzy AHP and Data Envelopment Analysis (DEA) model. Talinli et al. [26] analyzed three different scenarios based on the energy production technologies in the Turkish energy sector using the Fuzzy-AHP model. The study results confirm the results of the scientists discussed above: in order to develop a sustainable energy sector, Turkey needs to increase its production of renewable energy.

Using the AHP model as a basis, Blanco et al. [35] have proposed a tool to optimize the use of hydropower in Paraguay. Four possible energy policy alternatives based on economic, technical, social, environmental, and political criteria are analyzed and assessed in the study of Blanco et al.

Abotah and Daim [36] used the AHP method in order to prepare a model for the evaluation of the efficiency of energy policy measures by promoting the use of renewable energy.

Seeking to find the most suitable locations for the construction of wind power plants in Saudi Arabia, Baseer et al. [40] combined the AHP and Geographic Information System (GIS) modeling. The analysis was based on different climatic, economic, aesthetic, and environmental criteria. Tahri et al. [39] also used a very similar technique as Baseer et al. and assessed different locations for solar power plants in southern Morocco. Al-Yahyai et al. [37] applied the AHP method with the Ordered Weigh Averaging aggregation function and GIS, seeking to create a tool for selecting the most suitable location for the construction of wind power plants. Choudhary and Shankar [38] proposed the fuzzy AHP-TOPSIS based framework for selecting the most optimal location for the construction of thermal power plants.

Si et al. [42] used the AHP method for the implementation of eco-technologies in the modernization of buildings. Amin Hosseini et al. [43] used several MCDM methods (AHP, MIVES, and others) seeking to assess the sustainability of construction technologies of temporary housing after natural disasters. The assessment methodology developed by Hosseini et al. is universal enough and can be widely used in the selection of construction technologies for temporary housing. Rojas-Zerpa and Yusta [41] combined the AHP and VIKOR methods seeking to create a system for the assessment of electricity supply in rural and remote areas. Based on the developed system and also referring to the sustainability criteria established by experts and their weights, 13 alternatives for the electricity supply were assessed.

Balezentis and Streimikiene [61] studied different EU energy production scenarios by referring to the EU energy policy priorities (an increase of efficiency, development of renewable resources, reduction of CO_2 emissions). The following three MCDM methods were used for assessment: WASPAS, ARAS, and TOPSIS. Using the TOPSIS method as a basis, Diemuodeke et al. [60] have developed a methodology for the selection of the best energy project/different technologies referring to 15 economic, social, and environmental criteria. The study looked at the alternatives to hybrid renewable energy systems in Nigeria. Using Fuzzy TOPSIS in combination with multi-objective optimization, Perera et al. [44] have developed a decision-making tool for designing hybrid energy systems. Aplak et al. [59] combined game theory and Fuzzy TOPSIS seeking to create a system for the establishment of the most optimal energy management strategy in the industry sector.

Sakthivel et al. [32] have developed a decision-making system based on Fuzzy TOPSIS and Fuzzy VIKOR, which is designed to determine the best fuel mixtures that would increase the engine efficiency. The study of He et al. [64] designed to prepare a multi-criteria sustainable assessment method by combining the cooling, heating, and power systems. The model developed by He et al. is based on the ANP and TOPSIS techniques. Using the TOPSIS method as a basis, Rupf et al. [65] have developed an optimized biogas system design model for Sub-Saharan Africa. On the basis of the TOPSIS method and the sustainable assessment criteria, Streimikiene and Balezentis [63] made the assessment of small-scale CHP technologies in buildings in Lithuania. Boran et al. [49] used Intuitionistic Fuzzy TOPSIS for the assessment of production technologies of renewable energy resources in Turkey.

Vafaeipour et al. [67] used the WASPAS and SWARA methods during the creation of the system for the assessment of solar energy production projects. Using the PROMETHEE method as a basis, Tsoutsos et al. [68] have developed a decision-making tool for sustainable energy development at the national level. Parajuli et al. [71] and Ziolkowska [50] used the PROMETHEE method for the assessment of biomass energy production technologies. Cavallaro [69] assessed concentrated solar thermal technologies, while Troldborg et al. [70] assessed several energy production technologies from renewable energy resources using the same methods. Seeking to find out which combination of renewable energy resources is the most optimal in Columbia, Quijano et al. [73] used the VIKOR method, which allowed them to model 5151 possible alternatives and select the best one from them.

Using the ELECTRE III method as a basis, Dall'O' et al. [75] proposed a decision-making tool designed for governmental authorities, which are responsible for sustainable national energy policies. Using the ELECTRE III method, Karakosta et al. [74] sought to establish the most sustainable energy production technologies that would help to develop sustainable energy policies. The results of the study were analyzed using the examples from five countries (Chile, China, Israel, Kenya, and Thailand).

Using the ELECTRE method as a basis, Grujic et al. [76] have developed the assessment system and found out how to optimally meet the demand for heat in the centralized heat supply system in Belgrade. Three scenarios until 2030, corresponding to the different economic situation, investment environment, and possible energy efficiency in the country, were prepared. The alternatives analyzed consist of different production technologies and their combinations, while the evaluation criteria include essential aspects of sustainable energy development.

Vucicevic et al. [78] presented a methodology for the selection and calculation of sustainable development indicators for measuring the level of sustainability of residential buildings and used the ASPID method according to the selected criteria. Jovanovic et al. [45] analyzed the sustainability of the urban energy system and predicted the future energy needs using different simulation models. The impact of possible energy development scenarios on sustainability was assessed using the ASPID method.

Streimikiene and Balezentis [79] have developed a methodology for assessing climate change mitigation policy based on the priorities of the EU sustainable energy development. The assessment methodology is based on the MULTIMOORA method and can be universally applied to any EU member state. Balezentiene et al. [52] applied fuzzy MULTIMOORA in order to determine which technological option is the best one (according to pre-defined criteria) for biomass production in Lithuania. Using the MULTIMOORA and TOPSIS methods as a basis, Streimikiene et al. [62] have developed a decision-making system to identify the most sustainable technologies for electricity production.

After the categorization and detailed analysis of the scientific articles, Table 7 provides a SWOT analysis of the MCDM approaches in dealing with sustainable energy development issues.

Table 7. The SWOT analysis of the MCDM approaches in dealing with sustainable energy development issues.

Method	Strengths	Weaknesses	Opportunities	Threats
AHP, ANP	• one of the most popular method, often combined with other methods • faster comparing with other MCDM methods • method has comprehensible logic • widely used to solve energy policy/project selection questions • widely applied for technology evaluation and place selection	• further analysis is needed to verify the results	• advisable to combine sensitivity analysis	• different hierarchies of criteria may influence the difference in allocation of weights
Fuzzy Sets	• provides a solution to handling subjective uncertain data • there is no limit of criteria • makes the comprehensiveness of the decision-making process stronger • often combined with other methods	• an additional measure, requires further calculations	• possible to combine more with other methods, not only TOPSIS and AHP	• not observed

Table 7. *Cont.*

TOPSIS	• method has rational and comprehensible logic, the concept depicted in a simple mathematical form • the computation process is straightforward • one of the most popular MCDM techniques thanks to its easy application • consistency and reliability • faster compared with other MCDM methods • often combined with other methods • method is commonly applied to energy technology evaluation	• not observed	• method can be easily adapted to solve different energy sustainability issues	• not observed
WASPAS, WASPAS-G	• method consists of two mathematically-based techniques • method is popular for regional planning	• narrow application and experience in the field of energy	• useful to apply and compare the results from different methods	• possible errors in calculations
PROMETHEE, PROMETHEE II	• method is particularly useful when there are difficult to reconcile alternatives • method is commonly applied to energy technology evaluation and for energy sector planning at the national level • method measures the difference level between alternatives	• quite long computation process comparing with other MCDM methods	• useful to apply and compare the results from different methods to achieve strength reliability of the assessment	• possible errors in calculations because of a quite sophisticated computation process
VIKOR	• adapted to solve quite different energy problems • popular to combine with other methods • method is tolerant to deviations of values in the assessment period	• narrow experience in the field of energy	• useful to apply and compare the results from different methods to achieve strength reliability of the assessment	• possible errors in calculations

Table 7. *Cont.*

ELECTRE, ELECTRE III	• method is particularly useful when there are difficult to reconcile alternatives	• quite long computation process comparing with other MCDM methods • method only draws attention to the preference • and ignores the difference level between alternatives • further analysis is needed to verify the results • narrow application and experience in the field of energy	• useful to apply and compare the results from different methods to achieve strength reliability of the assessment	• possible errors in calculations because of a quite sophisticated computation process
ASPID	• method is applied for impact analysis	• narrow application and experience in the field of energy	• useful to apply and compare the results from different methods to achieve strength reliability of the assessment • could be applied to assess power generation technologies	• possible errors in calculations
MULTIMOORA	• method is tolerant to deviations of values in the assessment period • consistency and reliability • method consists of strongly mathematically-based techniques	• quite long computation process comparing with other MCDM methods • narrow application and experience in the field of energy	• method can be easily adapted to solve different energy sustainability issues	• possible errors in calculations because of a quite sophisticated computation process

Sustainable energy development issues are solved using other MCDM as well, such as WSM [85], SWARA [67], APIS [103], MACBETH [87], MIVE [43], PROSA [101], etc. It can be noted that the use of LCA is quite popular in combination with the multi-criteria decision analysis. LCA is used in 8 publications ([21,23,47,70,91,92,98,104]), and is most often applied for the assessment of energy production technologies or impact assessment. Additionally, a detailed analysis of articles has revealed that the Fuzzy Set Theory is most often used in combination with the AHP and TOPSIS methods.

4. Conclusions

As there is great concern about the environment and climate change, the energy sector has become one of the main areas in which changes are being sought by using various strategies and international agreements. Therefore, the issues of sustainable energy are increasingly being solved at the scientific level, seeking the most accurate and advanced methodologies in order to make reasonable decisions in developing a low carbon economy. The use of MCDM methods to deal with sustainable energy development issues is getting more and more popular lately and studies of this kind over the past three years represent more than half of all studies carried out in this field. The search of publications in the online WSCC database was made on the topics of “sustainable energy” and “multi-criteria decision making” in the period of 1990–2017. The University of Belgrade and Vilnius Gediminas Technical University are the leaders in this subject (11) among other higher education institutions. Renewable and Sustainable Energy Reviews is the most popular scientific journal containing articles on MCDM methods in dealing with sustainable energy development issues.

From all the publications identified (289), the study selected and reviewed 105 published papers from the WSCC database from 2004 to 2017 related to energy sustainability issues and MCDM methods in the Energy and Fuels category. Most often, the MCDM methods are used to deal with the issues related to the technology selection, project selection, energy policy, and energy planning at the national level. AHP, TOPSIS, PROMETRE, and Fuzzy Set are the most popular methods in the studies. Fuzzy Set Theory is most often used in combination with the AHP and TOPSIS methods.

The AHP method is commonly used for the energy policy/project selection issues. The AHP and Fuzzy Sets methods are mostly used for impact analysis. The Fuzzy Sets, AHP, TOPSIS, and PROMETHEE methods are commonly applied for technology evaluation. The AHP and WASPAS methods are popular for regional planning. The AHP, ANP, and Fuzzy sets methods are also applied for the selection of the best place for energy production. The AHP, ANP, Fuzzy Sets, and PROMETHEE methods are commonly used for the energy sector planning at the national level.

Sustainable energy development issues are solved by using other MCDMs as well, such as WSM, SWARA, APIS, MACBETH, MIVE, PROSA, etc. It can be noted that the use of LCA is quite popular in combination with the multi-criteria decision analysis. LCA is most often applied for the assessment of energy production technologies or impact assessments. Additionally, a detailed analysis of articles has revealed that the Fuzzy Set Theory is most often used in combination with the AHP and TOPSIS methods.

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