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Review

A comprehensive review of fuzzy multi criteria decision making methodologies for energy policy making

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ABSTRACT

Energy policy making is one of the most significant issues for countries and it can be evaluated by using multi-criteria decision making (MCDM) methods. The energy decision and policy-making problems include selecting among energy alternatives, evaluating energy supply technologies, determining energy policy and energy planning. There is a wide range of studies about energy decision-making problems in the literature and different types of energy alternatives are considered in these studies. The MCDM methods are used as effective tools in order to solve energy decision-making problems since they evaluate alternatives with different perspectives in terms of several conflicting criteria. In this context, the fuzzy set theory (FST) that expresses uncertainties in human opinions, can be successfully used together with the MCDM methods to get more sensitive, concrete and realistic results. This paper aims to present a comprehensive review and bring together existing literature and the most recent advances to lead researchers about the methodologies and applications of fuzzy MCDM in the energy field. For this aim, a large number of papers that use fuzzy MCDM methods to solve energy policy and decision making problems have been analyzed with respect to some characteristics such as types of fuzzy sets, year, journal, fuzzy MCDM method, country and document type. The results of this study indicate that fuzzy Analytic Hierarchy Process (AHP), as an individual tool or by integrating with another MCDM method, is the most applied MCDM method and type-1 fuzzy sets are the most preferred type of fuzzy sets. Additionally, Turkey and China are countries which have the highest number of publications related to fuzzy MCDM methods in energy-related problems.

1. Introduction

Energy is a vital component of industrial, technological and agricultural growth. In other words, economic and social development of the countries highly depends on energy planning. Energy policy making is a widespread discussion all over the world because of increasing energy demand and environmental issues. On the other hand, environmental issues have become more important day by day due to emissions of thermal power plants and industrial activities. Therefore, renewable energy sources are preferred by energy users owing to being environment friendly. At this point, type of energy source has an important role to meet energy requirement. Furthermore, energy conservation and sustainable development have recently become one of the main subjects of energy planning. These conditions add different aspects to energy decision-making problems and make them more complex.

Multi-Criteria Decision Making (MCDM) is a concept which enables to select the most appropriate one among predetermined alternatives by evaluating them in terms of many criteria [1]. MCDM methods, classified as conventional and fuzzy, are effectively used to rank alternatives. The conventional MCDM methods are seen inadequate to handle uncertainty in linguistic terms [2]. Hence, it is proposed to apply MCDM methods with the fuzzy sets to cope with vagueness in a decision-making process. Furthermore, these fuzzy methods enable to obtain more concrete results. The fuzzy MCDM studies related to energy can be ensampled as power plant site selection, evaluating energy resource and technology alternatives, energy investment, and determining energy policy. Several criteria, considered while solving energy problems, are technical, environmental, economic, social and political. It is necessary to evaluate alternatives in terms of these criteria in energy decision-making problems. In order to consider different criteria while making a decision, MCDM methods can be effectively used. Besides, the FST helps to decision makers in order to express their opinions by means of linguistic terms. Therefore, more sensitive results

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can be obtained by applying fuzzy MCDM methods. The literature widely includes fuzzy MCDM studies that handle energy policy and decision-making problems. In this paper, the studies, which apply fuzzy MCDM methods to energy policy and decision-making problems, have been analyzed so as to show necessity and contribution of the fuzzy MCDM methods. Tables and figures for each classification have been obtained according to document type, fuzzy MCDM method, year, journal, country, and type of fuzzy sets are presented in order to show recent developments of energy policy and decision making problems. By the way, this paper intends to bring out which type of fuzzy MCDM methods and for what purpose is used to deal with energy policy and decision-making problems. The recent research trends for fuzzy MCDM methods related to these problems are also surveyed to provide a roadmap to researchers studied in this field.

In this paper, a systematic literature review related to usage of fuzzy MCDM methods in energy policy and decision making has been realized by using academic databases such as Scopus and Web of Science. Following a methodological review process based on PRISMA methodology, a total of 245 papers published from 2000 to 2017 have been checked. The main aim of this paper is to answer the following research questions: (i) Which fuzzy MCDM methods have been used?; (ii) Which type of energy has been analyzed by using these fuzzy MCDM techniques?; (iii) Which one of the fuzzy MCDM methods have been used and which one of these methods have been more preferred?; (iv) Which journal published articles related to these fuzzy MCDM techniques?; (v) In which year, the authors published these papers? (vi) What the distribution of the papers according to countries is?; (vii) What the percentage distribution of the papers according to journals is?; (viii) What the percentages of the fuzzy MCDM methods in energy policy and decision making are?; (ix) What the distribution of the papers according to type of fuzzy sets is?; (x) How is a classification of MCDM studies with respect to type of fuzzy sets, MCDM methods and energy types made?; (xi) what are the recent developments in energy field?; (xii) what are the usage areas of energy? (xiii) What is the importance of energy in terms of sustainability? (xiv) Which energy problems are solved by using fuzzy MCDM methods? (xv) Which criteria are considered for energy decision making problems? (xvi) Is there any evidence related there is a difference between the papers based on renewable and non-renewable energy? (xvii) Is there any evidence related there is a difference between the papers based on fuzzy MCDM methods? and (xviii) Does fuzzy MCDM affects/limits the number of considered decision variants/criteria? These research questions have been answered by analyzing the related literature review. By the way, some statistical analyses have been applied to obtain answers for these questions. The one of the main aims is to create a road map for analyzing usage of MCDM methods in energy planning and decision making.

The rest of this paper has been organized as follows: In section 2, energy alternatives are briefly introduced. Section 3 includes general information about the fuzzy sets and fuzzy MCDM methods. Section 4 presents an inclusive literature analysis for fuzzy MCDM studies in energy policy and decision-making. The obtained results and future research suggestions have been discussed in Section 5.

2. Energy alternatives

Energy has significant importance for human life activities such as lighting, cooling, heating, cooking, transportation, and manufacturing [3]. These activities can be defined as usage areas of energy. It is preferred to use low-cost, environment-friendly and continuous energy sources in all of these areas. On the other hand, it has become important to provide alternative energy sources in order to meet energy demand generating from urbanization, industrialization and population increase. Therefore, it is necessary to make an assessment in terms of technical, environmental, social and economic criteria while ranking energy alternatives since security, supply, price, and environment are important concepts for energy policy making. At this point, MCDM methods are effectively utilized as analytical methods for solving energy problems.

Energy sources can be divided into two groups as renewable and non-renewable energy alternatives. While petroleum, coal, natural gas and nuclear energy are defined as non-renewable, solar, wind, hydroelectric, geothermal and biomass energy are classified as renewable energy. Renewable energy sources such as wind, solar photovoltaic, solar thermal, geothermal, biomass, municipal waste, tides and waves, and small and large hydro are being used globally to combat the deteriorating climatic conditions, and at the same time to meet the growing demand for energy. The renewable sources of energy are location independent and hence can be tapped anywhere, and can provide energy to people living in remote areas which are not connected to the grid [4]. The various forms of solar energy - solar heat, solar photovoltaic, solar thermal electricity, and solar fuels offer a clean, climate-friendly, very abundant and in-exhaustive energy resource to mankind. Solar power is the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power [5]. Nonrenewable energy sources cause more greenhouse gas emission compared to renewable energy sources. Therefore, it is aimed to increase usage of renewable energy alternatives in the world. By the way, assessment of energy alternatives is an essential part of energy policy making for governments.

3. The fuzzy sets and multi criteria decision making

Fuzzy logic was initially developed by Zadeh in 1965 [6]. A major contribution of the FST is its capability for representing vague knowledge. The theory of the fuzzy sets has advanced in a variety of ways and in many disciplines. Applications of the fuzzy sets can be found in artificial intelligence, computer science, control engineering, decision theory, expert systems, logic, management science, etc. The FST also allows mathematical operators and programming to apply to the fuzzy domain [7–17]. The FST, membership functions and fuzzy numbers, are effectively used to cope with vagueness in the decision making process [18]. There are several types of membership functions such as triangular, trapezoidal, sigmoid and Gaussian. All of these membership functions can be utilized to model decision making problems [19]. There are several extensions of the fuzzy sets in the literature. These are type-2 fuzzy sets, fuzzy multisets, hesitant fuzzy sets (HFS) and intuitionistic fuzzy sets (IFS). Besides, hesitant fuzzy linguistic term sets (HFLTS) have been developed recently to handle linguistic expressions of decision makers [20,21]. Type-2 fuzzy sets were presented by Zadeh as an extension of regular fuzzy sets. The main difference of type-2 fuzzy sets compared to type-1 fuzzy sets is to have fuzzy membership functions. These functions can take values between 0 and 1. On the other hand, type-2 fuzzy sets are three dimensional as different from type-1 fuzzy sets. The third dimension enables to cope with uncertainties in human thought. Type-2 fuzzy sets are more successful than type-1 fuzzy sets while dealing with vagueness. More sensitive results can be obtained by using type-2 fuzzy sets in decision making problems [18]. HFS, firstly introduced by Torra provide to have different values for the membership of a single element. HFS are considered as an extension of regular fuzzy sets and enable to use all possible membership values obtained from a group of experts. When decision makers have some hesitancy to indicate their preferences, HFS can be useful for them [22]. Intuitionistic Fuzzy Sets (IFS) were developed by Atanassov [23] as a generalization of fuzzy sets to express uncertainties in the decision making process due to the hesitancy of decision makers. An IFS is identified by a membership function and non-membership function as different from regular fuzzy sets and is seen quite effective tool to deal with imprecise or vague decision information [24,25]. In decision-making problems, fuzzy goals and fuzzy constraints can be defined precisely as fuzzy sets in the space of alternatives [26,27]. Because of its importance as indicated, decision makers desire to handle energy policy making problems more sensitively. Fuzzy

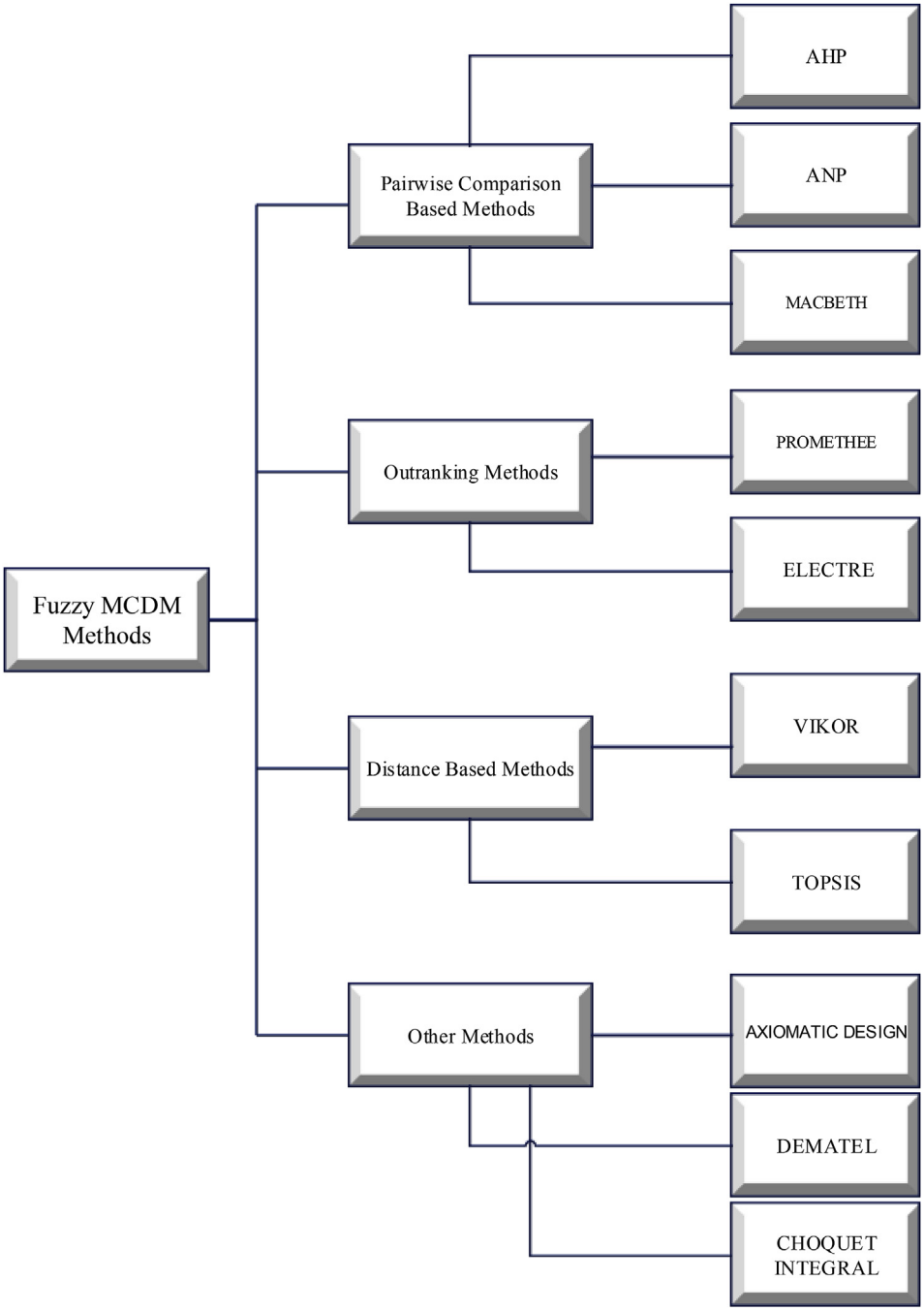


Fig. 1. A classification of fuzzy MCDM methods.

logic is seen as a suitable tool to obtain more sensitive results for energy policy and decision making problems. Therefore, conventional MCDM methods are extended with different types of fuzzy sets such as type-1 fuzzy sets, type-2 fuzzy sets, HFS and IFS by decision makers. Fuzzy MCDM methods enable to get more realistic results in decision making problems. In general, Analytic Hierarchy Process (AHP), Analytic Network Process (ANP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods are used with fuzzy sets. On the other hand, it is seen usage of fuzzy Multicriteria Optimization and Compromise Solution (VIKOR), fuzzy Elimination and Choice Expressing the Reality (ELECTRE), fuzzy Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), fuzzy Axiomatic Design (AD) and fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) methods to reach more sensitive solutions. In addition, integrated fuzzy decision making models, which combine two or more fuzzy MCDM methods, are commonly applied in energy problems. Fuzzy MCDM methods can be classified by using methods based on distance, outranking, pairwise comparison and other as shown in Fig. 1.

Fuzzy AHP and fuzzy ANP methods are located in pairwise comparison approach. These methods are applied to calculate relative importance values of criteria and alternatives by using pairwise comparison matrices. On the other hand, fuzzy TOPSIS and fuzzy VIKOR methods are classified as distance based methods. Alternatives are evaluated according to their distance to ideal solutions in these methods. Another group is outranking methods, which include fuzzy ELECTRE and fuzzy PROMETHEE methods. Fuzzy ELECTRE method utilizes outranking relations in order to evaluate alternatives. PROMETHEE is also an outranking method used for partial and complete

ranking of several alternatives. This method is also extended under fuzziness in order to get more sensitive results. The last classification topic is other methods including fuzzy DEMATEL that is used to determine interrelationships among criteria, fuzzy Axiomatic Design that is used to rate alternatives and criteria by expressing quantitatively and semantically, and fuzzy Choquet Integral that is used to determine conjunctive or disjunctive behaviors between criteria methods.

4. Literature review

MCDM is a well-known area of decision making. It is possible to apply MCDM methods together with fuzzy logic in order to deal with vagueness in decision-making problems. There are different types of fuzzy MCDM methods and their applications in the literature. In this paper, a literature review has been made to determine which fuzzy MCDM methods are applied to solve energy policy and decision-making problems. By the way, it is aimed to inform researchers who study in this field about recent developments.

4.1. Review methodology

We carry out our review process by taking into account Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology that was proposed by Moher et al. [28]. This methodology helps researchers to realize systematic reviews and meta analyses. The main objective of systematic reviews is to present a detailed review study for a specific research area and date interval. Besides, meta-analyses also present significant statistical and mathematical results in order to reveal recent developments in related research area. The PRISMA methodology consists of identification, screening, eligibility, and included steps in order to make a review study. We also adapt our review process to PRISMA methodology. For this aim, a flowchart including the steps of PRISMA methodology has been created for our review process and it has been shown in Fig. 2.

In the first step, we analyzed various academic databases to present a comprehensive review of MCDM methods used to solve energy policy and decision making problems. The related papers have been checked one by one. The literature analysis has been realized based on various keywords such as: “energy + decision making + fuzzy, energy + MCDM + fuzzy, energy + MCDM + fuzzy + AHP, energy + MCDM + fuzzy + ANP, energy + MCDM + fuzzy + TOPSIS, energy + MCDM + fuzzy + ELECTRE, energy + MCDM + fuzzy + PROMETHEE, energy + MCDM + fuzzy + VIKOR, energy + MCDM + fuzzy + DEMATEL” and other MCDM methods. Multi-Criteria Decision Analysis (MCDA) or MCDM are well-known acronyms for multiple-criteria decision-making. MCDA and MCDM may be used reciprocally with identical meaning. We also adopt our keywords by using MCDA. The review process has been applied to all of the databases. We have analyzed the papers published between 2000 and 2017 years. Totally, 245 papers have been extracted with respect to our keywords.

In the second step, we identified and screened papers related to MCDM methods and energy policy making. The irrelevant papers that are clarified by checking their contents have been removed. In this step, the papers that use MCDM methods to solve energy policy and decision making problems have been chosen. We also checked the duplication between conference papers and articles to avoid incorrect statistics.

In the third step, we handled eligible 150 full-text papers consisting of 98 articles, 51 conference papers and 1 book chapter for qualitative analysis. In the last step, a meta-analysis has been realized for included papers according to some features such as document type, publication year, journal name, country, and type of fuzzy sets and the results of this analysis have been presented via figures and tables.

4.2. Energy literature with fuzzy MCDM methods

Literature has a wide range of fuzzy MCDM studies, including evaluation of energy problems. In this section, literature is analyzed by regarding fuzzy MCDM methods. Furthermore, papers are presented in the historical order.

4.2.1. Fuzzy AHP

Literature widely includes the multi-criteria analysis, including fuzzy sets and AHP method for evaluation of energy problems. In this scope, Jaber et al. [29] evaluated seven different space-heating systems in Jordan by using fuzzy AHP method. They found that a wind-based heating system was a preferred scheme and the electric heating system was the most undesirable scheme to be used in Jordan. Therefore, they concluded that the system, which operates through renewable energy, should be preferred by considering financial criteria. Lee et al. [30] applied fuzzy AHP method in order to assess national competitiveness in the hydrogen technology sector. Lee et al. [31] proposed fuzzy AHP method so as to prioritize energy technologies for Korea sensitive energy market, which is easily affected by the change in oil prices. They concluded that building technology was the most preferred technology among energy technologies by considering high oil prices. Shen et al. [32] applied fuzzy AHP method to assess renewable energy sources with the aim of meeting goals that are related to energy, environment, and economy (3E). As a result of the study, they obtained that the renewable energy sources, which would be alternatives for meeting the 3E policy goals, are hydropower, solar energy, and wind energy. Kahraman and Kaya [8] suggested a fuzzy AHP methodology to select the best energy policy among predetermined energy policy alternatives. They determined wind energy as the best energy alternative with respect to four main criteria, which are technological, environmental, socio-political and economic. Heo et al. [33] established five criteria, which are technological, market-related, economic, environmental and policy-related, and a total of seventeen factors. They calculated the weight of each factor by using fuzzy AHP method. Then they evaluated usage of new and renewable energy alternatives in Korea. Lee et al. [34] determined the weights of hydrogen energy technologies by using fuzzy AHP approach. Wang et al. [35] proposed a fuzzy AHP model so as to score environmental impact of energy usage. Sagbas and Mazmanoglu [36] aimed to determine the weights of criteria for assessment of wind energy production alternatives located in Marmara region of Turkey. For this purpose, they developed a decision model based on fuzzy AHP method. Tasri and Susilawati [37] applied fuzzy AHP in order to make a selection among renewable energy alternatives for electricity generation in Indonesia. Abdullah and Najib [38] proposed an MCDM approach, named as intuitionistic fuzzy analytic hierarchy process (IF-AHP) for sustainable energy planning in Malaysia. They evaluated seven energy alternatives and selected nuclear energy as the most suitable alternative. Multazam et al. [39] evaluated five locations (Sukomoro, Rejoso, Lengkong, Nganjuk, and Pace) with respect to three main criteria named as economic, environmental and technical, and their sub-criteria by adopting fuzzy AHP for wind farm site selection in Indonesia. Bal Besikci et al. [40] examined operational measures related to Ship Energy Efficiency Management Plan (SEEMP). They utilized fuzzy AHP to determine the weights of measures by regarding the uncertainty of human opinions. Kulkarni et al. [41] applied fuzzy AHP in MATLAB software to rank energy generation alternatives such as Grid Extension, Microgrid, and Solar Home Systems.

4.2.2. Fuzzy ANP

Chen and Pang [42] proposed a conceptual model examining critical characteristics for successful photovoltaic (PV) solar energy industry in China. They developed a fuzzy ANP approach for analyzing appropriate forms of organization. They intended to distribute existing knowledge about PV solar energy industry as well as to create new knowledge. Kang et al. [43] evaluated wind farm performance by

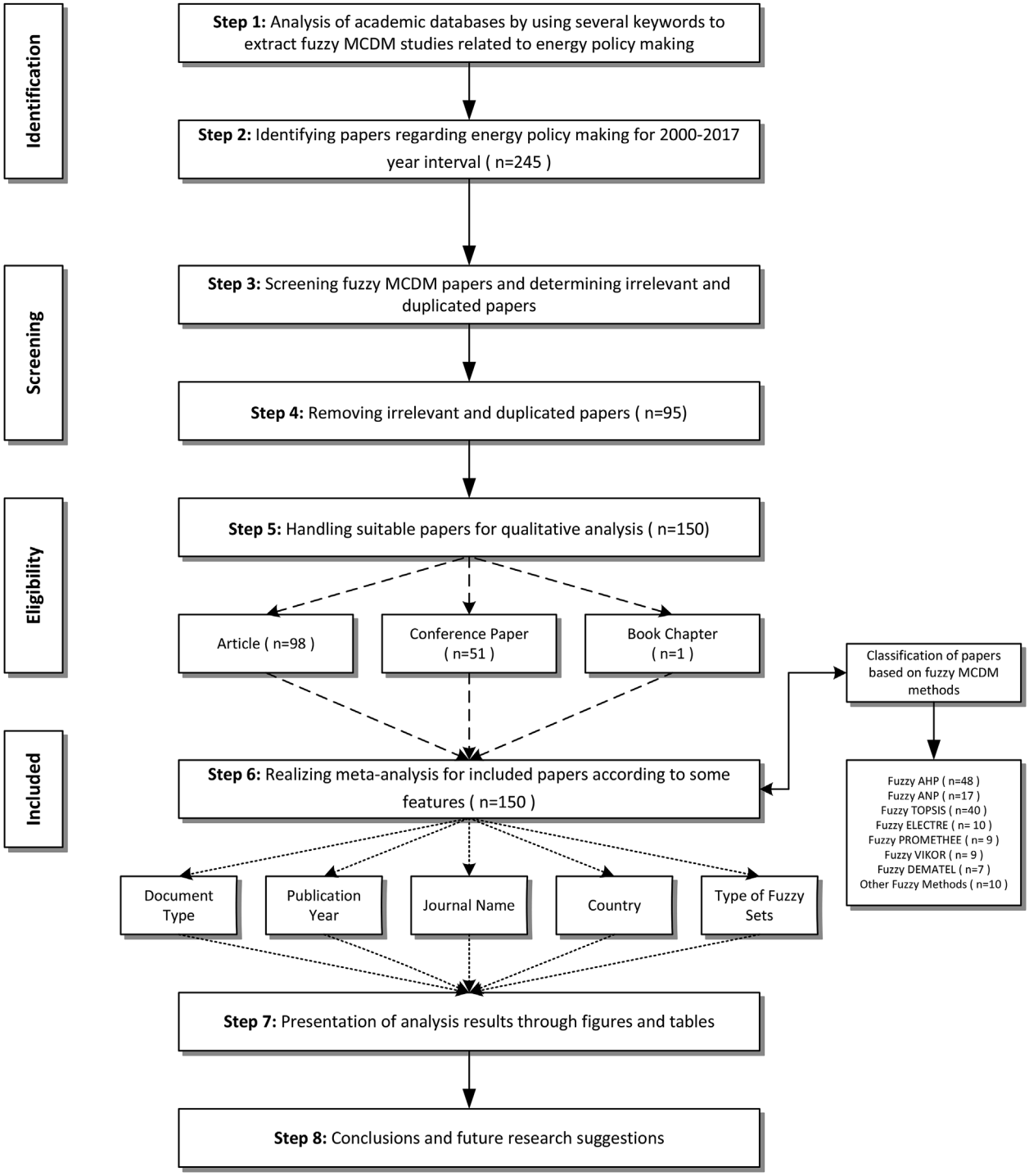


Fig. 2. The flowchart for the review methodology.

developing an integrated MCDM model. The proposed model consists of interpretive structural modelling (ISM), benefits, opportunities, costs and risks (BOCR) and fuzzy ANP methods. They used data from Taiwan energy industry to construct the empirical model. They evaluated the expected performance of several potential wind farms and suggested the most suitable alternative for wind-farm construction. Lee et al. [44] analyzed strategic products for PV solar cell power industry by combining fuzzy ANP with ISM and BOCR methods. Lee et al. [45] developed a MCDM methodology, including ISM and fuzzy ANP methods, to properly determine appropriate turbines while constructing a wind farm. Kabak et al. [46] proposed an integrated model, including strength, weakness, opportunity, and threat (SWOT) analysis and fuzzy ANP method, for evaluation of alternative energy policies. Oztaysi et al. [47] ranked green energy alternatives for Turkey by using fuzzy ANP. They evaluated alternatives in terms of technical, environmental and economic aspects. Kabak et al. [48] used fuzzy ANP method to evaluate alternative buildings with their overall energy performance in Turkey. Kabak et al. [49] proposed a MCDM methodology, integrating SWOT analysis and fuzzy ANP method, to evaluate alternative energy policies for Turkey. For this purpose, they used four main factors and twenty-one sub-factors to prioritize seven different policies.

4.2.3. Fuzzy TOPSIS

Kaya and Kahraman [50] suggested a modified fuzzy TOPSIS methodology for energy planning problem. Garcia-Cascales et al. [51] used fuzzy TOPSIS method to evaluate PV cell alternatives. Sengul et al. [52] applied fuzzy TOPSIS method to rank renewable energy supply systems for Turkey. They used interval Shannon's Entropy method to determine weights of evaluation criteria. At the end of this study, the hydropower station was selected as the best alternative for Turkey. Guo and Zhao [53] utilized fuzzy TOPSIS method to express vagueness for electric vehicle charging station site selection problem. Gumus et al. [54] proposed a MCDM methodology based on IFS and TOPSIS method to determine the best wind energy technology for sustainable energy planning in the United States. Liang and Xu [55] presented a new combination of fuzzy sets named as Hesitant Pythagorean fuzzy sets (HPFSs) obtained by integrating Pythagorean fuzzy sets (PFSs) and Hesitant fuzzy sets (HFSs). They applied HPFSs with together TOPSIS method to deal with an energy project selection problem. Perera et al. [56] presented a novel methodology integrating multi-criteria evaluation, decision making, and optimization to design distributed electrical hubs by using several criteria. They used fuzzy TOPSIS as a MCDM method. Papapostolou et al. [57] presented a new extension of fuzzy TOPSIS method for prioritization of alternative energy policy scenarios to realize targets of renewable energy in 2030. Boran [58] evaluated power plant alternatives through fuzzy TOPSIS method in terms of several criteria such as installation cost, CO2 emission, electricity cost, efficiency and social acceptance.

4.2.4. Fuzzy PROMETHEE

Goumas and Lygerou [59] stated that MCDM procedures were necessary to make a rigorous analysis. They applied PROMETHEE method, extended with fuzzy input data for evaluation and ranking of four alternative exploitation schemes for the low enthalpy geothermal field. Cavallaro and Ciraolo [60] used fuzzy PROMETHEE method to make comparison among a group of solar energy technologies.

4.2.5. Combined Fuzzy MCDM Methods

Combined fuzzy MCDM methods integrating two or more MCDM methods are commonly applied to solve energy policy and decision making problems. Kahraman et al. [61] suggested AHP and Axiomatic Design (AD) methods under fuzziness to determine the best renewable energy alternative. Initially, they applied fuzzy AHP to determine weights of evaluation criteria. Then they used fuzzy AD method to evaluate alternatives in terms of objective or subjective criteria. Lee et al. [62] applied a fuzzy model, consisting of AHP and Data Envelopment Analysis (DEA) methods, to properly measure the relative efficiency of R&D performance in the national hydrogen energy technology development. They applied this integrated method in two stages and obtained efficiency scores for countries. Kaya and Kahraman [63] applied an integrated methodology using VIKOR and AHP methods under fuzzy environment. They used the proposed methodology to determine the best energy policy for Istanbul. Then they aimed to determine the best energy production site among existing alternatives for Istanbul. Lee et al. [64] developed a model, integrating fuzzy AHP and DEA methods, to promote Korean national agenda called Low Carbon, Green Growth. Firstly, they used fuzzy AHP to determine the relative weights of five criteria, which are economical, commercial potential, inner capacity, technical offshoot and development cost. Then they applied DEA method to determine the relative efficiency of energy technologies against high oil prices according to economical aspects.

Ekmekcioglu et al. [65] developed fuzzy multi-criteria SWOT analysis by using integrated fuzzy AHP and fuzzy TOPSIS methods to solve nuclear power plant site selection problem. Zheng et al. [66] proposed a methodology using fuzzy AHP method and life cycle assessment (LCA) theory so as to evaluate building energy conservation. Sadeghi et al. [67] developed a methodology, including fuzzy AHP and fuzzy TOPSIS methods, to determine the best renewable energy alternative among solar, geothermal, hydropower and wind options. In the first step, they applied fuzzy AHP to figure out the relative weights of the evaluation criteria, and then they applied fuzzy TOPSIS to rank alternatives. Choudhary and Shankar [68] proposed a framework, which consists of fuzzy AHP and TOPSIS methods, in order to determine thermal power plant location. The proposed framework consists of three stages. Firstly, they determined feasible locations according to social, technical, economical, environmental and political (STEEP) factors. Then, fuzzy AHP has been used to calculate the weights of criteria, and TOPSIS method has been applied to rank alternative locations. Finally, they presented a case study to illustrate the proposed methodology. Locatelli and Mancini [69] proposed a two stage MCDM method so as to select the best nuclear reactor among several nuclear reactor designs. In this study, they applied fuzzy AHP and fuzzy TOPSIS methods. Daim et al. [70] presented a methodology to assess energy storage technologies and to select the best one for private or public utility according to predetermined criteria. Their methodology includes fuzzy Delphi method, AHP and fuzzy consistent matrix. Ertay et al. [71] determined renewable energy alternatives as solar, wind, hydropower and geothermal energy in Turkey. They used MACBETH and AHP methods under fuzziness so as to evaluate these alternatives. Gumus et al. [72] examined a decision making problem related to Hydrogen Energy Storage (HES). They proposed a combined MCDM methodology consisting of Buckley extension based fuzzy AHP and linear normalization based fuzzy Grey Relational Analysis (GRA) in order to determine the most suitable HES type for Turkey among the existing alternatives such as tank, metal hydride and chemical storage. Lazzerini and Pistolesi [73] proposed a linear programming model to generate alternatives for energy dispatching problems. Besides, they used fuzzy AHP and TOPSIS methods to prioritize these alternatives. Buyukozkan and Guleryuz [74] proposed a new MCDM approach combining fuzzy AHP and fuzzy TOPSIS methods. They calculated criteria weights through fuzzy AHP and ranked renewable energy alternatives by using fuzzy TOPSIS method. Kurt [75] handled nuclear power plant location selection problem by means of fuzzy TOPSIS method and generalized fuzzy Choquet integral algorithm. Van de Kaa et al. [76] evaluated dominance of five photovoltaic technologies using fuzzy AHP method and logarithmic fuzzy preference programming. They determined mono-crystalline silicon as the most dominant technology among alternatives. Fetanat and Khorasaninejad [77] used fuzzy ANP, fuzzy DEMATEL and fuzzy ELECTRE methods to evaluate four alternatives for offshore wind farm site selection problem. Erdogan and Kaya [78] re-constructed AHP and TOPSIS methods under type-2 fuzzy sets and obtained two new MCDM methods. They used these methods for calculating the weights of criteria and ranking energy alternatives for Turkey. Balin and Baracli [79] applied an integrated fuzzy MCDM methodology using AHP and TOPSIS methods with interval type-2 fuzzy sets for evaluation of renewable energy alternatives in Turkey. As a result of this study, they determined wind energy as the best alternative for Turkey. Ozkan et al. [80] applied a hybrid MCDM methodology integrating AHP and TOPSIS methods by using type-2 fuzzy sets. Firstly, they applied type-2 fuzzy AHP to determine the weights of criteria, and then they used type-2 fuzzy TOPSIS method to analyze alternatives in terms of criteria. Afsordegan et al. [81] assessed seven energy alternatives with respect to nine criteria by means of three environment and energy experts. They also used fuzzy AHP to determine weights of criteria and applied qualitative fuzzy TOPSIS method to rank alternatives. Erdogan and Kaya [18] applied a fuzzy MCDM methodology combining interval type-2 fuzzy AHP and interval type-2 fuzzy TOPSIS methods for nuclear power plant site selection problem in Turkey. Wu et al. [82] presented a new approach integrating DEMATEL and VIKOR methods under hesitant fuzzy environment for quality function deployment (QFD). They used HF-DEMATEL method to properly assess interrelationships and weights for customer requirements. Afterwards, they applied HF-VIKOR method to prioritize engineering characteristics. Wiguna et al. [83] developed a toolbox utilizing fuzzy AHP and PROMETHEE methods for ranking

solar farm alternatives in ArcGIS software. Mardani et al. [84] utilized key energy saving factors for ranking 10 Iranian hotels by means of MCDM methods. They selected 17 energy factors via fuzzy Delphi method and ranked them by using fuzzy AHP method. They also prioritized alternative hotels through fuzzy TOPSIS method. Buyukozkan and Guleryuz [85] aimed to determine the most suitable renewable energy alternative for Turkey by means of a group decision making approach using DEMATEL, ANP and TOPSIS methods with linguistic interval fuzzy preferences. Tabaraee et al. [86] utilized two fuzzy MCDM methods for assessment of power plants. They weighted evaluation criteria via ANP method, and then ranked alternatives by using fuzzy PROMETHEE II and fuzzy TOPSIS methods. Moreover, they compared the obtained results of these methods by means of correlation analysis. Ren and Liang [87] suggested an integrated fuzzy MCDM methodology combining fuzzy logarithmic least squares and fuzzy TOPSIS methods for sustainability evaluation of marine fuels. They calculated criteria weights through fuzzy logarithmic least squares method, and then ranked alternatives by using fuzzy TOPSIS method. Wang et al. [88] presented a multi-criteria evaluation model consisting of fuzzy best-worst network and interval TOPSIS methods in order to assess polygeneration systems. They determined criteria weights via fuzzy best-worst method and ranked alternatives through interval TOPSIS method. They also validated the obtained results by using interval GRA method. Alipour et al. [89] proposed a novel MCDM methodology combining fuzzy AHP with cumulative belief degree so as to determine the most appropriate energy investment alternative for Iran. Colak and Kaya [90] proposed a hybrid MCDM model based on interval type-2 fuzzy sets and hesitant fuzzy sets to derive the priorities of renewable energy alternatives for Turkey. They utilized interval type-2 fuzzy AHP and hesitant fuzzy TOPSIS methods to determine criteria weights and to rank renewable energy alternatives, respectively. Cayir Ervural et al. [3] suggested an integrated MCDM framework including SWOT analysis, ANP and fuzzy TOPSIS methods for ranking energy strategy alternatives in Turkey. The results of the study reveal that turning the country into an energy hub due to geo-strategic importance is the best strategy. Elzarka et al. [91] proposed a fuzzy MCDM framework, combining group rational behavior theory and the vague set fuzzy theory to determine the most suitable renewable energy technology for institutional owners. Sakthivel et al. [92] aimed to determine optimum fuel biodiesel blend for the internal combustion (IC) engine by means of multi-criteria analysis on the purpose of increasing energy efficiency. They ranked alternatives by using fuzzy TOPSIS and fuzzy VIKOR methods with fuzzy criteria weights. Akbas and Bilgen [93] proposed a fuzzy MCDM framework including AHP, ANP, QFD and TOPSIS methods for selection of the most suitable gas fuel at wastewater treatment plants. They ranked alternatives as biogas, natural gas, liquefied natural gas, compressed natural gas and landfill gas, respectively.

4.2.6. Other Fuzzy MCDM Methods

Mamlook et al. [94] used fuzzy set programming approach to determine the best solar energy options in Jordan. Wang et al. [95] used fuzzy MCDM methods in order to evaluate trigeneration systems and make a selection among them. Kahraman et al. [96] suggested fuzzy Axiomatic Design (AD) method so as to select among renewable energy alternatives. By this method, they tried to determine the most appropriate energy alternative for Turkey. Jing et al. [97] proposed a fuzzy decision-making methodology to assess CCHP systems operating by natural gas, biomass energy, fuel cell and combined gas-steam cycle. They applied grey relational analysis (GRA) and combination weighting method by considering technology, economic, social, and environmental criteria. They evaluated several energy alternatives in terms of environmental, social, technical and economic criteria. Suo et al. [98] presented a fuzzy ordered weighted averaging (OWA) operator for handling MCDM problems when uncertain inputs exist. Balezentiene et al. [99] applied fuzzy MULTIMOORA method which helps to decision makers to cope with imprecise information while prioritizing energy crops for Lithuania. Erol et al. [100] proposed a new MCDM methodology combining fuzzy Entropy and t-norm based fuzzy compromise programming methods to prioritize nuclear power plant sites. Wu et al. [101] presented a MCDM approach based on intuitionistic fuzzy sets for wind farm project plan selection and they showed the effectiveness of the proposed method through a case study. Wu et al. [102] proposed a decision making framework for solar thermal power plant site selection. They used the fuzzy measure to determine criteria weights and linguistic Choquet Integral to rank alternative sites. Zhang et al. [103] applied an improved MCDM method based on fuzzy measure and integral to assess four primary clean energy alternatives for Jiangsu Province. They ranked energy alternatives as solar photovoltaic, wind, biomass and nuclear energy. Cevik Onar et al. [104] aimed to determine the best wind energy technology to help investors. They proposed an interval-valued intuitionistic fuzzy approach to cope with vagueness and subjectivity. Long and Geng [105] evaluated alternatives for photovoltaic module selection problem by using interval-valued intuitionistic fuzzy entropy weight method to calculate criteria weights. Rehman and Khan [4] proposed a two-level decision strategy based on fuzzy logic and MCDM approach for wind turbine selection process. Cebi et al. [106] evaluated eight alternative locations in Aegean Region in terms of quantitative and qualitative criteria to select the most suitable site for a biomass power plant. They used a model that includes fuzzy sets, AHP, opinion aggregation method and AD method. Aktas and Kabak [107] proposed a decision-making method based on hesitant fuzzy linguistic term sets for renewable energy site selection problem. They obtained weights of evaluation criteria for wind turbine site selection through the proposed decision-making approach. Gitinavard et al. [108] proposed a decision-making approach based on VIKOR method and interval-valued hesitant fuzzy sets to solve energy selection problems. They obtained criteria weights by using extended maximizing deviation method. They also extended DEMATEL method under interval-valued hesitant fuzzy environment to compute the interdependencies between criteria. Cutz et al. [109] presented a fuzzy MCDM method to determine suitable biomass conversion technologies for Central America by evaluating alternatives with respect to technical, environmental, economic and sociopolitical aspects. Yunna et al. [110] applied ELECTRE-III outranking method with intuitionistic fuzzy sets for offshore wind farm site selection. They presented a case study for China to demonstrate the effectiveness of the proposed methodology. Mishra et al. [111] suggested Jensen-exponential divergence measure for intuitionistic fuzzy sets (IFs) and applied to evaluate an energy-related MCDM problem. They aimed to select among renewable energy alternatives by using this proposed methodology. Khistandar et al. [112] utilized a MCDM method based on hesitant fuzzy linguistic term sets for prioritization of bioenergy production technologies to provide a sustainable energy system in Iran. Peng and Wang [113] developed a new MCDM approach named as cloud decision model based on linguistic intuitionistic fuzzy numbers to handle sustainable energy crop selection problem. They showed the validity of the proposed method with an illustrative example. Zoghi et al. [114] developed a model consisting of fuzzy logic, MCDM and weighted linear combination for solar site selection problem. Jayaraman et al. [115] used fuzzy goal programming to analyze greenhouse gas emission reduction, energy consumption, economic development and workforce goals of the United Arab Emirates. Boran et al. [116] applied AD method by using fuzzy information axiom because of subjective criteria to determine energy policy for Turkey. They evaluated several energy alternatives in terms of environmental, social, technical and economic criteria.

4.3. Literature analysis

We analyzed the literature according to various aspects such as document type, publication year, journal, country, fuzzy MCDM method and type of fuzzy sets. We presented the results of the analysis

Table 1
Number of the papers based on document types.

Document Type	Number of Publications
Article	98
Conference Paper	51
Book Chapter	1

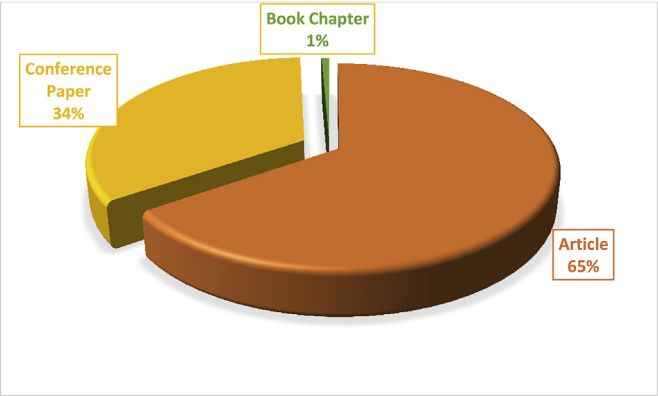


Fig. 3. The percentage distribution of the publications according to document types.

via tables and figures.

Firstly, we analyzed the literature according to document type and the publication number, as given in Table 1. In addition, we presented the percentages of document types in Fig. 3. We obtained that articles are the document type, which has the highest percentage according to the results of the analysis. We also concluded that fuzzy MCDM papers are generally in the form of an article in the energy decision making field.

Secondly, we analyzed the literature in terms of publication year. We presented the analysis results in Table 2 and Fig. 4. The number of studies increase year by year as shown in Table 2 and Fig. 4. Energy policy and decision-making has become more critical issues for governments because of limited energy sources. Therefore, there is a general tendency towards analytical methods to make a decision for energy policy making problems in recent years as observed in Fig. 4.

Then, we made an analysis according to journals. We presented the number of papers, applying fuzzy MCDM methods in energy policy and decision making with respect to journals, in Table 3. Moreover, we represented the percentage distribution of these publications in terms of journals in Fig. 5. As seen in Table 3, Energy journal has the largest number of publications about fuzzy MCDM methods in energy policy and decision making studies. This analysis may be beneficial for researchers while selecting a journal to publish their studies.

Table 2
Number of the papers based on years.

Year	Number of Publications
2017	25
2016	19
2015	19
2014	14
2013	12
2012	16
2011	13
2010	12
2009	9
2008	3
2007	2
2006	1
2005	0
2004	1
2003	2
2002	0
2001	1
2000	1

As seen in Table 4, Turkey is the country, which has the largest number of publications. China, India, and Iran follow Turkey, respectively. In addition, we gave the percentages for publication number according to countries in Fig. 6. Due to the importance of energy concept, we observed that fuzzy MCDM methods are utilized in different countries to solve energy decision-making problems.

In Table 5, we presented the number of papers according to fuzzy MCDM methods. Fuzzy AHP method is the most common one among fuzzy MCDM methods. Fuzzy TOPSIS method follows it with the percentage of 27. Furthermore, the percentages of other fuzzy MCDM methods such as fuzzy ANP, fuzzy VIKOR, fuzzy ELECTRE, and fuzzy PROMETHEE are close to each other as shown in Fig. 7.

When we performed an analysis according to the type of fuzzy sets as presented in Fig. 8, it can be said that type-1 fuzzy sets named as traditional fuzzy sets are the most used type of fuzzy sets in energy policy and decision-making problems. Researchers generally utilize triangular and trapezoidal fuzzy numbers in these studies. New extensions of traditional fuzzy sets such as type-2 fuzzy sets, hesitant fuzzy sets, and intuitionistic fuzzy sets are also applied with MCDM methods to get more realistic results in recent years. By the way, we can claim that the application of extended fuzzy sets for energy decision-making problems will increase day after day.

We proposed a summary table including energy type, fuzzy MCDM methods, and type of fuzzy sets in Table 6. As seen in this table, fuzzy AHP is the most utilized method in energy policy and decision-making problems. Besides, due to increasing energy demand and effects of environmental problems, there is a tendency towards renewable energy sources. The availability of renewable energy sources has increased in the last decade due to developing technology. Hence, energy planning of countries should cover renewable energy sources for sustainable development. In addition, the extensions of fuzzy sets such as intuitionistic, hesitant and type-2 fuzzy sets are commonly used with MCDM methods to obtain more convenient solutions in recent years.

We also conducted a comprehensive analysis related to application areas and criteria for fuzzy MCDM studies examined in this study and presented the results in Table 7. Also, we analyzed the application areas for energy decision making by using fuzzy MCDM techniques. The application areas have been classified and usage frequencies have been determined. By the way we have analyzed the number of criteria and sub-criteria to check whether a correlation between MCDM techniques and the numbers is or not by considering Tables 6 and 7.

As a result of this analysis, we determined that fuzzy MCDM methodologies are effectively utilized different types of energy decision making problems. The main application areas can be ranked as evaluation of energy alternatives, prioritization of renewable energy sources, power plant (solar, wind, biomass, nuclear) site selection and assessment of energy storage technologies. In addition, these methodologies are also applied for various specific energy decision making problems such as sustainable energy crop selection, evaluation of different space heating systems, evaluation of trigeneration systems, assessment of building' energy performance, photovoltaic technology selection and assessment of bioenergy production technologies. On the other hand, when an analysis is realized with respect to evaluation criteria it is seen that technical, environmental, economic, technological, social and political are the most utilized main criteria for energy decision making problems. Besides, the most common sub-criteria located under these main criteria has been presented as follows:

Technical: Efficiency, maturity, reliability, installed capacity, availability, and distance to user.

Environmental: Pollutant emission, land use/requirement, need of waste disposal, impact on ecology, pollution (air, water, noise etc.).

Economic: Investment cost, operation and maintenance cost,

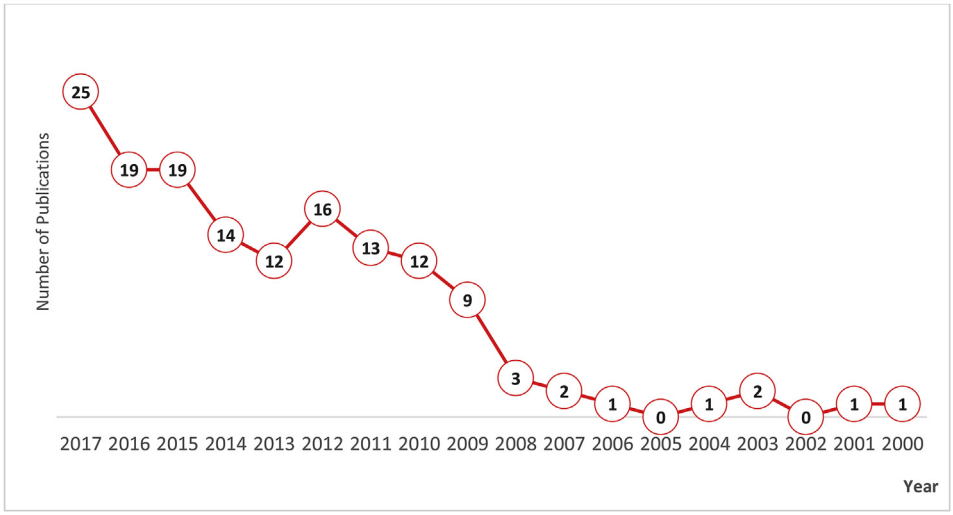


Fig. 4. A graphical summarization for the number of the publications according to years.

Table 3
Number of the papers based on journals.

Journal	Number of Publications
Energy	7
Energy Sources, Part B: Economics, Planning and Policy	6
Renewable and Sustainable Energy Reviews	6
Energy Conversion and Management	4
Applied Energy	5
Energies	3
Applied Soft Computing	3
Energy Procedia	3
Expert Systems with Applications	3

Table 4
Number of the papers based on countries.

Country	Number of Publications
Turkey	37
China	18
India	14
Iran	14
Taiwan	9
United States	8
Italy	7
Australia	6
Japan	5
South Korea	5

service life, payback period, affordability, availability of funds, net present value.

Technological: Risk, feasibility, local technical knowhow, duration of preparation phase, duration of implementation phase, continuity and predictability of performance.

Social: Social acceptance, job creation, social benefits.

Political: Political acceptance, compatibility with national energy policy, foreign dependency, national energy security.

Besides, we aimed to analyze relationship between the number of criteria and fuzzy MCDM methodologies. In fact, we tried to demonstrate with this analysis whether fuzzy MCDM methods affect the number of considered criteria. Therefore, we determined the number of

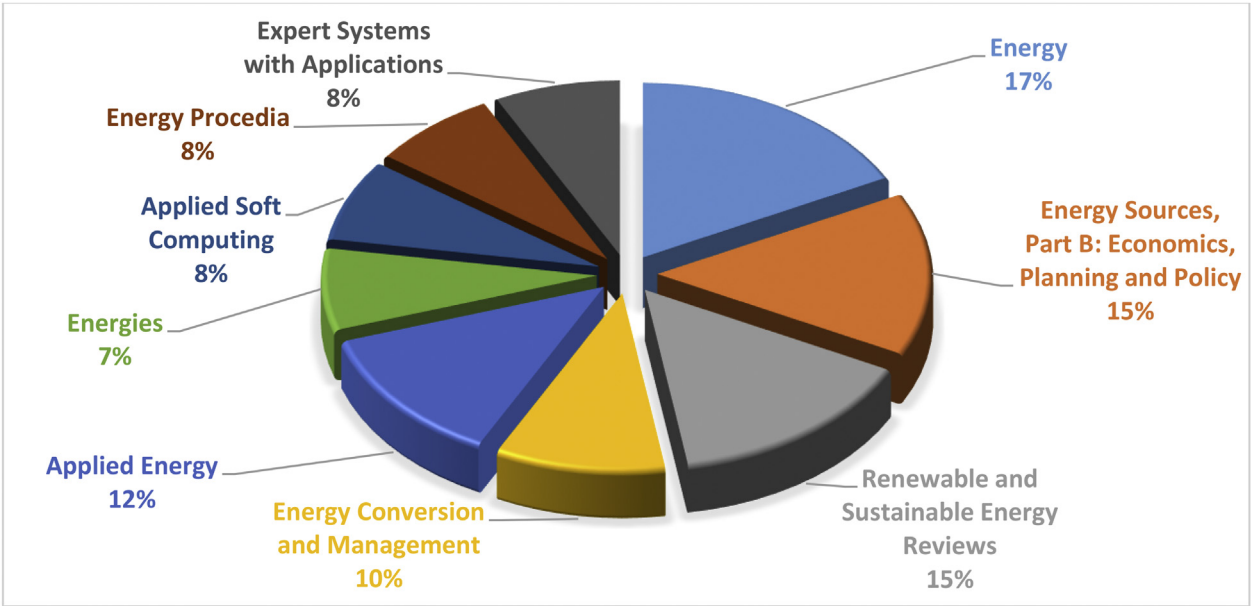


Fig. 5. The percentage distribution of the publications according to journals.

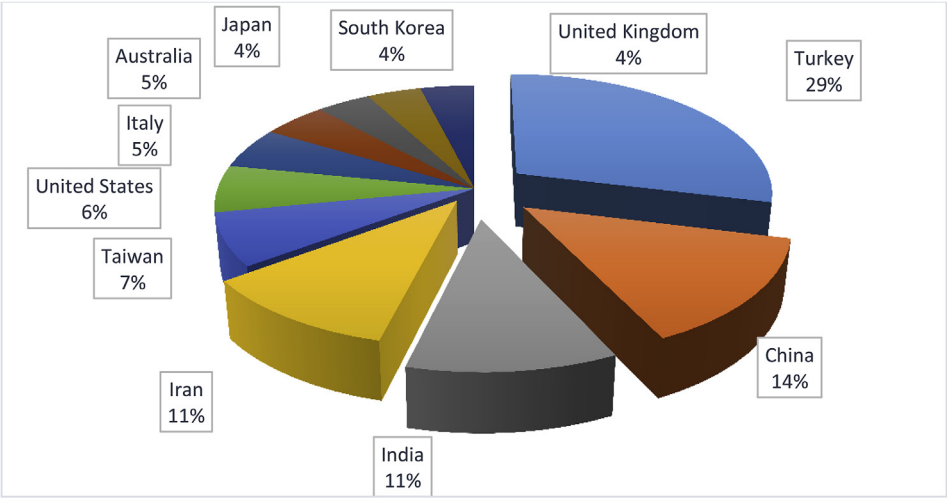


Fig. 6. The percentage distribution of the publications according to countries.

Table 5
Number of the papers based on fuzzy MCDM methods.

	Fuzzy MCDM Methods							
	AHP	ANP	TPSS	ELCTR	PRMTH	VKR	DMTL	Others
Number of Publications	48	17	40	10	9	9	7	10

main and sub-criteria for each fuzzy MCDM study examined in the scope of this paper. However, we cannot say that fuzzy MCDM techniques affect the number of evaluation criteria as a result of this analysis. Since, it can be seen that similar criteria are utilized with traditional MCDM methods for energy decision making problems in the literature. At this point, it is possible to say that more pragmatic and more realistic results can be obtained when the number of criteria increase and fuzzy methods are utilized.

We also realized some numerical analyses related to main criteria on the basis of energy decision making problems and the results of them have been presented in Figs. 9–11. Initially, we analyzed which main criteria are considered for all of energy decision making problems examined in this paper and collected them under eight criteria as economical, environmental, social/political, technological, geographical and structure, risk, efficiency and quality. The percentage distribution of these main criteria have been presented in Fig. 9.

According to Fig. 9, economical criteria are the most utilized criteria in energy decision making problems with the rate of 27%. These criteria are utilized as economic, economical, economy, cost, net present value, commercial, financial, finance and budget in the energy decision making problems. Besides, quality criterion are the least considered criteria with the rate of 2% in these problems. Similarly, the other criteria located in Fig. 9 can be utilized as different forms and these are given as follows:

Technological: Technological, technical, technic, technology.

Social/Political: Social, society, political, socio-political, policy, culture.

Environmental: Environment, environmental, emission, carbon, temperature, climate.

Geographical and Structure: Geological, meteorological, geographical, earthquake, land, distance, geomorphological, location.

Risk: Risk, reliability, safety.

We also made this criteria analysis in terms of the most common energy decision making problems such as evaluation of renewable energy alternatives, power plant site selection and energy assessment problems. The percentage distribution of main criteria for evaluation of

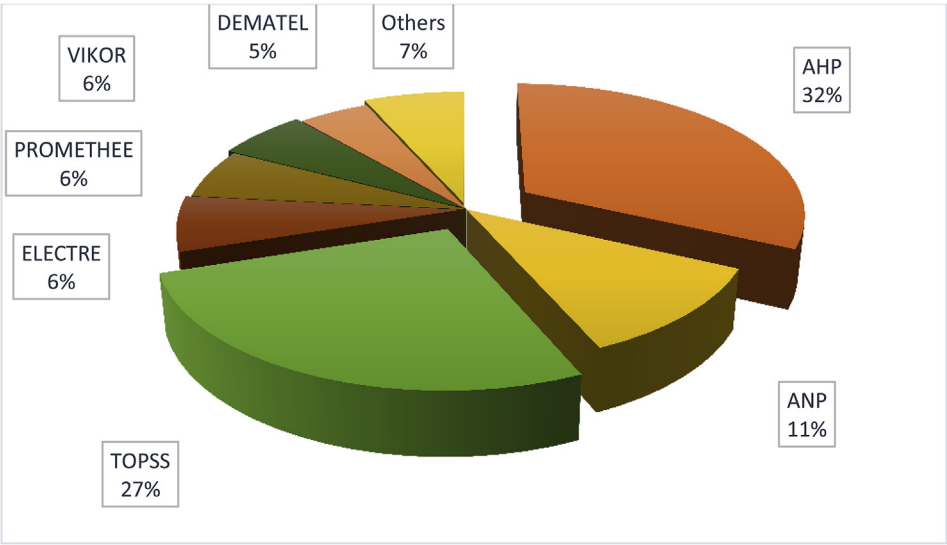


Fig. 7. The percentage distribution of the publications according to fuzzy MCDM methods.

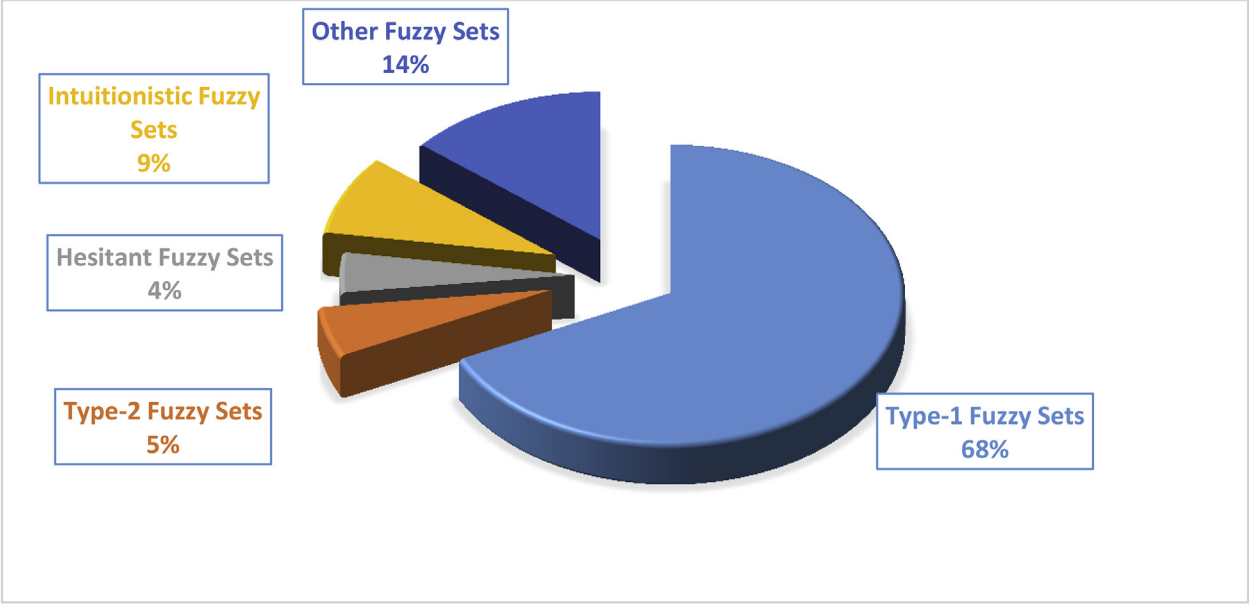


Fig. 8. The percentage distribution of the publications according to type of fuzzy sets.

renewable energy alternatives has been given in Fig. 10.

According to Fig. 10, economical and risk are the most and the least utilized criteria with the rates of 29% and 1% for this problem, respectively. It is also inferred from Fig. 10 that renewable energy alternatives are commonly evaluated in terms of social/political, technological and environmental aspects. By the way, we also analyzed usage of fuzzy MCDM techniques for renewable energy evaluation problems and see that the fuzzy AHP and fuzzy TOPSIS are most used techniques with the percentages of 41.67% and 25.00%, respectively. When we analyzed usage of fuzzy sets, we have determined that the type-1 fuzzy sets mostly preferred with the rate of 50.00% percent.

The percentage distributions of main criteria for power plant site selection and energy assessment problems have been given in Figs. 11 and 12, respectively.

As seen in Fig. 11, economical and risk are the most and the least utilized main criteria with the rates of 26% and 2% for power plant site selection problems, respectively. Besides, geographical/structure and environmental are the second and the third common main criteria for these problems. By the way, usage of fuzzy MCDM techniques for site selection problems have been prioritization as fuzzy AHP, other techniques and fuzzy TOPSIS with the rate of 30.43%, 30.43%, and 21.74, respectively. The other MCDM methods based on mathematical modelling, vague set theory, axiomatic design, Choquet Integral, fuzzy entropy have been often used in site selection problems. It is also clear that the type-1 fuzzy sets mostly preferred with the rate of 62.50% percent in these problems.

As seen in Fig. 12, similarly economical and risk are the most and the least considered criteria with the rates of %34 and %4 for energy assessment problems. Technological, environmental and social/political are the other commonly utilized main criteria for this problem, respectively. The usage of fuzzy MCDM techniques for energy assessment problems have been prioritization as fuzzy TOPSIS, fuzzy ANP and fuzzy AHP with the rate of 28.57%, 21.43%, and 21.43, respectively. We obtained that a critical result that is fuzzy TOPSIS that does not based on pair-wise comparison is mostly preferred in energy assessment problems. Additionally we see that the type-1 fuzzy sets mostly preferred with a highly rate of 71.43% percent in energy assessment problems.

By the way, a study related with the differences between energy types, fuzzy-based MCDM methods and type of fuzzy sets has been managed with respect to years. For this aim, the number of the papers from 2010 to 2017 have been analyzed based on these differences as shown in Table 8.

Some statistical analyses have been applied to obtain results of research questions. For this aim, two sample *t*-test has been applied to check there is any difference between renewable and non-renewable energy papers with respect to years. The obtained results are shown in Fig. 13.

According to Fig. 13 and 95% confidence interval is (2.38, 7.62) and it does not include zero, thus suggesting that there is a difference between number of the papers with respect to energy types. By the way, we see that the test statistic value is 4.09, with P-value of 0.001. Since the P-value is not greater than α-level (0.05), there is an evidence for a difference in number of the papers based on renewable energy versus non-renewable energy.

Then some hypotheses have been checked to analyze there is any difference between the papers with respect to fuzzy MCDM methods. Statistical analyses show that there is no difference between the papers with respect to usage of fuzzy ELECTRE, fuzzy PROMETHEE, fuzzy VIKOR and fuzzy DEMATEL methods. There are some evidences for the papers that use fuzzy AHP, fuzzy ANP and fuzzy TOPSIS methods. These papers have been exhaustively checked as shown in Figs. 14–16.

According to Fig. 14, the 95% confidence interval is (−0.80, 4.80) and it includes zero, thus suggesting that there is no difference between number of the papers that used fuzzy ANP and fuzzy TOPSIS methods. By the way, we see that the test statistic value is 1.53, with P-value of 0.148. Since the P-value is greater than α-level (0.05), there is no evidence for a difference in number of the papers based on fuzzy ANP and fuzzy TOPSIS. As MCDM methods these techniques have similar effect in energy decision making.

As seen in Fig. 15, test statistic value is 5.05, with P-value of 0.000. Since the P-value is not greater than α-level (0.05), there is an evidence for a difference in number of the papers that use fuzzy ANP and fuzzy AHP methods. We cannot say that as MCDM methods these techniques have similar effect in energy decision making. It is clear that the fuzzy AHP is the most preferred technique as a fuzzy MCDM method.

As seen in Fig. 16, the test statistic value is 0.71, with P-value of 0.491. Since the P-value is greater than α-level (0.05), there is no evidence for a difference in number of the papers based on fuzzy AHP and fuzzy TOPSIS methods. As MCDM methods these techniques have similar effect in energy decision making. By the way, to analyze the difference between number of the papers based on fuzzy AHP and fuzzy

Table 6
A classification of MCDM studies with respect to type of fuzzy sets, MCDM methods and energy types.

	Energy Types		Fuzzy MCDM Methods								Type of Fuzzy Sets				
	Renewable	Non-Renewable	AHP	ANP	TPSS	ELCTR	PRMTH	VKR	DMTL	Other	Type-1	Type-2	Hesitant	Intuitionistic	Other
Jayaraman et al. [115]										✓	✓				
Zoghi et al. [114]	✓									✓					✓
Akbas and Bilgen [93]	✓	✓	✓	✓						✓	✓				
Sakthivel et al. [92]	✓				✓			✓			✓				
Cayir Ervural et al. [3]					✓						✓				
Colak and Kaya [90]	✓		✓		✓							✓	✓		
Alipour et al. [89]	✓	✓	✓								✓				
Wang et al. [88]					✓						✓				✓
Boran [58]	✓	✓			✓						✓				
Kulkarni et al. [41]	✓		✓								✓				
Papapostolou et al. [57]	✓				✓						✓				
Ren and Liang [87]					✓					✓	✓				
Peng and Wang [113]										✓				✓	
Tabaraee et al. [86]					✓		✓				✓				
Perera et al. [56]					✓										✓
Khistandar et al. [112]	✓									✓					✓
Mishra et al. [111]	✓									✓				✓	
Elzarka et al. [91]	✓									✓					✓
Liang and Xu [55]					✓								✓		✓
Buyukozkan and Guleryuz [85]	✓			✓	✓				✓						✓
Wiguna et al. [83]	✓		✓								✓				
Multazam et al. [39]	✓		✓								✓				
Bal Besikci et al. [40]			✓								✓				
Mardani et al. [84]			✓		✓					✓	✓				
Aktas and Kabak [107]	✓									✓					✓
Gitinavard et al. [108]	✓							✓	✓				✓		
Cebi et al. [106]	✓		✓							✓	✓				
Abdullah and Najib [38]	✓	✓	✓											✓	
Erdogan and Kaya [18]		✓	✓		✓							✓			
Gumus et al. [54]	✓				✓									✓	
Cutz et al. [109]	✓									✓	✓				
Afsordegan et al. [81]	✓	✓	✓		✓						✓				
Yunna et al. [110]	✓					✓								✓	
Kabak et al. [49]				✓							✓				
Wu et al. [82]								✓	✓				✓		
Rehman and Khan [4]	✓									✓					✓
Erdogan and Kaya [78]			✓		✓							✓			
Ozkan et al. [80]			✓		✓							✓			
Fetanat and Khorasaninejad [77]	✓			✓		✓			✓		✓				
Cevik Onar et al. [104]	✓		✓							✓				✓	
Balin and Baracli [79]	✓		✓		✓							✓			
Zhang et al. [103]	✓	✓								✓					✓
Guo and Zhao [53]					✓						✓				
Long and Geng [105]	✓				✓					✓				✓	
Sengul et al. [52]	✓				✓					✓					✓
Van de Kaa et al. [76]	✓									✓	✓				
Wu et al. [101]	✓									✓				✓	
Buyukozkan and Guleryuz [74]	✓		✓		✓										✓
Wu et al. [102]	✓									✓					✓
Kurt [75]		✓			✓					✓	✓				
Tasri and Susilawati [37]	✓		✓								✓				
Erol et al. [100]		✓								✓	✓				
Kabak et al. [48]				✓							✓				
Sagbas and Mazmanoglu [36]	✓		✓								✓				
Ertay et al. [71]	✓		✓								✓				
Balezentiene et al. [99]										✓	✓				
Lazzerini and Pistolesi [73]			✓								✓				
Lee et al. [64]			✓								✓				
Cavallaro and Ciraolo [60]	✓						✓				✓				
Gumus et al. [72]	✓		✓							✓	✓				
Oztaysi et al. [47]	✓			✓							✓				
Kabak et al. [46]				✓							✓				
Suo et al. [98]										✓	✓				
Boran et al. [116]										✓	✓				
Lee et al. [45]	✓			✓							✓				
Choudhary and Shankar [68]		✓	✓								✓				
Locatelli and Mancini [69]		✓	✓								✓				
Daim et al. [70]	✓									✓	✓				
Garcia-Cascales et al. [51]	✓				✓						✓				
Jing et al. [97]										✓	✓				

(*continued on next page*)

Table 6 (*continued*)

	Energy Types		Fuzzy MCDM Methods								Type of Fuzzy Sets				
	Renewable	Non-Renewable	AHP	ANP	TPSS	ELCTR	PRMTH	VKR	DMTL	Other	Type-1	Type-2	Hesitant	Intuitionistic	Other
Sadeghi et al. [67]	✓		✓		✓						✓				
Zheng et al. [66]			✓								✓				
Lee et al. [44]	✓			✓							✓				
Ekmekcioglu et al. [65]		✓	✓		✓					✓	✓				
Kang et al. [43]	✓			✓							✓				
Lee et al. [34]	✓		✓								✓				
Wang et al. [35]			✓								✓				
Kaya and Kahraman [50]					✓						✓				
Chen and Pang [42]	✓			✓							✓				
Lee et al. [62]	✓		✓								✓				
Heo et al. [33]	✓		✓								✓				
Kaya and Kahraman [63]	✓		✓					✓			✓				
Kahraman and Kaya [8]	✓	✓	✓								✓				
Shen et al. [32]	✓		✓								✓				
Kahraman et al. [96]	✓									✓	✓				
Kahraman et al. [61]	✓		✓							✓	✓				
Lee et al. [31]			✓								✓				
Lee et al. [30]	✓		✓								✓				
Wang et al. [95]										✓	✓				
Jaber et al. [29]	✓	✓								✓					✓
Mamlook et al. [94]	✓									✓					✓
Goumas and Lygerou [59]							✓				✓				

TOPSIS with respect to years, a statistical analysis tool named Chi-Square Test has been constructed. The obtained results are shown in Fig. 17.

As shown in Fig. 17, the P-value and test statistic are determined as 0.047 and 14.272, respectively. As a result, we can reject null hypothesis when the α is 0.05. We can claim that there is no difference based on the years with respect to number of the papers that use fuzzy AHP and fuzzy TOPSIS methods. It is clear that there is no dependency between years for these papers and the usage of fuzzy TOPSIS and fuzzy AHP methods since they are not changing with respect to years.

5. Conclusions and future research suggestions

In general, energy policy and decision making problems include several conflicting criteria and it causes to more complexity in these problems. These problems can be evaluated in multi-dimensional space of different parameters and objectives in order to cope with complexity. To make this evaluation, multi-criteria decision making (MCDM) is one of the most suitable ways. Use of MCDM methods for these problems provides a reliable compromising solution by assessing energy sources, technologies and projects by regarding various objectives, aspects, and criteria. On the other hand, the collected data in these problems include vagueness and uncertainties. To deal with vagueness and uncertainties, fuzzy sets are used with MCDM methods in the decision-making process. Uncertainties are unavoidable due to increasing complexity of energy policy and decision making problems. Therefore, fuzzy MCDM methods are applied as analytic and effective approaches for solving these problems. Determination of correct energy policy from many available alternatives is so critical and needs detailed consideration of various criteria in the decision-making process. The application of the fuzzy MCDM methods in energy decision and policy-making problems provides some advantages such as to integrate a large number of different and often conflicting values into criteria and to make criteria evaluation phase for the various alternatives much more flexible, objective and acceptable. Moreover, these methods provide insight into priorities and sensitivities of the various weights involved. We observed that satisfying and consistent outcomes are generally obtained in these studies. Another point is that there are different kinds of fuzzy MCDM methods, but different results may be obtained by applying these methods.

In the scope of this study, 150 studies, consisting of 98 articles, 51 conference papers, and 1 book chapter, have been examined. We analyzed these studies by grouping them according to years, document types, journals, countries, type of fuzzy sets and fuzzy MCDM methods. As a result of this analysis, we concluded that the most used method is fuzzy AHP and it is generally applied together with another MCDM method. Actually, most studies include an application of two or more different types of MCDM methods jointly. Fuzzy MCDM methods have successfully facilitated in identifying the importance of various energy alternatives, scenario analysis, schemes, project plans, and investment decisions. One of the results is that these fuzzy MCDM methods are appropriate tools for energy policy and decision making problems. As a result of this literature analysis, we determined that a large number of fuzzy MCDM methods exist and many of these methods are applicable for the solution of energy policy and decision making problems such as selecting energy alternative, evaluating energy supply technologies, and determining energy policy. On the other hand, energy demand in all over the world increases, which is driven by industrialization and population growth, so this subject is an important study area for researchers. Hence, the number of studies increases in recent years as seen in the number of publications with respect to years. We expect that it will increase in the coming years, as well.

In addition, when a detailed analysis is made it is seen that there are many different application areas of fuzzy MCDM techniques for energy decision making problems. Prioritization of energy alternatives (non-renewable and renewable), power plant (nuclear, solar, wind etc.) site selection, assessment of energy storage options, evaluation of electricity generation alternatives, determination of energy policy for different countries, and sustainability assessment of energy alternatives can be indicated as the main application areas of fuzzy MCDM techniques for energy decision making problems. Besides, many main and sub-criteria are considered in order to evaluate these energy problems. The most common main criteria are technical, environmental, economic, social, and political. There are several sub-criteria locate under each main criterion. Reliability, efficiency, maturity, and availability are generally utilized as the sub-criteria of technical criterion. Investment, operation and maintenance costs, service life, net present value, and payback period locate under economic criterion as sub-criteria. Greenhouse gas emissions, land use, need of waste disposal, and environmental damage are the sub-criteria of environmental criterion. While social criterion

Table 7
A summarization of literature analysis with respect to criteria and application areas.

Author(s)	Application Area	Main Criteria	Number of Main Criteria	Number of Sub-Criteria
Jayaraman et al. [115]	Determination of optimal resource allocation for energy consumption, workforce, and GHG emission reduction	Gross Domestic Product (GDP), Electricity consumption, Greenhouse Gas (GHG) Emissions, Number of employees	4	–
Zoghi et al. [114]	Optimum solar site selection	Environmental, Geomorphological, Location, Climatic	4	15
Akbas and Bilgen [93]	Selection of the ideal gas fuel at wastewater treatment plants	Low emission, High energy content, High quality gas, Easy procurement, Affordable unit price, Low operational cost, Feasible investment, Reliable technology	8	–
Sakthivel et al. [92]	Selection of optimum fuel biodiesel blend	Oxides of nitrogen, Smoke, Brake thermal efficiency, Carbon dioxide, Carbon monoxide, Hydrocarbon, Exhaust gas temperature, Ignition delay, Combustion duration, Maximum rate of pressure rise	10	–
Cayir Ervural et al. [3]	Energy planning	Strengths, Weaknesses, Opportunities, Threats	4	24
Colak and Kaya [90]	Prioritization of renewable energy alternatives	Quality of energy source, Technical, Environmental, Technological, Economic, Sociopolitical	6	29
Alipour et al. [89]	Prioritization of energy alternatives	Social, Technological, Economic, Environmental, Political	5	23
Wang et al. [88]	Assessment of polygeneration systems	Economic, Technological, Environmental, Social	4	11
Boran [58]	Evaluation of power plants	Efficiency, Installation cost, Electricity cost, Emission of O_2, Social acceptance	5	–
Kulkarni et al. [41]	Assessment of energy generation alternatives	Economic, Technical, Social, Environmental	4	–
Papapostolou et al. [57]	Assessment of alternative policy scenarios	Static efficiency, Flexibility, Applicability, Political acceptability	4	–
Ren and Liang [87]	Assessment of alternative marine fuels	Environmental, Economic, Technological, Social	4	11
Peng and Wang [113]	Selection of sustainable energy crop	Photosynthesis type, Energy safety, Biomass yield, Storability, Transportability	5	–
Tabaraee et al. [86]	Evaluation of power plants	Economic aspect, Technical aspect, Environmental aspect	3	7
Perera et al. [56]	Assessment of the design site specific distributed electrical hubs	Levelized energy cost, Initial capital cost, Grid integration level, Levelized CO2 emission, Utilization of renewable energy, Flexibility of the system, Loss of load probability	7	–
Khistandar et al. [112]	Assessment of bioenergy production technologies	Environmental, Economic, Technological, Social	4	15
Mishra et al. [111]	Evaluation of renewable energy alternatives	Feasibility, Economic risks, Pollutant Emission, Land requirement, Need of waste disposal, Land disruption, Water pollution, Investment costs, Security of energy supply, Source durability, Sustainability of the energy resources, Compatibility with national energy policy objective, Energy efficiency, Labour impact	14	–
Elzarka et al. [91]	Assessment of onsite renewable energy technologies	Environmental benefits, Reliability, Practicality, Maintenance, Cost effectiveness	5	–
Liang and Xu [55]	Selection of energy project	Economic, Technological, Environmental, Sociopolitical	4	–
Buyukozkan and Guleryuz [85]	Evaluation of renewable energy resources	Technical aspects, Economic aspects, Political aspects, Social aspects, Environmental aspects	5	20
Wiguna et al. [83]	Solar farm site selection	Distance from residential areas, Distance from roads, Slope, Orientation, Transmission line and substation Distance, Solar radiation	6	–
Multazam et al. [39]	Wind farm site selection	Technical, Economy, Environment	3	9
Bal Besikci et al. [40]	Prioritization of ship operational energy efficiency measures	Voyage performance management, Hull and propeller condition management, Engine maintenance onboard, Fuel management, System energy management, Increasing energy awareness	6	9
Mardani et al. [84]	Selection of energy saving technologies and solutions	Energy management, System efficiency, Equipment efficiency, Reduction of heating and cooling demands, Renewable energy	5	17
Aktas and Kabak [107]	Wind turbine location selection	Economic aspects, Environmental aspects, Social aspects, Technical aspects	4	16
Gitinavard et al. [108]	Evaluation of energy alternatives	Technology and sustainability, Environmental, Social-political, Economical	4	12
Cebi et al. [106]	Biomass power plant site selection	Main biomass source produced in the region, Alternative biomass sources produced in the region, Energy potential of the region, Setup and operating costs	4	15
Abdullah and Najib [38]	Sustainable energy planning	Technical, Economic, Environmental, Social	4	9
Erdogan and Kaya [18]	Nuclear power plant site selection	Technical, Economic, Reliability and safety, Natural conditions, Welfare-related	5	25
Gumus et al. [54]	Determination of the best wind energy technology	Employment, Government Tax, Income, Business Profit, Import, Land footprint, Water withdrawal, Energy use, Total GHG	9	–
Cutz et al. [109]	Evaluation of biomass energy sources and technologies	Moisture content, Ash content, Climate conditions, Availability, Stage of technology, Scale of operation, Complexity, Pretreatment, Cleaning systems, Residues, Process efficiency, Personnel competence, Manufacturing equipment, Engineering companies, Investment, Polygeneration, Versatility, Market availability, Market stability, Environmental impact, Manufacturer's warranty, Incentives and subsidies	22	–
Afsordegan et al. [81]	Selection of sustainable energy alternatives	Technical, Economic, Environmental, Social	4	9
Yunna et al. [110]	Offshore wind farm site selection	Wind resources, Construction and maintenance conditions, Supporting conditions onshore, Environmental impacts, Economic, Society benefits	6	22
Kabak et al. [49]	Energy policy making	Strengths, Weaknesses, Opportunities, Threats	4	21

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Table 7 (*continued*)

Author(s)	Application Area	Main Criteria	Number of Main Criteria	Number of Sub-Criteria
Wu et al. [82]	Product development of electric vehicle	Easy to drive, Fully automatic drive, Range of 80 km per charge, Easy to charge at home or office, Disc brakes, with increased regenerative braking, Tubeless tyres	5	–
Rehman and Khan [4]	Evaluation of wind turbine alternatives	Hub height, Wind speed, Mean energy output	3	3
Erdogan and Kaya [78]	Evaluation of energy alternatives	Technological, Environmental, Economical, Socio-political, Technical	5	31
Ozkan et al. [80]	Selection among energy storage alternatives	Political and Social, Environmental impacts, Cost, Technical	4	18
Fetanat and Khorasaninejad [77]	Wind farm site selection	Depth and height, Environmental issues, Proximity to facilities, Economic aspects, Resource technical, Culture	6	31
Cevik Onar et al. [104]	Wind energy technology selection	Reliability, Technical Characteristics, Performance, Cost factors, Availability, Maintenance, Cooperation, Domesticity	8	–
Balin and Baracli [79]	Evaluation of renewable energy alternatives	Efficiency, Exergy efficiency, Investment cost, Operation and maintenance cost, NO_x emission, CO_2 emission, Land use, Social acceptability, Job creation, Net present value	10	–
Zhang et al. [103]	Evaluation of energy alternatives	Technical, Economic Environmental, Social	4	7
Guo and Zhao [53]	Electric vehicle charging station site selection	Environmental, Economic, Social	3	11
Long and Geng [105]	Photovoltaic module selection	Quality, Cost, Reputation, Operational condition, Production capacity, After-sale service	6	26
Sengul et al. [52]	Prioritization of renewable energy supply systems	Technical, Economic, Environmental, Social	4	9
Van de Kaa et al. [76]	Photovoltaic technology selection	Characteristics of the standard supporter, Characteristics of the standard, Standard support strategy, Other stakeholders	4	13
Wu et al. [101]	Wind farm project plan selection	Quality, Economy, Risk, Environment, Contribution	5	41
Buyukozkan and Guleryuz [74]	Evaluation of renewable energy alternatives	Technical aspects, Economical aspects, Political aspects, Social aspects, Environmental aspects	5	16
Wu et al. [102]	Solar thermal power plant site selection	Energy, Infrastructure, Land, Environmental, Social	5	13
Kurt [75]	Nuclear power plant site selection	Geological, Meteorological, Socio-economic, Geographical	4	15
Tasri and Susilawati [37]	Evaluation of renewable energy alternatives	Quality of the energy source, Socio-political, Economic, Technological, Environmental	5	15
Erol et al. [100]	Nuclear power plant site selection	Population density, Earthquake, Geographic conditions, Meteorological characteristics, Cooling water features, Land use, Economic conditions	7	21
Kabak et al. [48]	Assessment of building' energy performance	Location and climate data, Geometrical shape, Building envelope, Mechanical systems, Lighting system, Hot water system, Renewable energy & cogeneration	7	–
Ertay et al. [71]	Evaluation of renewable energy alternatives	Technological, Environmental, Socio-Political, Economic	4	15
Balezentiene et al. [99]	Sustainable energy crop selection	Photosynthesis type, Soil carbon sequestration, Water adaptation, N input requirement, Erosion control, dry mass, Energy yield	7	–
Lazzerini and Pistolesi [73]	The choice of the best alternative in energy dispatching in smart (micro)grids	Environmental impact, Cost of the energy, Distance of supply, Load level of the power lines	4	–
Lee et al. [64]	Assessment of the strategic energy technologies against high oil prices	Economic impact, Commercial potential, Inner capacity, Technical spin-off, Development cost	5	–
Gumus et al. [72]	Determination of the most suitable hydrogen energy storage alternative	Weightlessness, Capacity, Storage Loss and Leak, Reliability, Total System Cost	5	–
Oztaysi et al. [47]	Assessment of green energy alternatives	Economical, Environmental, Technical-Technological, Social, Political, Opportunity, Cost, Risk	8	33
Suo et al. [98]	Planning of electric power systems	Operation and maintenance costs, Capital cost, GHG emission, Energy intensity, Potential capacity, Current capacity, Scheduled retirement, Service life	8	–
Boran et al. [116]	Evaluation of energy policies	Economic, Environmental, Technical, Social benefits	4	7
Lee et al. [45]	Wind turbine evaluation	Machine characteristics, Economic aspects, Environmental issues, Technical levels	4	14
Choudhary and Shankar [68]	Thermal power plant site selection	Cost, Availability of resources, Accessibility, Biological environment, Physical environment, Socio-economic development	6	20
Locatelli and Mancini [69]	Nuclear power plant site selection	Financial-Related, Site-Related, Welfare-Related, Project-Life-Cycle	4	17
Daim et al. [70]	Evaluation of energy storage technologies	Technical, Economic, Environmental, Social	4	26
Garcia-Cascales et al. [51]	Evaluation of photovoltaic cells	Manufacturing cost, Efficiency in energy conversion, Market share, Emissions of greenhouse gases generated during the manufacturing process, Energy pay-back time	5	–
Jing et al. [97]	Assessment of combined cooling, heating and power (CCHP) systems	Technology, Economy, Environment, Society	4	17
Sadeghi et al. [67]	Evaluation of renewable energy sources	Socio-political, Economic, Environmental, Technological	4	13
Zheng et al. [66]	Evaluation for building energy conservation	Design stage, Construction stage, Use stage, Breaking stage	4	35
Lee et al. [34]	Assessment of hydrogen energy technologies	Economic impact, Commercial potential, Inner capacity, Technical spin-off	4	–
Ekmekcioglu et al. [65]	Nuclear power plant site selection	Internal, External	2	10
Kang et al. [43]	Wind farm performance evaluation	International trends, Domestic political issues, Environmental consciousness	3	14

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Table 7 (*continued*)

Author(s)	Application Area	Main Criteria	Number of Main Criteria	Number of Sub-Criteria
Lee et al. [44]	Analysis of strategic products for photovoltaic silicon thin-film solar cell power industry	Benefits, Opportunities, Costs, Risks	4	20
Wang et al. [35]	Evaluation for environmental impact of energy usage	Structure of energy use and industry, Technology and efficiency, Environmental impacts, Socio-economic benefits	4	17
Kaya and Kahraman [50]	Energy technology selection	Technical, Economic, Environmental, Social	4	9
Chen and Pang [42]	Evaluation of organizational forms for knowledge management in energy sector	Relationship & market capability, Business drive capability, Skills capability	3	9
Lee et al. [62]	Assessment of the R&D performance in the national hydrogen energy technology	Technological Status, Hydrogen technology infrastructure, R&D human resources, R&D budgets	4	–
Heo et al. [33]	Evaluation for usage of new and renewable energy alternatives	Technological, Market-Related, Economic, Environmental, Policy-Related	5	17
Kaya and Kahraman [63]	Selection of the best renewable energy	Technical, Economic, Environmental, Social	4	8
Kahraman and Kaya [8]	Selection among energy policies	Technological, Environmental, Socio-political, Economic	4	17
Shen et al. [32]	Evaluation of exploiting renewable energy sources	Energy, Environmental, Economic	3	14
Kahraman et al. [96]	Selection among renewable energy alternatives	Technological, Environmental, Economic, Socio-political	4	17
Kahraman et al. [61]	Selection among renewable energy alternatives	Technological, Environmental, Socio-political, Economic	4	17
Lee et al. [31]	Prioritization of energy technologies against high oil prices	Economical spin-off, Possibility of commercialization, Inner capacity, Technical spinoff	4	–
Lee et al. [30]	Evaluation of national competitiveness in the hydrogen technology sector	Technological status, R&D human resources, R&D budget, The hydrogen technology infrastructure	4	–
Wang et al. [95]	Evaluation of trigeneration systems	Economical, Technical, Environmental, Social	4	17
Jaber et al. [29]	Evaluation of different space heating systems	Reliability, National economy, Social benefits, Safety, Fuel, Maintenance, Service, Auxiliaries, Environmental	9	–
Mamlook et al. [94]	Evaluation of solar systems	Hardware cost, Maintenance and service, Auxiliary system, Environmental constraints	4	–
Goumas and Lygerou [59]	Evaluation and ranking of alternative exploitation schemes for the low enthalpy geothermal field	Net present value, Jobs, Energy use, Risk index	4	–

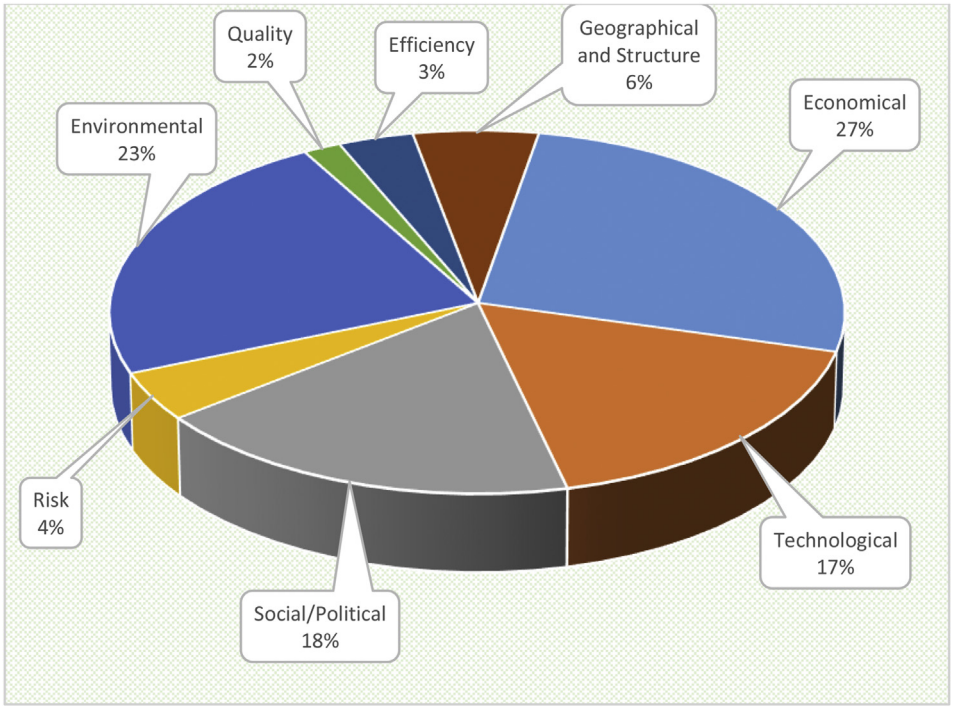


Fig. 9. The percentage distribution of main criteria for energy decision making problems.

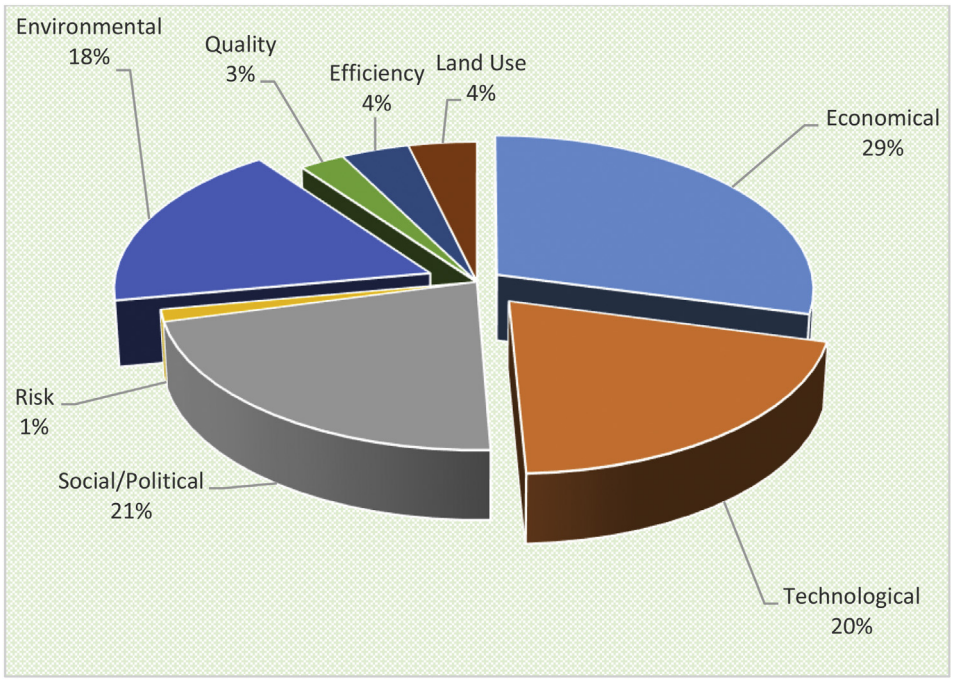


Fig. 10. The percentage distribution of main criteria for renewable energy evaluation problems.

includes labour impact and social acceptance criteria, political criterion includes political acceptance and compatibility with national energy policy. On the other hand, the sustainability impact of energy concept is evaluated in some of the fuzzy MCDM studies. In these studies, energy alternatives and energy policies are evaluated in terms of economic, environmental, and social aspects. Furthermore, while articles are reviewed, the criteria used in the problem are investigated and summarized. As a result of this analysis, the criteria are categorized in terms of four problem types, such as energy decision making, renewable energy evaluation, power plant site selection and energy assessment, in reviewed articles. It is seen that the most utilized criterion in all problem types is economical. On the other hand, the risk criterion is the least used one in the three of problem types.

When we completed the literature analysis, we saw that researchers are interested in renewable energy sources since they cause less greenhouse gas emission and known as clean and environment-friendly energy alternatives. Consequently, countries have become more open and inquiring towards renewable energy sources. This situation can be observed in the literature, which widely includes decision making studies for renewable energy sources. Generally, MCDM methodologies

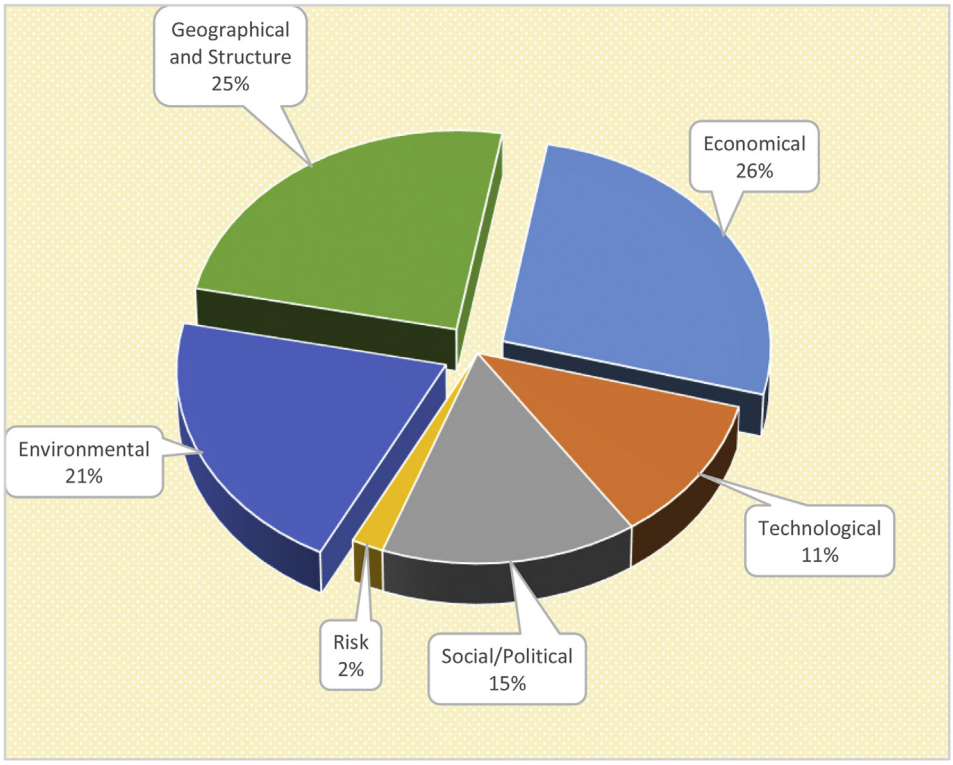


Fig. 11. The percentage distribution of main criteria for power plant site selection problems.

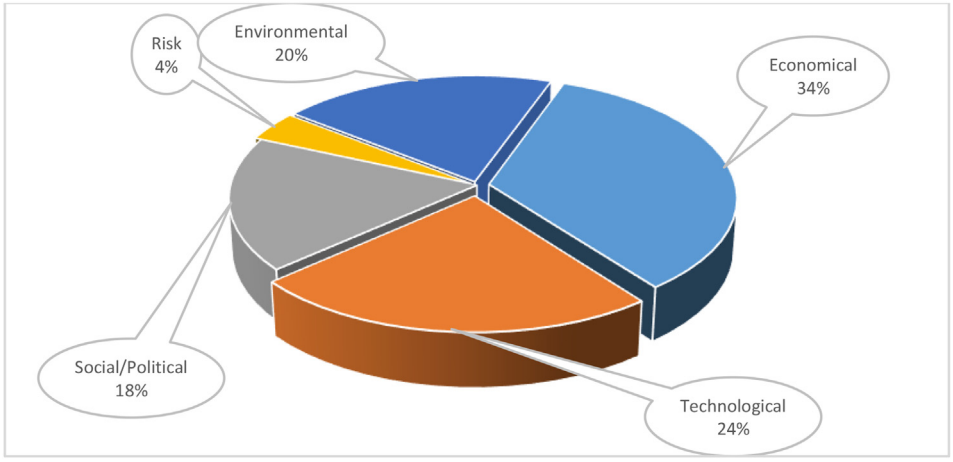


Fig. 12. The percentage distribution of main criteria for energy assessment problems.

Table 8
Numbers of MCDM studies with respect to type of fuzzy sets, MCDM methods and energy types based on years.

	Energy Types		Fuzzy MCDM Methods								Type of Fuzzy Sets				
	Renewable	Non-Renewable	AHP	ANP	TPSS	ELCTR	PRMTH	VKR	DMTL	Other	Type-1	Type-2	Hesitant	Intuitionistic	Other
2017	12	3	4	2	11	0	1	1	1	8	11	1	2	2	7
2016	11	3	8	1	4	1	0	2	2	5	8	1	2	3	2
2015	6	1	4	1	6	1	0	0	1	4	2	3	0	2	2
2014	6	2	3	1	2	0	0	0	0	5	6	0	0	1	2
2013	4	0	4	1	0	0	1	0	0	2	7	0	0	0	0
2012	4	2	3	2	2	0	0	0	0	4	10	0	0	0	0
2011	3	1	4	2	2	0	0	0	0	1	7	0	0	0	0
2010	7	1	5	1	0	0	0	1	0	1	7	0	0	0	0

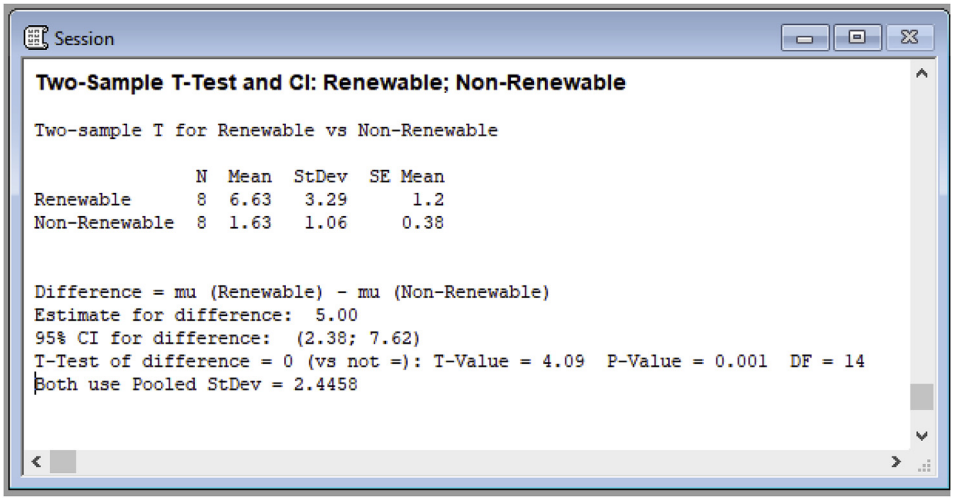


Fig. 13. Results of hypothesis test for energy types.

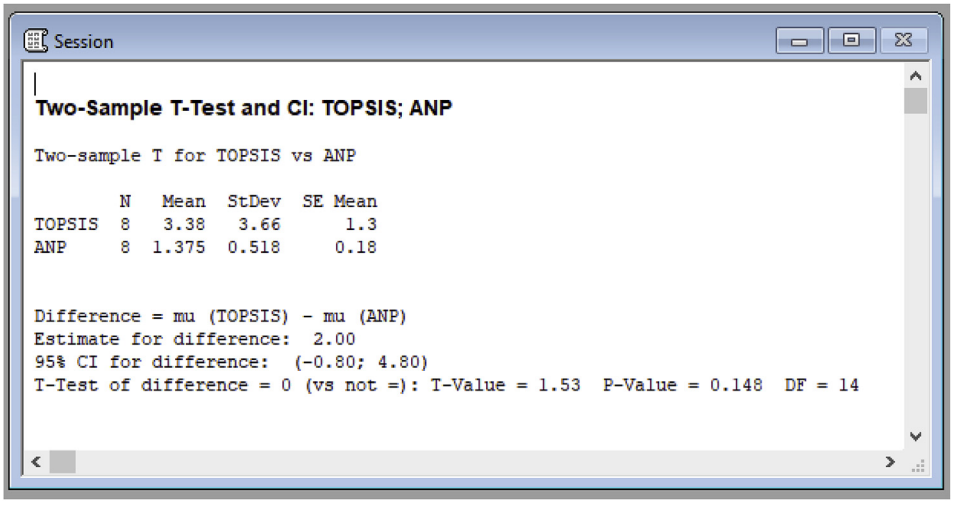


Fig. 14. Results of hypothesis test for fuzzy ANP and fuzzy TOPSIS.

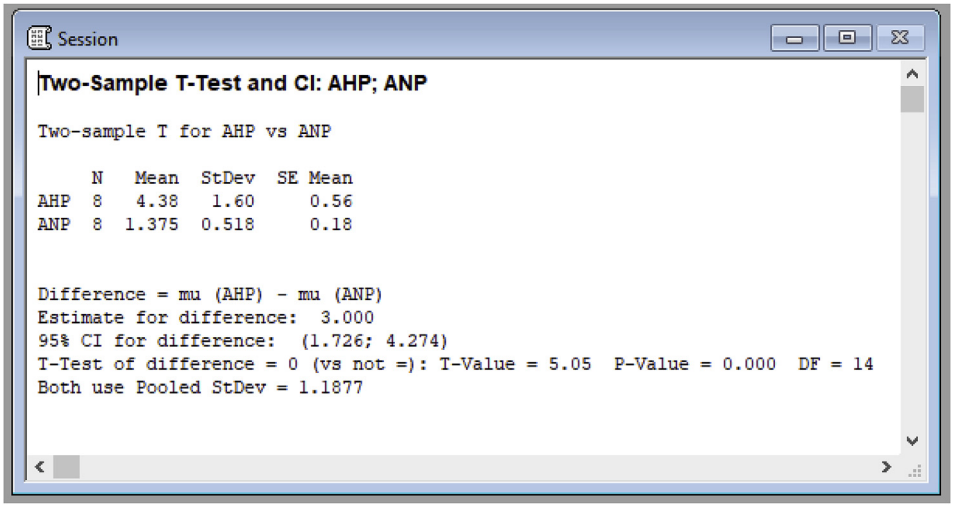


Fig. 15. Results of hypothesis test for fuzzy AHP and fuzzy ANP.

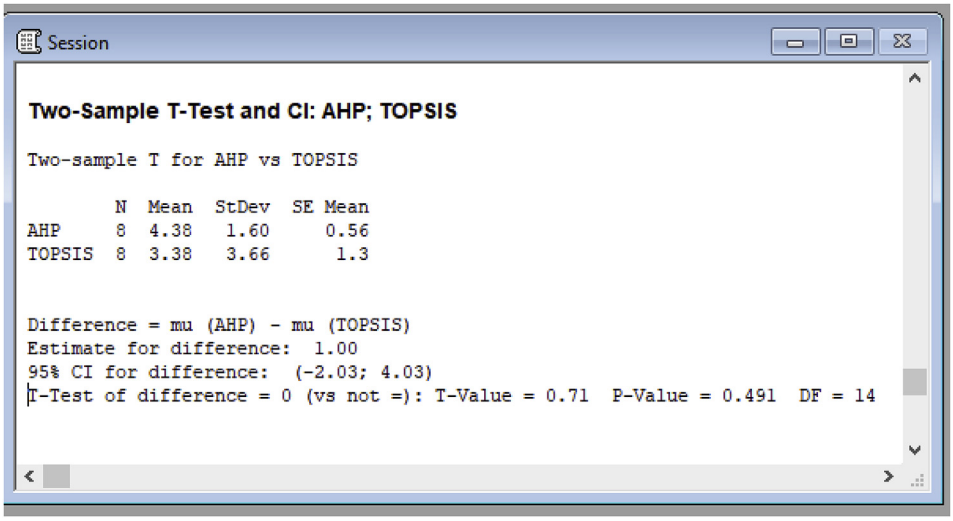


Fig. 16. Results of hypothesis test for fuzzy AHP and fuzzy TOPSIS.

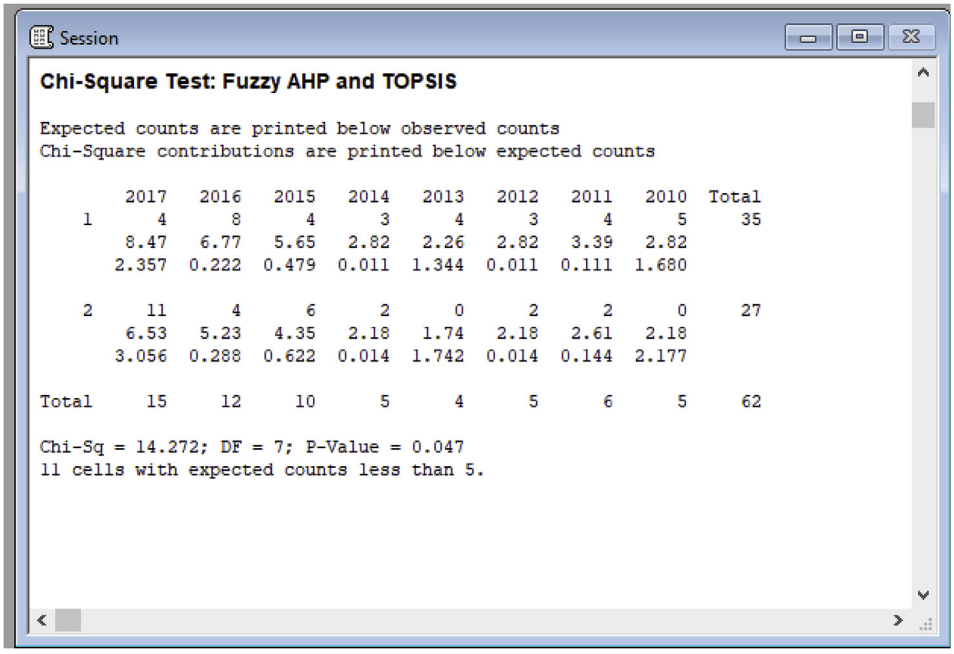


Fig. 17. Results of Chi-Square Test for fuzzy AHP and fuzzy TOPSIS.

use facilitated energy policy and decision making in renewable energy investments and evaluations. In addition, mostly preferred type of fuzzy sets is type-1 fuzzy sets.

In short, we realized a comprehensive literature review to examine fuzzy MCDM applications for energy policy-making problems. We aimed to provide a roadmap to researchers by providing them a comprehensive and relatively concise resume on this topic. Besides, it is aimed to reveal gaps in the fuzzy MCDM literature related to energy problems in terms of different aspects such as MCDM method, document type, and type of fuzzy sets. As a future work, a more general literature research about conventional MCDM applications can be conducted to investigate effects of conventional MCDM methods. Additionally, the results of fuzzy and traditional MCDM methods can be compared and discussed. By the way, we can suggest that the extended version of fuzzy sets such as type-2, hesitant, intuitionistic … etc. can be more analyzed and adopted into MCDM problems in energy policy-making. From this point, the new generations of fuzzy sets have been applied into AHP and TOPSIS to analyze energy policy-making problems.

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