Renewable and Sustainable Energy Reviews 80 (2017) 840–853

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Prioritization of renewable energy alternatives by using an integrated fuzzy MCDM model: A real case application for Turkey

Murat Çolak[a], İhsan Kaya[b,*]

[a] Kocaeli University, Department of Industrial Engineering, 41380 Izmit, Kocaeli, Turkey
[b] Yildiz Technical University, Department of Industrial Engineering, 34349 Besiktas, Istanbul, Turkey

ARTICLE INFO

Keywords:
Interval type-2 fuzzy sets
Hesitant fuzzy sets
AHP
Multi criteria decision making
Renewable energy sources
TOPSIS

ABSTRACT

Nowadays, energy demand is increasing as a result of growing population all over the world. Current conventional sources are not an adequate level in order to meet this energy requirement. Therefore, it is necessary to consider economic and clean alternative energy sources. In this context, renewable energy sources can be contemplated as a solution for this energy problem. On the other hand, selection among energy alternatives is a multi-criteria decision making (MCDM) problem and it is necessary to make an assessment in terms of several conflicting criteria. Sometimes, it may not be easy to evaluate these criteria by using crisp numbers and we need to evaluate by using human judgements and linguistic terms that can be used for a more flexible and sensitive evaluation. However, the fuzzy sets enable to cope with vagueness of evaluations in decision making process. In this study, an integrated MCDM model based on the fuzzy sets is proposed for prioritization of renewable energy alternatives in Turkey. The suggested fuzzy MCDM model combines analytic hierarchy process (AHP) based on interval type-2 fuzzy sets and hesitant fuzzy TOPSIS methods. Since the type-2 fuzzy sets whose membership functions are also fuzzy and hesitant fuzzy sets that enable to handle situations that an element has several membership value are more able to model uncertainties in decision making process, in this paper a MCDM methodology based on these two methods are suggested to evaluate renewable energy alternatives for Turkey. Interval type-2 fuzzy AHP method is applied to determine the weights of decision criteria, and hesitant fuzzy TOPSIS method is applied to prioritize renewable energy alternatives. A real case application has been presented via expert evaluations to indicate applicability of the proposed model. Besides, a sensitivity analysis has been performed to examine the effects of main criteria weights in ranking.

1. Introduction

Energy can be defined as ability to do a job and it is evaluated as a life source for people. Energy can be obtained from primary energy sources such as coal, oil, natural gas, uranium, biomass, geothermal, hydro, solar and wind in nature. Energy sources named oil, natural gas, coal and nuclear energy are known as fossil energy sources. On the other hand, wind, solar, biomass, hydraulic, geothermal, wave and hydrogen energy named as renewable energy. Renewable energy causes less greenhouse gas emission and renews itself continuously [1]. In a globalized world, energy has vital importance for countries as an important indicator of economic development. It is necessary to have abundant energy sources to provide sustainable development in a society. These energy sources should be obtained with a reasonable cost and should be used for all requirements of society without causing any negative social effects. Although fossil energy sources are finite, renewable energy sources like hydropower, solar and wind are found in the nature in the long run [2]. The population of world has increased by 2,5 times since 1950. Energy demand has increased seven-fold as a result of this increment. It is anticipated to increase of energy consumption more than %100 in Turkey, in 2030 compared to the present. Therefore, it is aimed to make the transition to renewable energy sources instead of conventional energy sources in Turkey [1]. In this paper, a new multi-criteria decision making (MCDM) model based on type-2 fuzzy sets and hesitant fuzzy sets is proposed to evaluate renewable energy alternatives for Turkey. By the way, multi-criteria decision making (MCDM) is a concept that used to select the best one among a set of alternatives by evaluating them in terms of several criteria [3]. MCDM methods enable to evaluate alternatives and make a selection among them. Although, selection among renewable energy alternatives is seen an easy process, it is necessary to make an assessment in terms of technical, economical, technological, socio-political and environmental aspects. Making evaluation with crisp numbers is not always possible. Therefore, sometimes linguistic

* Cooresponding author.
E-mail addresses: iekaya@yahoo.com, ihkaya@yildiz.edu.tr (İ. Kaya).

http://dx.doi.org/10.1016/j.rser.2017.05.194
Received 10 August 2016; Received in revised form 20 February 2017; Accepted 21 May 2017

variables are used to evaluate selection criteria [3]. Fuzzy sets which was developed by Zadeh [4], provides easiness to deal with uncertainties in decision making problems. Some new generalizations of fuzzy sets are developed to express uncertainties better in decision making process such as type-2 fuzzy sets, intuitionistic fuzzy sets, fuzzy multisets and hesitant fuzzy sets. Type-2 fuzzy sets are improved by Zadeh [5] as an extension of type-1 fuzzy sets. Type-2 fuzzy sets enable to minimize the effects of uncertainties in rule-based fuzzy logic systems. Type-1 fuzzy sets are not able to model uncertainties because their membership functions are crisp. On the other hand, type-2 fuzzy sets are able to model uncertainties in decision making process because their membership functions are also fuzzy [6]. Hesitant Fuzzy Sets (HFS) developed by Torra [7] enable to have several membership values for each element. In this paper, interval type-2 fuzzy sets and hesitant fuzzy sets are used with MCDM methods to evaluate renewable energy alternatives for Turkey. The seven alternatives named as hydraulic, wind, solar, geothermal, biomass, wave and hydrogen energy are evaluated in terms of six main criteria and twenty-nine sub-criteria. Interval type-2 fuzzy AHP method is utilized to calculate weights of criteria. Afterwards, TOPSIS method is applied with hesitant fuzzy sets to rank renewable energy alternatives. It is aimed to prioritize renewable alternatives and to propose energy roadmap for Turkey by means of this study.

In this paper, an integrated MCDM methodology consists of analytic hierarchy process (AHP) based on interval type-2 fuzzy sets and TOPSIS based on hesitant fuzzy sets. This integration based on hesitant and type-2 fuzzy sets has been suggested for prioritization of renewable energy alternatives for Turkey. Hesitant fuzzy sets can be successfully used when experts being hesitate among a set of membership degrees. It is possible to model these cases by using different membership values. In this manner, it is possible to increase the ability and flexibility of decision making process. By the way, in this paper the type-2 fuzzy sets are used to overcome incapability of traditional fuzzy sets in representing uncertainty through their membership functions. These two new methods are integrated into MCDM to increase flexibility and sensitiveness of decision making.

The rest of this paper is organized as follows: Section 2 gives some information about renewable energy alternatives and presents a literature review for renewable energy decision problems. Section 3 mentions about the proposed multi-criteria decision making model. Section 4 includes a real case application to rank renewable energy alternatives for Turkey. Section 5 presents obtained results and the future research suggestions.

2. Renewable energy alternatives

Turkey is located in the northern hemisphere between the 36–42 northern parallels and the 26–45 eastern meridians as one of the largest countries in both Europe and the Middle East. The surface of Turkey is 783.562 square km. Turkey has high population growth and quick urbanization. As a result of these situations, Turkey's energy demand is continuously increasing during last years. The total energy consumption of Turkey is nearly 150 Mtoe in 2010 and it is anticipated to reach 280 Mtoe until 2020. On the other hand, Turkey is an energy-importing country and need alternative energy sources to decrease the country's dependence on imported energy. In fact, Turkey has abundant renewable energy sources that can be a solution for its dependence on energy. Therefore, the Turkish government encourages energy users to prefer renewable energy sources such as solar, wind and hydropower because of inadequate quantity of domestic oil and natural gas [8].

The Turkish government desires to increase usage of renewable energy in all parts of life. For example, the share of renewable energy in electricity production is not at the desired level in Turkey. It is seen that the big part of electric power is provided from imported fossil energy sources. There are some negative effects of these imported energy

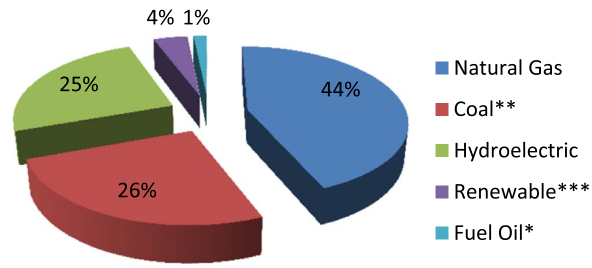

Fig. 1. Resource-based electric power production percentages [9], *Diesel and naphtha plants are included. **Domestic and imported coal are included. Asphaltites are included. ***It includes wind, geothermal, biomass and other renewable energy plants.

Table 1
Planned installed capacity values based on renewable energy sources [9].

Planned Installed Power Values Based on Renewable Energy Sources (MW)	2013	2015	2017	2019
Hydraulic	22,289	25,000	27,700	32,000
Wind	2759	5600	9500	10,000
Geothermal	311	360	420	700
Solar	–	300	1800	3000
Biomass	237	380	540	700

sources to national economy. Therefore, Ministry of Energy and National Resources (MENR) aims to increase the ratio of renewable energy sources in electricity production. The percentages of resource based electric power production according to 2015–2019 strategic plan of MENR are given in Fig. 1.

Planned installed capacity values based on renewable energy sources according to 2015–2019 strategic plan of MENR are given in Table 1. It is understood from Table 1 that Turkish government plans to increase the usage of renewable energy sources at strategic level.

The short explanations of renewable energy alternatives are given as follows:

2.1. Hydraulic energy

Hydraulic energy is obtained by transforming potential energy of water to kinetic energy. Obtained kinetic energy is initially transformed to mechanical energy with water turbines, afterwards mechanical energy is also transformed to electricity by means of a generator system [10]. Hydraulic energy has a big share in the renewable energy potential of Turkey. While theoretical hydroelectric potential of Turkey is 433 billion kWh, technical and economic potential are 216 and 140 billion kWh/year respectively. It is aimed to evaluate all of the hydroelectric potential defined as technical and economic for electricity generation by the year 2023 [11].

2.2. Solar energy

Solar energy is another type of renewable energy that obtained by collecting sunlight through solar or photovoltaic cells. High-intensity heat source is created by focusing sunlight with mirrors to generate electricity. Solar energy can be utilized for cooling, lighting, heating and other energy demands [8]. Turkey has high solar energy potential as a result of its geographic position. Total installed solar collector field has been calculated approximately as 18.640.000 m^2 by the year 2012 in Turkey. 768,000 tons of oil equivalent (toe) thermal energy was produced with solar collectors in 2012. 500,000 toe of produced thermal energy was used in housing and the rest of generated energy was utilized in industry. The installed capacity of 861 solar power plants has been calculated as 660,2 MW by the end of September 2016 [11].

2.3. Wind energy

Wind energy is obtained from air masses encountering different temperature ranges and is converted to electricity by means of wind turbines [1]. The wind energy potential of Turkey is determined as 48.000 MW. The total field corresponding to this potential is equal to % 1.3 of Turkey's surface. In Turkey, the annual wind energy production amount was determined as 11.652 GWh by the end of 2015 and the installed capacity of operated wind energy plants has been calculated as 5.228 MW by the end of September 2016 [11].

2.4. Geothermal energy

Geothermal energy is obtained from heat stored under the Earth's surface or by collecting absorbed heat derived from underground in the atmosphere and oceans [12]. Geothermal energy is evaluated as clean energy because of causing less greenhouse gas emission. Turkey has important geothermal energy potential because of locating on Alpine-Himalayan zone. The geothermal potential of Turkey is theoretically 31.500 MW. The geothermal energy fields distribute as West Anatolia (%79), Central Anatolia (%8,5), Marmara Region (%7,5), East Anatolia (%4,5) and the other regions (%0,5). The ninety-four percent of geothermal sources are low and medium temperature sources and used for heating, thermal tourism and obtaining mineral. Besides, the rest of them is suitable for electricity generation [11].

2.5. Biomass energy

Biomass is a renewable energy source and provides sustainable energy to users. Reducing greenhouse gas emission, conservation of fossil fuels and providing fuel supply can be said as advantages of biomass energy [13]. Various fuels named as biofuel can be generated from biomass sources and these fuels are classified as biodiesel, ethanol and biogas. Biodiesel can be used in all areas where diesel is used except very cold regions in Turkey. Bioethanol is a clean alternative fuel causes less greenhouse gas emission and can be used in transportation sector. Biogas is methane and carbon dioxide which occurs as a result of biodegradation of organic compounds such as animal, plantal and industrial wastes in oxygenless situations. It is estimated that the biogas amount that can be produced in Turkey is 1,5-2 Mtoe [11]. Besides, there are several biomass sources such as agricultural crops, municipal solid waste, animal manure and urban wastewater treatment sludge in Turkey. Agricultural crops are better than the others in terms of energy generation [13].

2.6. Hydrogen energy

Hydrogen energy is a secondary energy source generated from various raw materials such as fossil fuels, biomass and water. Hydrogen is %33 more efficient fuel compared to petroleum fuels. Although hydrogen is a clean and environment friendly energy source, it is not common because of high cost [1].

2.7. Wave energy

Wave energy occurs when winds bloat the surface of the water as a result of friction in the sea or ocean surface. The typical wave heights change between 2 and 3 m to obtain wave energy. Wave energy is more efficient than wind and solar as non-conventional energy. However, due to high energy conversion cost it is not commonly used [15]. The one fifth of coasts that not used maritime traffic, tourism, fishery and coastal facilities is suitable to obtain energy in Turkey. It is calculated that annual 18,5 billion kWh wave energy can be obtained from this part [14].

There are many studies where MCDM methods were used for evaluating renewable energy alternatives. Some of these studies are summarized as follows:

Haralambopoulos and Polatidis [16] presented an applicable group decision making framework to support multi-criteria analysis in renewable energy projects and used PROMETHEE II technique as a ranking method. Beccali et al. [17] presented an application of multi-criteria decision making methodology (MCDM) which utilized to evaluate an action plan for the diffusion of renewable energy technologies at regional scale. Then, they performed a case study for Sardinia Island and ranked three different scenarios with ELECTRE III method. Nigim et al. [18] used two MCDM methods to help communities in pre-feasibility ranking of local renewable energy sources. They respectively used analytic hierarchy process (AHP) and sequential interactive model for urban sustainability (SIMUS) methods. Madlener et al. [19] determined the contribution of renewable energy sources in heat and electricity production as a national and international purpose for sustainable development. They used PROMETHEE technique as a MCDM method and assessed five renewable energy scenarios in Austria for the year 2020. Kowalski et al. [20] analyzed integrated usage of scenario building and participatory multi-criteria analysis (PMCA) in the context of renewable energy with a methodologic point of view and evaluated five renewable energy scenarios in terms of seventeen sustainability criteria for Austria for 2020. Amer and Daim [21] handled renewable energy sources for electricity generation in Pakistan from technical, economic, social, environmental and political perspectives. They determined wind energy, solar photovoltaic energy, solar thermal energy and biomass energy as alternatives and applied analytic hierarchy process (AHP) method to prioritize these alternatives. Yazdani-Chamzini et al. [22] applied an integrated complex proportional assessment (COPRAS) – analytic hierarchy process (AHP) methodology to select the best renewable energy project. They compared the model with five MCDM tools to validate the output of the proposed model. Troldborg et al. [23] aimed to apply a multi-criteria analysis for a national scale sustainability evaluation and ranking of eleven renewable energy technologies in Scotland. Kabak and Dagdeviren [8] proposed a hybrid model based on analytic network process (ANP) and benefits, opportunities, costs and risks (BOCR) to determine the energy state of Turkey and to prioritize alternative renewable energy sources. They evaluated five alternatives in terms of nineteen criteria and determined hydro power as the best alternative for Turkey. Kahraman et al. [24] aimed to determine the best renewable energy alternative for Turkey by using fuzzy analytic hierarchy process and fuzzy axiomatic design methods. Wind energy is selected as the best renewable energy alternative in both methods. Kahraman et al. [25] proposed axiomatic design methodology to select among renewable energy alternatives under fuzziness. They aimed to determine the best renewable energy source for Turkey by means of this approach. Kaya and Kahraman [26] adopted two objectives in their study. Firstly, they used an integrated fuzzy AHP-VIKOR method to determine the best renewable energy alternative for Istanbul. Secondly, they aimed to select among alternative energy production sites in İstanbul through same methodology. They used AHP method to determine criteria weights and TOPSIS method to rank alternatives. Sadeghi et al. [27] proposed a fuzzy MCDM approach to evaluate four renewable energy alternatives (solar, geothermal, hydropower and wind energies) in Yazd province in Iran. They applied fuzzy analytic hierarchy process (FAHP) method to determine weights of criteria and ranked alternatives with fuzzy TOPSIS method. At the end of study they determined solar energy as the most appropriate alternative for the selected area. Manzardo et al. [28] developed a grey-based group decision-making methodology for selection of the best renewable energy technology by using life cycle sustainability approach. They evaluated twelve hydrogen production technologies by means of the proposed methodology and determined electrolysis of water as the best alternative. Ertay et al. [29] assessed the renewable energy alternatives as a key to abolish energy-related challenges of Turkey. They used MACBETH and AHP methods under fuzziness to evaluate renewable energy alternatives. Tasri and Susilawati [30] proposed a selection methodology based on fuzzy AHP to determine the most appropriate renewable energy alternative for electricity production in Indonesia. Buyukozkan and Guleryuz [31] developed a model to help investors in order to prioritize renewable energy alternatives. They proposed a new approach based on fuzzy analytic hierarchy process (FAHP) with linguistic interval fuzzy preference relations to obtain weights of evaluation criteria. Then, they applied fuzzy TOPSIS method to rank the alternatives. Sengul et al. [1] developed a multi-criteria decision support framework for ranking renewable energy supply systems in Turkey. They used ınterval Shannon's entropy methodology to determine criteria weights and fuzzy TOPSIS method to prioritize alternatives. Balin and Baraçli [32], proposed a MCDM model based on interval type-2 fuzzy sets for ranking renewable energy sources for Turkey. They used interval type-2 fuzzy AHP to calculate weights of criteria and applied interval type-2 fuzzy TOPSIS method to prioritize alternatives. Adhikary et al. [33], proposed a MCDM approach including TOPSIS and VIKOR methods to rank renewable energy alternatives for a site in Himalayan Region. Buyukozkan and Guleryuz [34], presented an integrated MCDM model combining the Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP) methods in order to determine the most suitable renewable energy resource for Turkey. Al Garni et al. [35], applied a MCDM methodology based on Analytic Hierarchy Process (AHP) to prioritize renewable power generation alternatives in terms of economic, environmental, socio-political and technical criteria. They presented a case study for Saudi Arabia as a big oil producer in the world. Celikbilek and Tuysuz [36], evaluated renewable energy sources by using a grey based MCDM methodology integrating DEMATEL, ANP and VIKOR methods. They demonstrated the effectiveness of the improved model through a case study. On the other hand, two review studies is realized to examine decision making applications for renewable energy. Suganthi et al. [37], realized a review on fuzzy logic based models with respect to renewable energy systems namely wind, bioenergy, solar, micro-grid and hybrid applications. They showed effectiveness of the fuzzy models to obtain more realistic results. Kumar et al. [38], made a comprehensive literature review of multi criteria decision making models which used in renewable energy applications.

Some analyses for classical and fuzzy MCDM papers examined in the scope of this study have been presented with figures as follows. Fig. 2. shows that the number of MCDM studies which made in energy field increase year by year. Most of studies has been realized in the last decade. The fourthy-seven percent of studies have been published between 2011 and 2017 years with the highest percentage.

Fig. 3. shows that the AHP method is the most common MCDM technique in energy field. This method is utilized both to rank alternatives and to calculate the weights of criteria. AHP method is followed by PROMETHEE, ELECTRE, TOPSIS and ANP methods respectively. It is seen that VIKOR method is used rarely and it can be suggested to apply this method in future studies.

Fig. 4. shows that fuzzy MCDM methods are also used for decision making problems in energy field. The seventy-two percent of fuzzy MCDM papers have been published between 2011 and 2017 years with the highest percentage. This percentage shows the interest to fuzzy sets in decision making problems. Fuzzy sets helps decision makers to handle uncertainties in decision making process. Therefore, different extensions of fuzzy sets are applied with MCDM methods to solve energy decision making problems.

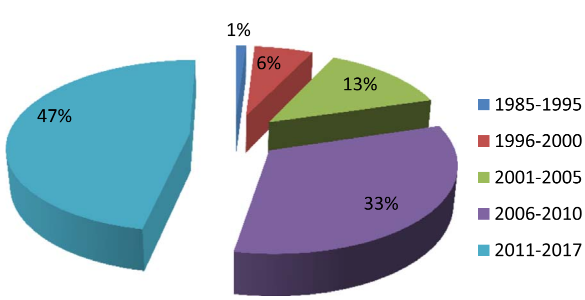

Fig. 2. A classification of MCDM papers based on years.

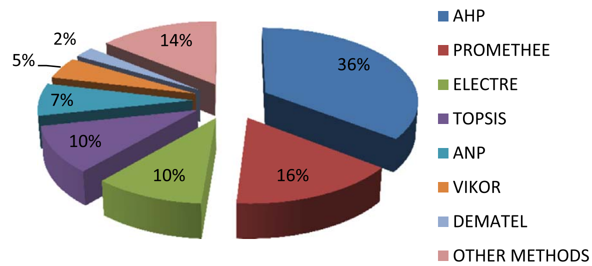

Fig. 3. The percentages of MCDM methods in energy decision making problems.

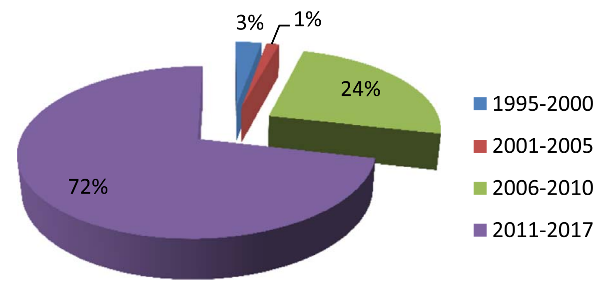

Fig. 4. A classification of fuzzy MCDM papers based on years.

Fig. 5. shows that fuzzy AHP method is the most common MCDM technique to solve decision making problems in energy field. This method is used in the fourthy percent of fuzzy MCDM studies. Fuzzy AHP is followed by fuzzy TOPSIS and fuzzy ANP methods.

In addition to these analyses, we can say that MCDM techniques are applied to solve energy decision making problems in different countries such as Iran, Greece, India, Spain and China. Due to importance of energy for sustainable development, countries desire to utilize analytical methods to determine energy policy. Therefore, conventional and fuzzy MCDM methods are applied to handle decision making problems based on energy in various regions of the world. When the literature is examined, it is seen that fuzzy MCDM methods which enable to cope with vagueness are preferred compared to history in recent years. Researchers also apply integrated methodologies that combine two or more methods to obtain more effective results.

3. The proposed fuzzy model

In this paper, an integrated fuzzy MCDM model is proposed to prioritize renewable energy alternatives for Turkey. The proposed model consists of a combination of interval type-2 fuzzy AHP and hesitant fuzzy TOPSIS methodologies. The model includes some phases as determination of selection criteria and renewable energy alternatives, taking expert assessments, interval type-2 fuzzy AHP calculations and ranking of renewable energy alternatives. A flowchart for the proposed model is presented in Fig. 6. In the first phase, the selection

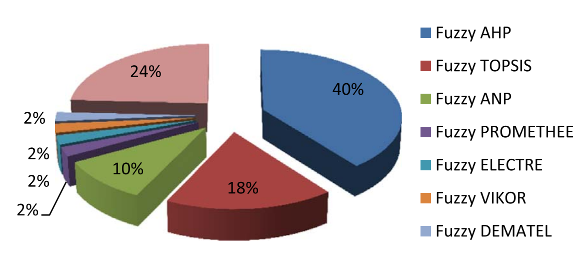

Fig. 5. The percentages of fuzzy MCDM methods in energy decision making problems.

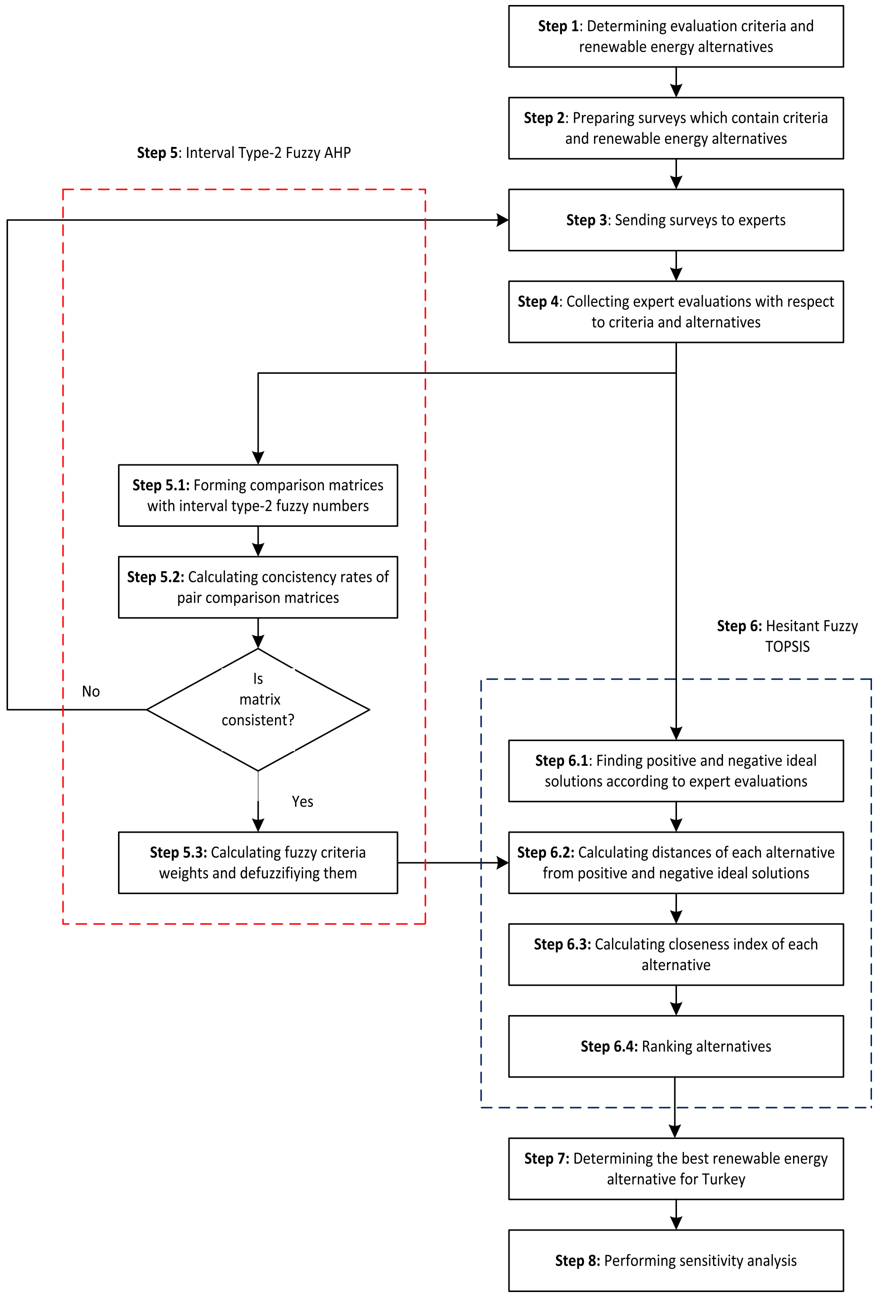

Fig. 6. The flowchart for the proposed fuzzy model.

Table 2
Linguistic terms and corresponding interval type-2 fuzzy numbers [43].

Linguistic Terms	Interval Type-2 Fuzzy Numbers
Absolutely Strong (AS)	(7, 8, 9, 9; 1, 1) (7.2, 8.2, 8.8, 9; 0.8, 0.8)
Very Strong (VS)	(5, 6, 8, 9; 1, 1) (5.2, 6.2, 7.8, 8.8; 0.8, 0.8)
Fairly Strong (FS)	(3, 4, 6, 7; 1, 1) (3.2, 4.2, 5.8, 6.8; 0.8, 0.8)
Slightly Strong (SS)	(1, 2, 4, 5; 1, 1) (1.2, 2.2, 3.8, 4.8; 0.8, 0.8)
Exactly Equal (E)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)

criteria and renewable energy alternatives are determined and a hierarchical structure is established related to criteria and alternatives. Afterwards, expert assessments are taken with respect to criteria and alternatives. The experts are selected among people studied energy and energy decision making. In the second phase, pairwise comparison matrices related to experts' individual assessments are formed through linguistic variables given in Table 2. Geometric mean is used to aggregate expert evaluations and final pairwise comparison matrices are obtained. The consistency of each pairwise comparison matrix is checked and the fuzzy criteria weights is calculated by using interval type-2 fuzzy AHP. At the end of this phase, interval type-2 fuzzy weights are defuzzified via the center of area (COA) method used by Kılıç and Kaya [3]. In the third phase, the ranks of renewable energy alternatives are determined by using hesitant fuzzy TOPSIS method. Alternatives are ranked according to their relative closeness value. The alternative which has the highest closeness value is selected as the best alternative.

3.1. Interval type-2 fuzzy sets

Type-2 fuzzy sets are developed by Zadeh [5] as an extension of type-1 fuzzy sets. The membership functions are also fuzzy in type-2 fuzzy sets as a difference from type-1 fuzzy sets. Type-2 fuzzy sets are more adequate than type-1 fuzzy sets to express uncertainties in human opinions. Interval type-2 fuzzy sets is a special form of type-2 fuzzy sets and used commonly in the literature. In this section, basic definitions and operations about interval type-2 fuzzy sets are given as follows [3,39,40,41]:

Definition 3.1. A type-2 fuzzy set $\tilde{\tilde{A}}$ in the universe of discourse X can be represented by a type-2 membership function $\mu_{\tilde{\tilde{A}}}$, shown as follows:

$$\tilde{\tilde{A}} = \{((x, u), \mu_{\tilde{\tilde{A}}}(x, u)) \ \forall\, x \in X, \forall\, u \in J_x \subseteq [0, 1], 0 \le \mu_{\tilde{\tilde{A}}}(x, u) \le 1\} \tag{1}$$

Where J_x denotes an interval in [0,1]. Moreover, the type-2 fuzzy set $\tilde{\tilde{A}}$ also can be represented as follows:

$$\tilde{\tilde{A}} = \int_{x\in X}\int_{u\in J_x} \frac{\mu_{\tilde{\tilde{A}}}(x, u)}{(x, u)} \tag{2}$$

Definition 3.2. Let $\tilde{\tilde{A}}$ be a type-2 fuzzy set in the universe of discourse X represented by the type-2 membership function $\mu_{\tilde{\tilde{A}}}$. If all $\mu_{\tilde{\tilde{A}}}(x, u) = 1$, then $\tilde{\tilde{A}}$ is called an interval type-2 fuzzy set. An interval type-2 fuzzy set $\tilde{\tilde{A}}$ can be regarded as a special case of a type-2 fuzzy sets, represented as follows:

$$\tilde{\tilde{A}} = \int_{x\in X}\int_{u\in J_x} \frac{1}{(x, u)} \tag{3}$$

where $J_x \subseteq [0, 1]$

$$\tilde{\tilde{A}}_1 = (\tilde{A}_1^U, \tilde{A}_1^L) = ((a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U))(a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)))$$

$$\tilde{\tilde{A}}_2 = (\tilde{A}_2^U, \tilde{A}_2^L) = ((a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; H_1(\tilde{A}_2^U), H_2(\tilde{A}_2^U))(a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; H_1(\tilde{A}_2^L), H_2(\tilde{A}_2^L)))$$

Let $\tilde{\tilde{A}}_1$ and $\tilde{\tilde{A}}_2$ be interval type-2 fuzzy sets. The basic operations between these two trapezoidal interval type-2 fuzzy sets are defined as follows:

Definition 3.3. Addition between two interval type-2 fuzzy sets is given as follows:

$$\begin{aligned}\tilde{\tilde{A}}_1 \oplus \tilde{\tilde{A}}_2 &= (\widetilde{A_1^U}, \widetilde{A_1^L}) \oplus (\widetilde{A_2^U}, \widetilde{A_2^L})\\ &=((((a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U;\ \min(H_1(\widetilde{A_1^U}), H_1(\widetilde{A_2^U})),\\ &\min(H_2(\widetilde{A_1^U}), H_2(\widetilde{A_2^U}))),\\ &(a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L;\ \min(H_1(\widetilde{A_1^L}), H_1(\widetilde{A_2^L})),\\ &\min(H_2(\widetilde{A_1^L}), H_2(\widetilde{A_2^L}))).\end{aligned} \tag{4}$$

Definition 3.4. Multiplication between two interval type-2 fuzzy sets is given as follows:

$$\begin{aligned}\tilde{\tilde{A}}_1 \otimes \tilde{\tilde{A}}_2 &= (\widetilde{A_1^U}, \widetilde{A_1^L}) \otimes (\widetilde{A_2^U}, \widetilde{A_2^L})\\ &=((((a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U;\ \min(H_1(\widetilde{A_1^U}), H_1(\widetilde{A_2^U})),\\ &\min(H_2(\widetilde{A_1^U}), H_2(\widetilde{A_2^U}))),\\ &(a_{11}^L \otimes a_{21}^L, a_{12}^L \otimes a_{22}^L, a_{13}^L \otimes a_{23}^L, a_{14}^L \otimes a_{24}^L;\ \min(H_1(\widetilde{A_1^L}), H_1(\widetilde{A_2^L})),\\ &\min(H_2(\widetilde{A_1^L}), H_2(\widetilde{A_2^L}))).\end{aligned} \tag{5}$$

Definition 3.5. Multiplication of an interval type-2 fuzzy number with a crisp number k is given as follows: where k > 0

$$\begin{aligned}k \times \tilde{\tilde{A}}_1 &= ((k \times a_{11}^U, k \times a_{12}^U, k \times a_{13}^U, k \times a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U)),\\ &(k \times a_{11}^L, k \times a_{12}^L, k \times a_{13}^L, k \times a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L))\end{aligned} \tag{6}$$

3.2. Interval type-2 fuzzy AHP

AHP is a multi-criteria decision making method proposed by Saaty [42]. In traditional AHP method, a 1–9 scale is utilized to form pairwise comparison matrix. Experts compare evaluation criteria by means of this scale and the priority vector is computed with crisp numbers. However, expert evaluations often contain some amount of uncertainty and subjectivity. For example, when an expert is not sure about comparative degree between two criteria, need another scale to evaluate them. Sometimes, experts cannot compare two criteria because of inadequate information. In this case, as an extension of type-1 fuzzy sets, type-2 fuzzy sets provide a mathematical easiness to express the uncertainties [3]. The steps of type-2 fuzzy AHP method are given as follows [3,40,41,43]:

Step 1: Decision making problem is defined and a hierarchical structure including purpose, criteria and alternatives is established.
Step 2: Type-2 fuzzy pairwise comparison matrix is formed according to expert evaluations by using interval type-2 fuzzy numbers. Each element of the pairwise comparison matrix is obtained with geometric mean of expert evaluations, and represent importance degree between two criteria. The linguistic terms used in evaluation process are given in Table 2.

The fuzzy pairwise comparison matrix is shown as follows:

$$\tilde{\tilde{A}} = \begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1n}\\ \tilde{\tilde{a}}_{21} & 1 & \cdots & \tilde{\tilde{a}}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \tilde{\tilde{a}}_{n1} & \tilde{\tilde{a}}_{n2} & \cdots & 1\end{bmatrix} = \begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1n}\\ 1/\tilde{\tilde{a}}_{12} & 1 & \cdots & \tilde{\tilde{a}}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 1/\tilde{\tilde{a}}_{1n} & 1/\tilde{\tilde{a}}_{2n} & \cdots & 1\end{bmatrix} \tag{7}$$

$$\tilde{\tilde{a}}_{ij} = \frac{1}{\tilde{\tilde{a}}_{ji}} \tag{8}$$

$$\tilde{\tilde{a}} = ((a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(a^U), H_2(a^U)(a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(a^L), H_2(a^L)) \tag{9}$$

$$\frac{1}{\tilde{\tilde{a}}} = ((\frac{1}{a_{14}^U}, \frac{1}{a_{13}^U}, \frac{1}{a_{12}^U}, \frac{1}{a_{11}^U}; H_1(a^U); H_2(a^U)(\frac{1}{a_{14}^L}, \frac{1}{a_{13}^L}, \frac{1}{a_{12}^L}, \frac{1}{a_{11}^L}; H_1(a^L); H_2(a^L)) \tag{10}$$

Geometric mean is used to aggregate expert opinions. The geometric mean of n interval type-2 fuzzy numbers is calculated as follows:

$$\tilde{\tilde{a}}_{ij} = \sqrt[n]{\tilde{\tilde{a}}_{ij}^1 \otimes \tilde{\tilde{a}}_{ij}^2 \otimes \ldots \otimes \tilde{\tilde{a}}_{ij}^n} = \left[\tilde{\tilde{a}}_{ij}^1 \otimes \tilde{\tilde{a}}_{ij}^2 \otimes \ldots \otimes \tilde{\tilde{a}}_{ij}^n\right]^{1/n} \tag{11}$$

$$\begin{aligned}\sqrt[n]{\tilde{\tilde{a}}_{ij}} &= ((\sqrt[n]{a_{ij1}^U}, \sqrt[n]{a_{ij2}^U}, \sqrt[n]{a_{ij3}^U}, \sqrt[n]{a_{ij4}^U}; H_1^U(a_{ij}), H_2^U(a_{ij}))\\ &(\sqrt[n]{a_{ij1}^L}, \sqrt[n]{a_{ij2}^L}, \sqrt[n]{a_{ij3}^L}, \sqrt[n]{a_{ij4}^L}; H_1^L(a_{ij}), H_2^L(a_{ij}))\end{aligned} \tag{12}$$

Step 3: The fuzzy pairwise comparison matrices are defuzzified and checked for consistency. If there is no consistency, the matrix is formed again.
Step 4: Fuzzy geometric mean is calculated for each criterion. The fuzzy geometric mean for each row is calculated as follows:

$$\tilde{\tilde{r}}_i = [\tilde{\tilde{a}}_{i1} \otimes \tilde{\tilde{a}}_{i2} \otimes \ldots \otimes \tilde{\tilde{a}}_{in}]^{1/n} \tag{13}$$

Step 5: The fuzzy weights are calculated for each criterion in a comparison matrix. The fuzzy weight of ith criterion is calculated as follows:

$$w_i = \tilde{\tilde{r}}_i \otimes [\tilde{\tilde{r}}_1 \oplus \ldots \oplus \tilde{\tilde{r}}_i \oplus \ldots \oplus \tilde{\tilde{r}}_n]^{-1} \quad (14)$$

As a result of this operation the local weights of criteria are calculated. The local weights of each sub-criteria should be multiplied with local weight of the upper level criteria to find global weights of each sub-criteria.

Step 6: Interval type-2 fuzzy weights are defuzzified. In this study, the center of area (COA) method is applied to defuzzify upper and lower membership values of interval type-2 fuzzy weights and obtain best nonfuzzy performance (BNP) value. The BNP value can be obtained as follows:

$$\tilde{w}_j = \frac{\int x u(x)dx}{\int u(x)dx} = \frac{-w_{j1} \times w_{j2} + w_{j3} \times w_{j4} + 1/3(w_{j4} - w_{j3})^2 - 1/3(w_{j2} - w_{j1})^2}{-w_{j1} - w_{j2} + w_{j3} + w_{j4}} \quad (15)$$

As the fuzzy numbers are symmetrical we could use the arithmetical mean of upper bound and lower bound to defuzzify interval type-2 fuzzy weights.

3.3. Hesitant fuzzy sets

Hesitant Fuzzy Sets (HFS) proposed by Torra as an extension of fuzzy sets, enable to have different membership values between zero and one for each element [44]. Interval valued HFS, generalized HFS, dual HFS, triangular fuzzy HFS and hesitant fuzzy linguistic terms sets can be considered as a classification for hesitant fuzzy sets [45]. Hesitant Fuzzy Sets are defined by Torra as follows [7]**:**

Definition 3.6. Let X be a reference set, then we define hesitant fuzzy set on X in terms of a function h that when applied to X returns a subset of [0,1]. Mathematical expression for HFS is given as follows:

$$E = \{ < x, h_E(x) > x \in X\},$$

where $h_E(x)$ is a set of some values in [0,1], denoting the possible membership degrees of the element $x \in X$ to the set E. For convenience, h = hE(x) is called as a hesitant fuzzy element (HFE) and H the set of all HFEs [46]. Some basic definitions about h, are given as follows [7];

The upper and lower bound of h, are given as follows:

$$\text{lowerbound: } h^-(x) = \min h(x) \quad (16)$$

$$\text{upperbound: } h^+(x) = \max h(x) \quad (17)$$

The complement of h is defined as h^c(x) and is given as follows:

$$h^c = \cup_{\gamma \in h} \{1 - \gamma\} \quad (18)$$

Intuitionistic fuzzy set $A_{env(h)}$ is defined as the envelope of h and given as follows:

$$A_{env(h)} = \{x, \mu(x), v(x)\} \quad (19)$$

where

$$\mu(x) = h^-(x) \quad (20)$$

$$v(x) = 1 - h^+(x) \quad (21)$$

Let $h = \cup_{\gamma \in h}\{\gamma\}$, $h_1 = \cup_{\gamma_1 \in h_1}\{\gamma_1\}$ and $h_2 = \cup_{\gamma_2 \in h_2}\{\gamma_2\}$ be three HFEs, basic operations on these elements are given as follows [43,46]**:**

$$h^\lambda = \cup_{\gamma \in h} \{\gamma^h\}; \quad (22)$$

$$\lambda h = \cup_{\gamma \in h} \{1 - (1 - \gamma)^\lambda\}; \quad (23)$$

$$h_1 \cup h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} , \max\{\gamma_1, \gamma_2\}; \quad (24)$$

$$h_1 \cap h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} , \min\{\gamma_1, \gamma_2\}; \quad (25)$$

$$h_1 \oplus h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} ,\{\gamma_1 + \gamma_2 - \gamma_1 \times \gamma_2\}; \quad (26)$$

$$h_1 \otimes h_2 = \cup_{\gamma_1 \in h_1, \gamma_2 \in h_2} ,\{\gamma_1\gamma_2\}; \quad (27)$$

There are some different distance measures used to calculate distance between two hesitant fuzzy elements. Xu and Xia [47], defined hesitant Euclidean distance measure as follows:

$$\|h_1 - h_2\| = \sqrt{\frac{1}{l}\sum_{i=1}^{l} |h_{1\sigma(i)} - h_{2\sigma(i)}|^2} \quad (28)$$

Zhang and Wei [46], suggested hesitant Hamming distance measure as follows:

$$\|h_1 - h_2\| = \frac{1}{l}\sum_{i=1}^{l} |h_{1\sigma(i)} - h_{2\sigma(i)}| \quad (29)$$

where l(h) indicates the number of elements in h, and defined as the length of HFE. However, the length of HFEs may not be equal. For example, while h_1 has two elements, h_2 may has three elements. In this case, because of $l_{h_1} < l_{h_2}$, h_1 should be extended by adding any value in it. The determination of this value generally depends on decision makers' preferences. Optimistic decision makers expect positive results and they can add the maximum value. On the other hand, pessimistic decision makers expect negative results and they can add the minimum value [46].

Decision makers may have some hesitancy in different levels of decision making process. Hesitant fuzzy sets can be beneficial for them to express their preferences in these situations [43]. By the way, MCDM methods are restructured by using HFS to obtain more sensitive results in decision making problems. There are many studies combining hesitant fuzzy sets and MCDM techniques in the literature.

Xu and Zhang [48]**,** proposed a new approach used TOPSIS method with hesitant fuzzy sets and implemented this approach for energy policy selection problem. Zhang and Wei [46]**,** used hesitant fuzzy sets with TOPSIS and VIKOR techniques for project ranking problem and compared the results of these methods. Zeng et al. [49]**,** presented MULTIMOORA-HF multi-criteria decision making method in order to deal with hesitant fuzzy information. Chen et al. [50]**,** developed hesitant fuzzy ELECTRE I method and applied this method to solve multi-criteria decision making problems. Liu and Rodrigues [51]**,** proposed a presentation of hesitant fuzzy linguistic term sets through fuzzy envelope and implemented this approach in a case study by using TOPSIS method. Çevik Onar et al. [43]**,** proposed an integrated interval type-2 fuzzy AHP and hesitant fuzzy TOPSIS methodology for strategic decision selection problem. Chen and Xu [52], proposed a novel MCDM approach entitled as hesitant fuzzy ELECTRE II method combining HFS and ELECTRE II technique. They presented numerical examples to show calculation details of the proposed method. Wang et al. [53], built an outranking method based on hesitant fuzzy linguistic term sets (HFLTS) to prioritize alternatives in MCDM problems. They presented a numerical example for supply chain management in order to explain this approach. Peng et al. [44], suggested an outranking method using multi-hesitant fuzzy sets (MHFS) similar to ELECTRE III for ranking alternatives in MCDM problems. Liao et al. [54], extended VIKOR method by using hesitant fuzzy linguistic term sets (HFLTS) to solve MCDM problems. They demonstrated the advantages of the proposed method via numerical examples. Yavuz et al. [55], evaluated alternative-fuel vehicles by using a hierarchical hesitant fuzzy linguistic model. They ranked alternatives according to hesitant linguistic assessments of experts and determined electric vehicle as the best alternative. Çevik Onar et al. [45], applied a novel fuzzy quality function deployment approach based on hesitant fuzzy linguistic term sets (HFLTS) in order to determine the best computer workstation. Aktas and Kabak [56], obtained criteria weights for wind turbine site selection problem by using a MCDM approach based on hesitant fuzzy sets. Wu et al. [57], developed a two-stage

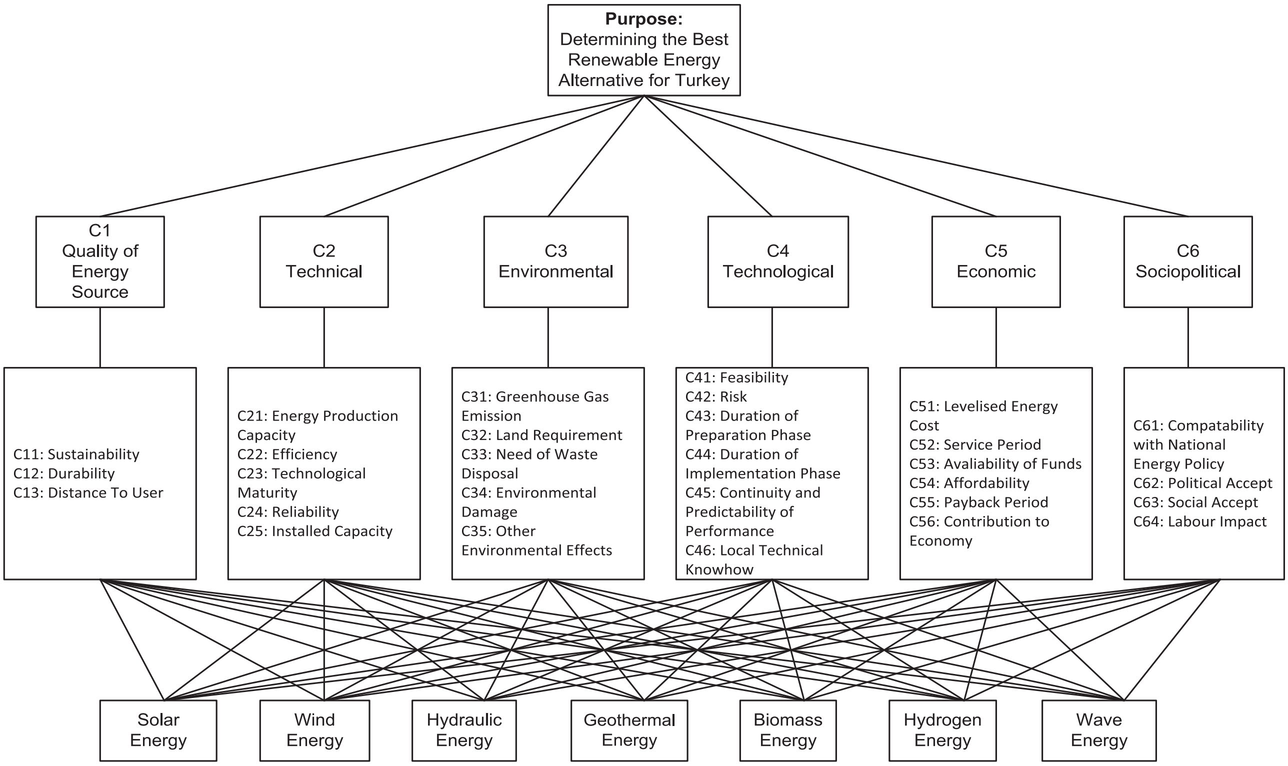

Fig. 7. The hierarchical structure for evaluation of renewable energy alternatives.

Quality Function Deployment (QFD) model combining DEMATEL and VIKOR methods under hesitant fuzzy environment. They used HF-DEMATEL technique in order to calculate customer requirements and ranked engineering characteristics through HF-VIKOR method. Senvar et al. [58], used hesitant fuzzy sets with TOPSIS method as a MCDM tool for hospital site selection problem. Adem and Dagdeviren [59], suggested a hierarchical hesitant fuzzy linguistic model to rank three life insurance policy alternatives. They assessed alternatives according to five main criteria and their sub-criteria. Gou et al. [60], suggested some hesitant fuzzy linguistic entropy and cross-entropy measures and developed a model for calculating the weights of criteria. Besides, they presented a hesitant fuzzy linguistic alternative queuing method (HFL-AQM) in order to solve MCDM problems.

3.4. Hesitant fuzzy TOPSIS

TOPSIS is a multi-criteria decision making technique initially developed by Hwang and Yoon [61]. This technique evaluates alternatives according to their distances to ideal solution. In this method, firstly positive and negative ideal solutions are determined according to criterion type. After that, the distances of each alternative to positive and negative ideal solutions are calculated. Relative closeness index of each alternative are calculated by means of these values. Finally, the alternative which has the highest closeness value is selected as the best alternative. In this paper, TOPSIS method is restructured with hesitant fuzzy sets to express uncertainties in human opinions. The steps of hesitant fuzzy TOPSIS method are given as follows [43,46]**:**

Step 1: The positive and negative ideal solutions are defined as follows:

$$A^{*} = \{h_1^{*}, h_2^{*}, h_3^{*}, \ldots, h_n^{*}\}$$

where

$$h_j^{*} = \cup_{i=1}^{m} h_{ij} = \cup_{\gamma_{1j}\in h_{1j},\ldots,\gamma_{mj}\in h_{mj}}\ \max\{\gamma_{1j}, \ldots, \gamma_{mj}\}\ j = 1, 2, \ldots, n \tag{30}$$

$$A^{-} = \{h_1^{-}, h_2^{-}, h_3^{-}, \ldots, h_n^{-}\}$$

where

$$h_j^{-} = \cap_{i=1}^{m} h_{ij} = \cap_{\gamma_{1j}\in h_{1j},\ldots,\gamma_{mj}\in h_{mj}}\ \min\{\gamma_{1j}, \ldots, \gamma_{mj}\}\ j = 1, 2, \ldots, n \tag{31}$$

Step 2: The distance of each alternative from the ideal solution is calculated. In this study, weighted hesitant normalized Euclidean distance is utilized for this purpose. The distance of an alternative from positive and negative ideal solution is calculated as follows:

$$D_i^{+} = \sum_{j=1}^{n} w_j \|h_{ij} - h_j^{*}\| \tag{32}$$

$$D_i^{-} = \sum_{j=1}^{n} w_j \|h_{ij} - h_j^{-}\| \tag{33}$$

where w_j expresses the crisp weight of the jth criterion calculated by interval type-2 fuzzy AHP.

Step 3: The relative closeness index used to rank alternatives is calculated as follows:

$$C_i = \frac{D_i^{-}}{(D_i^{-} + D_i^{+})} \tag{34}$$

Step 4: In this step, alternatives are ranked according to their relative closeness values. The alternative which has the biggest relative closeness value is selected as the best alternative.

4. A real case application for Turkey

In this study, an integrated fuzzy MCDM model based on interval type-2 fuzzy sets and hesitant fuzzy sets is proposed to evaluate renewable energy alternatives for Turkey. A comprehensive evaluation is made in terms of technical, sociopolitical, economic, technologic and environmental criteria. To evaluate renewable energy alternatives for

Table 3
The criteria for renewable energy alternatives.

Main Criteria	Sub-Criteria	Related References
C1 Quality of Energy Source	C11: Sustainability	Tasri and Susilawati, 2014 [30]
	C12: Durability	Tasri and Susilawati, 2014 [30]
	C13: Distance to user	Tasri and Susilawati, 2014 [30]
C2 Technical	C21: Energy production capacity	Troldborg et al., 2014 [23]
	C22: Efficiency	Kaya and Kahraman, 2010 [26]; Sengül et al., 2015 [1]
	C23: Technologic maturity	Kaya and Kahraman, 2010 [26]; Troldborg et al., 2014 [23]
	C24: Reliability	Kaya and Kahraman, 2010 [26]; Troldborg et al., 2014 [23]
	C25: Installed capacity	Sengül et al., 2015 [1]
C3 Environmental	C31: Greenhouse gas emission	Troldborg et al., 2014 [23]
	C32: Land requirement	Kahraman and Kaya, 2010; Tasri and Susilawati, 2014; Troldborg et al., 2014 [12,23,30]
	C33: Need of waste disposal	Kahraman and Kaya, 2010 [12]
	C34: Environmental damage	Kabak and Dagdeviren, 2014 [8]
	C35: Other environmental effects	Troldborg et al., 2014 [23]
C4 Technological	C41: Feasibility	Kahraman and Kaya, 2010 [12]
	C42: Risk	Kahraman and Kaya, 2010 [12]; Tasri and Susilawati, 2014 [30]
	C43: The duration of preparation phase	Kahraman and Kaya, 2010 [12]
	C44: The duration of implementation phase	Kahraman and Kaya, 2010 [12]
	C45: Continuity and predictability of performance	Kahraman and Kaya, 2010 [12]; Tasri and Susilawati, 2014 [30]
	C46: Local technical knowhow	Kahraman and Kaya, 2010 [12]; Tasri and Susilawati, 2014 [30]
C5 Economic	C51: Levelised energy cost	Troldborg et al., 2014 [23]
	C52: Service period	Sengül et al., 2015 [1]
	C53: Avaliability of funds	Kahraman and Kaya, 2010 [12]
	C54: Affordability	Tasri and Susilawati, 2014 [30]
	C55: Payback period	Sengül et al., 2015 [1]
	C56: Contribution to economy	Troldborg et al., 2014 [23]
C6 Sociopolitical	C61: Compatibility to national energy policy	Kahraman and Kaya, 2010 [12]
	C62: Political accept	Kahraman and Kaya, 2010 [12]
	C63: Social accept	Kahraman and Kaya, 2010 [12]; Kaya and Kahraman, 2010 [26]; Tasri and Susilawati, 2014 [30]; Troldborg et al., 2014 [23]
	C64: Labour impact	Kahraman and Kaya, 2010 [12]; Tasri and Susilawati, 2014 [30]; Sengül et al., 2015 [1]

Table 4
The linguistic evaluations for main criteria.

	C1	C2	C3	C4	C5	C6
	E1, E2, E3	**E1, E2, E3**	**E1, E2, E3**	**E1, E2, E3**	**E1, E2, E3**	**E1, E2, E3**
C1	E,E,E	FS,E,FS	SS,1/FS,SS	1/SS,1/SS,FS	1/SS,1/FS,SS	1/SS,SS,VS
C2	1/FS,E,1/FS	E,E,E	1/SS,1/SS,1/SS	1/FS,E,E	1/FS,1/SS,1/FS	1/FS,FS,FS
C3	1/SS,FS,1/SS	SS,SS,SS	E,E,E	1/SS,SS,SS	1/SS,SS,1/SS	1/SS,FS,FS
C4	SS,SS,1/FS	FS,E,E	SS,1/SS,1/SS	E,E,E	E,E,1/FS	E,FS,FS
C5	SS,FS,1/SS	FS,SS,FS	SS,1/SS,SS	E,E,FS	E,E,E	E,FS,VS
C6	SS,1/SS,1/VS	FS,1/FS,1/FS	SS,1/FS,1/FS	E,1/FS,1/FS	E,1/FS,1/VS	E,E,E

Turkey, a hierarchical structure includes 6 main, 29 sub-criteria and 7 alternatives is used. These criteria and alternatives are determined from review of energy decision making papers in the literature and experts' ideas. The proposed hierarchical structure for renewable energy alternatives for Turkey is shown in Fig. 7. The criteria used for decision making process and related literature are given in Table 3.

These criteria can be briefly summarized as follow [1,8,12,23,26,30]:

C11. Sustainability: This criterion is used to measure the ability of renewable energy source to continuously provide energy to end user.

C12. Durability: This criterion measures the length of period which renewable energy sources can be used. We know that the renewable energy sources have different levels of durability. For instance, durability of biomass energy is lower than other renewable energy sources because of seasonality, land use and biological processes.

C13. Distance to User: This criterion indicates distance of renewable energy source to users. Besides, it is significant to evaluate loss of energy and cost of structure during transmission.

C21. Energy production capacity: This criterion measures annual energy generation amount of renewable energy sources.

C22. Efficiency: This criterion indicates how much efficient energy can be obtained from renewable energy sources. It is one of the mostly used criteria to assess energy sources.

C23. Technological maturity: This criterion is an indicator of modernity of renewable energy source. It indicates amount of use of energy source both national and international levels.

C24. Reliability: This criterion is also important to evaluate renewable energy alternatives and examines interruption frequency of energy supply.

C25. Installed capacity: This criterion is used to assess renewable energy alternatives according to their installed capacity values.

C31. Greenhouse gas emission: This criterion is used to examine total greenhouse gas emission originated from renewable energy sources.

C32. Land requirement: This criterion is used to analyze the amount of land will be used to build renewable energy plant.

C33. Need of waste disposal: This criterion evaluates the negative impacts of renewable energy sources on the quality of environment. It is important criterion to decrease negative impacts of energy alternative on life quality.

Table 5
Aggregated fuzzy pairwise comparison matrix for main criteria.

	C1	C2	C3
C1	(1,1,1,1;1,1) (1,1,1,1;1,1)	(2.08,2.52,3.3,3.66;1,1) (2.17,2.6,3.23,3.59;0.8,0.8)	(0.52,0.88,1.59,2.02;1,1) (0.6,0.94,1.51,1.93;0.8,0.8)
C2	(0.27,0.31,0.40,0.48;1,1) (0.28,0.31,0.39,0.46;0.8,0.8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(0.2,0.25,0.50,1;1,1) (0.21,0.26,0.45,0.83;0.8,0.8)
C3	(0.49,0.63,1.14,1.91;1,1) (0.52,0.66,1.06,1.67;0.8,0.8)	(1,2,4,5;1,1) (1.2,2.2,3.8,4.8;0.8,0.8)	(1,1,1,1;1,1) (1,1,1,1;1,1)
C4	(0.52,0.88,1.59,2.02;1,1) (0.6,0.94,1.51,1.93;0.8,0.8)	(1.44,1.59,1.82,1.91;1,1) (1.47,1.61,1.8,1.89;0.8,0.8)	(0.34,0.50,1,1.71;1,1) (0.38,0.53,0.92,1.49;0.8,0.8)
C5	(0.84,1.26,2.29,3.27;1,1) (0.93,1.34,2.15,3;0.8,0.8)	(2.08,3.17,5.24,6.26;1,1) (2.31,3.39,5.04,6.05;0.8,0.8)	(0.59,1,2,2.92;1,1) (0.67,1.08,1.87,2.67;0.8,0.8)
C6	(0.28,0.4,0.7,1;1,1) (0.3,0.42,0.65,0.91;0.8,0.8)	(0.39,0.49,0.72,0.91;1,1) (0.42,0.5,0.69,0.87;0.8,0.8)	(0.27,0.39,0.63,0.82;1,1) (0.3,0.4,0.6,0.77;0.8,0.8)
	C4	**C5**	**C6**
C1	(0.49,0.63,1.14,1.91;1,1) (0.52,0.66,1.06,1.67;0.8,0.8)	(0.3,0.44,0.79,1.18;1,1) (0.34,0.46,0.74,1.07;0.8,0.8)	(1,1.44,2.52,3.56;1,1) (1.09,1.52,2.37,3.27;0.8,0.8)
C2	(0.52,0.55,0.63,0.69;1,1) (0.53,0.55,0.62,0.68;0.8,0.8)	(0.16,0.19,0.31,0.48;1,1) (0.17,0.2,0.3,0.43;0.8,0.8)	(1.08,1.40,2.08,2.53;1,1) ((1.15,1.44,2.01,2.43;0.8,0.8)
C3	(0.58,1,2,2.92;1,1) (0.67,1.08,1.87,2.67;0.8,0.8)	(0.34,0.5,1,1.71;1,1) (0.38,0.53,0.92,1.49;0.8,0.8)	(1.22,1.59,2.62,3.66;1,1) (1.29,1.66,2.47,3.37;0.8,0.8)
C4	(1,1,1,1;1,1) (1,1,1,1;1,1)	(0.52,0.55,0.63,0.69;1,1) (0.53,0.55,0.62,0.68;0.8,0.8)	(2.08,2.52,3.3,3.66;1,1) (2.17,2.6,3.23,3.59;0.8,0.8)
C5	(1.44,1.59,1.82,1.91;1,1) (1.47,1.61,1.8,1.89;0.8,0.8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(2.47,2.88,3.63,3.98;1,1) (2.55,2.96,3.56,3.91;0.8,0.8)
C6	(0.27,0.31,0.4,0.48;1,1) (0.28,0.31,0.39,0.46;0.8,0.8)	(0.25,0.28,0.35,0.4;1,1) (0.25,0.28,0.34,0.39;0.8,0.8)	(1,1,1,1;1,1) (1,1,1,1;1,1)

Table 6
Fuzzy geometric means.

C1	(0.74,0.98,1.51,1.98;1,1) (0.79,1.02,1.44,1.85;0.8,0.8)
C2	(0.41,0.47,0.66,0.86;1,1) (0.43,0.48,0.63,0.8;0.8,0.8)
C3	(0.7,1,1.7,2.37;1,1) (0.77,1.05,1.6,2.18;0.8,0.8)
C4	(0.81,1,1.35,1.6;1,1) (0.85,1.02,1.31,1.54;0.8,0.8)
C5	(1.24,1.62,2.33,2.77;1,1) (1.33,1.69,2.25,2.67;0.8,0.8)
C6	(0.35,0.43,0.59,0.72;1,1) (0.37,0.44,0.57,0.69;0.8,0.8)

Table 7
The weights of main criteria.

	Type-2 Fuzzy Weights	Defuzzified Weights	Normalized Weights
C1	(0.07,0.12,0.28,0.47;1,1) (0.08,0.13,0.25,0.41;0.8,0.8)	0.2302	0.1865
C2	(0.04,0.06,0.12,0.20;1,1) (0.04,0.06,0.11,0.18;0.8,0.8)	0.1037	0.0840
C3	(0.07,0.12,0.31,0.56;1,1) (0.08,0.14,0.28,0.48;0.8,0.8)	0.2603	0.2109
C4	(0.08,0.12,0.25,0.38;1,1) (0.09,0.13,0.23,0.34;0.8,0.8)	0.2037	0.1650
C5	(0.12,0.20,0.42,0.65;1,1) (0.14,0.22,0.39,0.59;0.8,0.8)	0.3458	0.2802
C6	(0.03,0.05,0.11,0.17;1,1) (0.04,0.06,0.10,0.15;0.8,0.8)	0.0905	0.0733

C34. Environmental damage: This criterion is used to examine the damage of renewable energy sources to environment and land.
C35. Other environmental effects: This criterion indicates the other impacts of renewable energy sources such as visual, noise and odor nuisances.
C41. Feasibility: This criterion measures convenience of implementation of the renewable energy sources. The number of successful tests obtained from renewable energy source can be used as a decision parameter.
C42. Risk: This criterion evaluates renewable energy sources by measuring the number of failures in a tested case.
C43. Duration of preparation phase: This criterion measures availability of the renewable energy sources to decrease financial assets and to provide the minimum cost.
C44. Duration of implementation phase: This criterion measures applicability of renewable energy sources to reach the minimum cost.
C45. Continuity and predictability of performance: This criterion evaluates operation and performance of renewable energy sources.
C46. Local technical knowhow: This criterion measures the ability of local workers to use renewable energy sources. Since the renewable energy plants are found distant places and it must be considered the availability of workers can make maintenance service.
C51. Levelised energy cost: This criterion includes all of the costs like investment, operating, fuel, maintenance and capital in the life of renewable energy source.
C52. Service period: This criterion evaluates useful life of renewable energy plant.

Table 8
The weights of sub-criteria.

	Type-2 Fuzzy Weights	Defuzzified Weights	Normalized Weights
C11	(0.03,0.06,0.20,0.40;1,1) (0.04,0.07,0.18,0.34;0.8,0.8)	0.1702	0.0910
C12	(0.01,0.02,0.08,0.18;1,1) (0.01,0.03,0.07,0.15;0.8,0.8)	0.0731	0.0391
C13	(0.01,0.01,0.05,0.11;1,1) (0.01,0.02,0.04,0.09;0.8,0.8)	0.0445	0.0238
C21	(0.00,0.01,0.04,0.11;1,1) (0.00,0.01,0.03,0.09;0.8,0.8)	0.0395	0.0211
C22	(0.01,0.01,0.05,0.13;1,1) (0.01,0.01,0.04,0.10;0.8,0.8)	0.0479	0.0256
C23	(0.00,0.01,0.02,0.06;1,1) (0.00,0.01,0.02,0.05;0.8,0.8)	0.0235	0,0126
C24	(0.00,0.01,0.03,0.10;1,1) (0.00,0.01,0.03,0.07;0.8,0.8)	0.0342	0.0183
C25	(0.00,0.01,0.02,0.06;1,1) (0.00,0.01,0.02,0.05;0.8,0.8)	0.0232	0.0124
C31	(0.01,0.04,0.18,0.45;1,1) (0.02,0.04,0.15,0.36;0.8,0.8)	0.1657	0.0885
C32	(0.00,0.01,0.03,0.10;1,1) (0.00,0.01,0.03,0.07;0.8,0.8)	0.0340	0.0182
C33	(0.01,0.01,0.07,0.19;1,1) (0.01,0.02,0.06,0.15;0.8,0.8)	0.0677	0.0362
C34	(0.01,0.03,0.12,0.30;1,1) (0.01,0.03,0.10,0.24;0.8,0.8)	0.1100	0.0588
C35	(0.00,0.01,0.03,0.08;1,1) (0.00,0.01,0.02,0.06;0.8,0.8)	0.0293	0.0157
C41	(0.01,0.02,0.08,0.19;1,1) (0.01,0.02,0.07,0.16;0.8,0.8)	0.0732	0.0391
C42	(0.01,0.02,0.09,0.20;1,1) (0.01,0.03,0.08,0.16;0.8,0.8)	0.0778	0.0416
C43	(0.00,0.01,0.03,0.07;1,1) (0.00,0.01,0.02,0.05;0.8,0.8)	0,0250	0.0134
C44	(0.00,0.01,0.03,0.07;1,1) (0.00,0.01,0.02,0.05;0.8,0.8)	0.0254	0.0136
C45	(0.01,0.02,0.09,0.20;1,1) (0.01,0.03,0.08,0.16;0.8,0.8)	0.0771	0.0412
C46	(0.00,0.01,0.05,0.12;1,1) (0.01,0.01,0.04,0.09;0.8,0.8)	0.0434	0.0232
C51	(0.01,0.01,0.07,0.17;1,1) (0.01,0.02,0.06,0.14;0.8,0.8)	0.0632	0.0338
C52	(0.00,0.01,0.05,0.14;1,1) (0.01,0.01,0.04,0.11;0.8,0.8)	0.0499	0.0266
C53	(0.02,0.05,0.25,0.60;1,1) (0.02,0.07,0.22,0.49;0.8,0.8)	0.2268	0.1212
C54	(0.01,0.01,0.05,0.14;1,1) (0.01,0.01,0.04,0.11;0.8,0.8)	0.0514	0.0275
C55	(0.01,0.02,0.08,0.20;1,1) (0.01,0.02,0.07,0.16;0.08,0.8)	0.0742	0.0397
C56	(0.01,0.03,0.12,0.28;1,1) (0.01,0.03,0.10,0.23;0.8,0.8)	0.1062	0.0568
C61	(0.01,0.02,0.06,0.12;1,1) (0.01,0.02,0.06,0.11;0.8,0.8)	0.0538	0.0288
C62	(0.00,0.01,0.02,0.04;1,1) (0.00,0.01,0.02,0.03;0.8,0.8)	0.0156	0.0083
C63	(0.00,0.01,0.02,0.03;1,1) (0.00,0.01,0.01,0.03;0.8,0.8)	0.0135	0.0072
C64	(0.01,0.01,0.04,0.08;1,1) (0.01,0.01,0.03,0.06;0.8,0.8)	0.0318	0.0170

C53. Avaliability of funds: This criterion evaluates national and international sources of funds and economic support of government.
C54. Affordability: This criterion is related to price of energy. It compares the price of renewable energy with average energy cost.
C55. Payback period: This criterion indicates the period that is necessary to compensate the original cost of renewable energy plant.
C56. Contribution to economy: This criterion evaluates renewable energy alternative in terms of its contribution to Turkish national economy by creating new industrial estates and business fields.
C61. Compatibility to national economy policy: This criterion evaluates compatibility of the proposed energy source with national economy policy.
C62. Political accept: This criterion evaluates consensus among political leaders for the proposed renewable energy alternatives.
C63. Social accept: This criterion evaluates consensus among social partners for the proposed renewable energy alternatives.
C64. Labour impact: This criterion examines the impact of renewable energy sources on unemployment. It evaluates job opportunities that can be provided by renewable energy alternative.

In this study, the weights of criteria are obtained by evaluations of experts who have experience in energy decision making problems. For this aim, surveys that contain criteria and renewable energy alternatives are prepared and have been evaluated by three experts by using linguistic variables. As a result of expert evaluations, the pairwise comparison matrices are obtained. Then, consistency ratios of each pairwise comparison matrix are clarified and confirmed. The expert evaluations related to main criteria are given in Table 4:

By the way, the aggregated fuzzy pairwise comparison matrix for main criteria is also presented in Table 5:

Then, the fuzzy geometric mean of each criteria has been calculated as shown in Table 6.

At the end of this stage, the interval type-2 fuzzy weights are calculated and these are defuzzified by using the center of area (COA) method. These weights are shown in Table 7 and Table 8, respectively.

The results show that the criterion "Economic" is determined as the most important criterion among main criteria with the weight of 0.2802. It is followed by the criteria named as "Environmental", "Quality of Energy Source", "Technological" and "Technical" respectively. By the way, the criterion named "Sociopolitical" is determined as the least important among main criteria and its weight is clarified as 0.0733. Also, we can say that the sub-criteria named "Availability of Funds" is also determined as the most important sub-criteria with the weight of 0.12 and the sub-criteria called as "Social Accept" is determined as the least important among sub-criteria.

After the criteria and subcriteria weights are determined by using AHP based on type-2 fuzzy sets, the TOPSIS method based on hesitant fuzzy sets (HFS) is applied for prioritization of renewable energy

Table 9
The decision matrix based on hesitant fuzzy sets.

Alternatives	**C11**	**C12**	**C13**	**C21**	**C22**
Solar Energy	{0.7,0.9,1}	{0.6,0.9,1}	{0.7,0.8,1}	{0.6,0.8,1}	{0.7,0.8,0.9}
Wind Energy	{0.5,0.7,0.8}	{0.6,0.7,0.9}	{0.5,0.7,0.8}	{0.6,0.7,0.8}	{0.7,0.8,1}
Hydraulic Energy	{0.5,0.7,0.8}	{0.7}	{0.4,0.5,0.6}	{0.5,0.6,0.7}	{0.4,0.6,0.7}
Geothermal Energy	{0.5,0.6,0.7}	{0.5,0.6,0.7}	{0.4,0.6,0.7}	{0.2,0.5}	{0.2,0.5,0.6}
Biomass Energy	{0.4,0.6,0.8}	{0.2,0.4,0.6}	{0.5,0.7,0.8}	{0.5,0.7}	{0.6}
Hydrogen Energy	{0.5,0.7,0.8}	{0.5,0.6,0.8}	{0.5,0.6,0.8}	{0.7,0.9}	{0.5,0.7,0.8}
Wave Energy	{0.2,0.6,0.7}	{0.4,0.6,0.7}	{0.2,0.4,0.6}	{0.5,0.7,0.8}	{0.5,0.6,0.8}
Alternatives	**C23**	**C24**	**C25**	**C31**	**C32**
Solar Energy	{0.7,0.8}	{0.7,0.9,1}	{0.5,0.7,0.8}	{0.6,0.7,1}	{0.6,0.7,0.8}
Wind Energy	{0.6,0.9,1}	{0.6,0.7,0.9}	{0.6,0.7,0.8}	{0.6,0.8,0.9}	{0.6,0.7,0.8}
Hydraulic Energy	{0.6,0.8,0.9}	{0.5,0.7,0.8}	{0.7,0.8,1}	{0.5,0.6,0.8}	{0.6,0.7,1}
Geothermal Energy	{0.5,0.7,0.8}	{0.5,0.7,0.8}	{0.5,0.6,0.7}	{0.5,0.6,0.7}	{0.5}
Biomass Energy	{0.6,0.7,0.8}	{0.5,0.6,0.7}	{0.4,0.5}	{0.2,0.4,0.5}	{0.3,0.5,0.7}
Hydrogen Energy	{0.2,0.5}	{0.2,0.4,0.6}	{0.2,0.3,0.4}	{0.3,0.4,0.5}	{0.2,0.3}
Wave Energy	{0.3,0.4,0.7}	{0.4,0.5,0.6}	{0.2}	{0.4,0.5,0.6}	{0.4,0.5,0.7}
Alternatives	**C33**	**C34**	**C35**	**C41**	**C42**
Solar Energy	{0.6,1}	{0.5,0.7,1}	{0.5,0.6,0.8}	{0.7,0.8,1}	{0.6,0.7,1}
Wind Energy	{0.5,0.7,0.8}	{0.7,0.9}	{0.6,0.7,1}	{0.7,0.9}	{0.5,0.7,0.8}
Hydraulic Energy	{0.4}	{0.2,0.4,0.5}	{0.4,0.5}	{0.7,0.8,0.9}	{0.6,0.7,0.8}
Geothermal Energy	{0.4,0.5,0.6}	{0.3,0.4,0.5}	{0.3,0.5,0.7}	{0.6,0.7,0.8}	{0.4,0.5,0.7}
Biomass Energy	{0.4,0.5,0.7}	{0.4,0.5,0.7}	{0.3,0.6}	{0.5,0.7,0.8}	{0.4,0.6,0.8}
Hydrogen Energy	{0.5,0.7,0.8}	{0.3,0.5,0.7}	{0.2,0.3,0.7}	{0.2,0.4,0.5}	{0.5,0.6,0.7}
Wave Energy	{0.2,0.4,0.6}	{0.4,0.5}	{0.4,0.5,0.6}	{0.4,0.6,0.7}	{0.2,0.5,0.6}
Alternatives	**C43**	**C44**	**C45**	**C46**	**C51**
Solar Energy	{0.7,0.8,1}	{0.6,0.8,1}	{0.5,0.7,0.9}	{0.6,0.8,0.9}	{0.6,0.9,1}
Wind Energy	{0.6,0.7,0.8}	{0.6,0.8}	{0.8,1}	{0.7,0.8,1}	{0.6,0.9}
Hydraulic Energy	{0.5,0.6,0.7}	{0.5,0.6,0.7}	{0.5,0.7,0.8}	{0.6,0.7,0.8}	{0.2,0.3,0.5}
Geothermal Energy	{0.6,0.7,0.8}	{0.6,0.7,0.8}	{0.5,0.6,0.8}	{0.5,0.7,0.8}	{0.5,0.7,0.8}
Biomass Energy	{0.5,0.6,0.7}	{0.7,0.8,0.9}	{0.7,0.8}	{0.5,0.6,0.7}	{0.5,0.7,0.9}
Hydrogen Energy	{0.4,0.5,0.6}	{0.2,0.4,0.7}	{0.4,0.6,0.8}	{0.2,0.3,0.4}	{0.2,0.5,0.6}
Wave Energy	{0.2,0.5,0.6}	{0.4,0.5,0.6}	{0.2,0.4,0.6}	{0.6,0.7,0.8}	{0.3,0.5,0.6}
Alternatives	**C52**	**C53**	**C54**	**C55**	**C56**
Solar Energy	{0.7,0.8,1}	{0.6,0.7,0.9}	{0.5,0.7,0.8}	{0.6,0.8,1}	{0.4,0.7,0.8}
Wind Energy	{0.7,0.9}	{0.7,0.9,1}	{0.6,0.7,0.8}	{0.7,0.8,0.9}	{0.6,0.9,1}
Hydraulic Energy	{0.7,0.8,0.9}	{0.5,0.6}	{0.6,0.7,0.8}	{0.5,0.6,0.7}	{0.6,0.7,0.8}
Geothermal Energy	{0.7,0.8,1}	{0.4,0.5,0.6}	{0.7,0.8,0.9}	{0.6,0.8,0.9}	{0.7,0.8,0.9}
Biomass Energy	{0.7,0.8,0.9}	{0.4,0.6,0.8}	{0.8,0.9,1}	{0.6,0.7,0.9}	{0.7,0.8}
Hydrogen Energy	{0.5,0.7}	{0.2,0.4,0.5}	{0.2,0.5,0.7}	{0.2,0.4,0.6}	{0.2,0.3,0.5}
Wave Energy	{0.2,0.6,0.8}	{0.3,0.4,0.5}	{0.3,0.4,0.6}	{0.4,0.5,0.6}	{0.4,0.5,0.6}
Alternatives	**C61**	**C62**	**C63**	**C64**	
Solar Energy	{0.7,0.8}	{0.6,0.8,1}	{0.7,0.9,1}	{0.5,0.7,0.8}	
Wind Energy	{0.9,1}	{0.6,0.8,0.9}	{0.8}	{0.5,0.7,0.9}	
Hydraulic Energy	{0.7,0.8}	{0.6,0.7,0.8}	{0.5,0.6,0.7}	{0.7,0.8,1}	
Geothermal Energy	{0.6,0.7,0.8}	{0.8,1}	{0.6,0.7,0.8}	{0.7,0.8}	
Biomass Energy	{0.8,0.9}	{0.6,0.7,0.8}	{0.6,0.8,0.9}	{0.4,0.6,0.7}	
Hydrogen Energy	{0.2,0.3,0.4}	{0.2,0.3,0.5}	{0.3,0.4,0.5}	{0.2,0.3,0.4}	
Wave Energy	{0.3,0.5,0.6}	{0.3,0.4,0.5}	{0.2,0.3,0.5}	{0.3,0.6}	

Table 10
The obtained results for renewable energy alternatives.

Alternatives	**D+**	**D-**	**C_i**	**Rank**
Wind Energy	0.259	0.586	0.693	1
Solar Energy	0.276	0.588	0.681	2
Hydraulic Energy	0.393	0.433	0.524	3
Biomass Energy	0.407	0.435	0.517	4
Geothermal Energy	0.406	0.422	0.510	5
Wave energy	0.539	0.310	0.365	6
Hydrogen Energy	0.542	0.308	0.362	7

alternatives. The decision matrix based on HFS that shown in Table 9 and shows possible membership values of each renewable energy alternatives is obtained by expert evaluations.

Then, the relative closeness values for each renewable energy alternative are calculated. The obtained values for each alternative and ranking results are shown in Table 10:

According to Table 10, the alternative "Wind Energy" is determined as the best renewable energy alternative for Turkey with the highest relative closeness value. This alternative is followed by "Solar Energy", "Hydraulic Energy", "Biomass Energy", "Geothermal Energy", and "Wave Energy". By the way, it is obtained that the alternative "Hydrogen Energy" is determined as the worst alternative for Turkey.

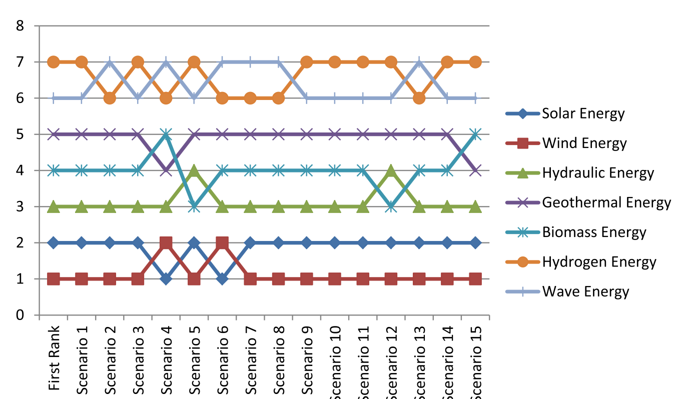

Fig. 8. The sensitivity analysis results for renewable energy alternatives.

4.1. Sensitivity analysis

In this section a sensitivity analysis is performed by changing the weights of main criteria to analyze the impact of criteria weights on ranking values of renewable energy alternatives. For this aim, 15 different scenarios are obtained by changing the weights of main criteria. The different ranks obtained from these scenarios are utilized to analyze impact of criteria weights. The scenarios have been generated as follows:

Scenario 1: By changing the weights of quality of energy source and technical criteria.
Scenario 2: By changing the weights of quality of energy source and environmental criteria.
Scenario 3: By changing the weights of quality of energy source and technological criteria.
Scenario 4: By changing the weights of quality of energy source and economic criteria.
Scenario 5: By changing the weights of quality of energy source and sociopolitical criteria.
Scenario 6: By changing the weights of technical and environmental criteria.
Scenario 7: By changing the weights of technical and technological criteria.
Scenario 8: By changing the weights of technical and economic criteria.
Scenario 9: By changing the weights of technical and sociopolitical criteria.
Scenario 10: By changing the weights of environmental and technological criteria.
Scenario 11: By changing the weights of environmental and economic criteria.
Scenario 12: By changing the weights of environmental and sociopolitical criteria.
Scenario 13: By changing the weights of technological and economic criteria.
Scenario 14: By changing the weights of technological and sociopolitical criteria.
Scenario 15: By changing the weights of economic and sociopolitical criteria.

The ranking of energy alternatives obtained from sensitivity analysis with respect to these scenarios are presented in Fig. 8.

According to results of sensitivity analysis, the alternative "Wind Energy" is clarified as the first alternative for 13 scenarios and is determined as the second alternative for other scenarios. The alternative "Solar Energy" is generally determined as the second alternative. The alternatives "Hydraulic Energy", "Biomass Energy" and "Geothermal Energy" have similar ranking for different scenarios. By the way, it is easy to make an inference that is the alternatives "Wave Energy" and "Hydrogen Energy" are determined as the sixth and seventh alternatives for all scenarios.

5. Conclusions

The energy requirement of Turkey increases with increasing population day by day. On the other hand, available energy sources are not enough to meet energy requirement in Turkey yet. In this sense, Turkey is dependent foreign energy sources. To overcome this dependency, the renewable energy sources are seen as an alternative in terms of being clean and environmentally sensitive. In this paper, evaluating renewable energy alternatives for Turkey is handled as a MCDM problem and aimed to determine the best renewable energy alternative. Thus, it is aimed to contribute to the energy policy of country at strategic level.

For this aim, a fuzzy based MCDM model has been suggested for prioritization of renewable energy alternatives. The proposed model consists of AHP methodology based on interval type-2 fuzzy sets and TOPSIS methodology based on hesitant fuzzy sets. The proposed fuzzy MCDM model based on these two methodologies are suggested to evaluate renewable energy alternatives for Turkey. We obtained that the type-2 fuzzy sets whose membership functions are also fuzzy and hesitant fuzzy sets that enable to handle situations that an element has several membership values are more able to evaluate energy decision making problems.

The proposed MCDM model has been applied to analyze renewable energy alternatives of Turkey. For this aim, six main criteria and twenty-nine sub-criteria are used to evaluate alternatives that are determined with respect to Turkey's energy perspective. These alternatives are solar, wind, hydraulic, geothermal, biomass, hydrogen and wave energies. The weights of main and sub-criteria that are clarified as a parameter to solve energy decision making problem are calculated by using AHP methodology based on interval type-2 fuzzy sets. The ranking results of these alternatives are also determined by using TOPSIS methodology based on hesitant fuzzy sets. Additionally, a sensitivity analysis is performed to check impact of criteria weights on the ranking. As a result, the proposed fuzzy based MCDM model shows that the alternative "Wind Energy" is determined as the best renewable energy alternative with its relative closeness value 0.693 for Turkey and the ranking is {Wind Energy, Solar Energy, Hydraulic Energy, Biomass Energy, Geothermal Energy, Wave Energy, Hydrogen Energy}, respectively.

As a future research suggestion, different integrated fuzzy MCDM methodologies can be used to solve this problem and the obtained results can be compared with the results of this paper.

References

[1] Sengul U, Eren M, Eslamian Shiraz S, Gezder V, Sengul AB. Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. Renew Energy 2015;75:617–25.
[2] Yuksel I. Energy production and sustainable energy policies in Turkey. Renew Energy 2010;35:1469–76.
[3] Kılıc M, Kaya I. Investment project evaluation by a decision making methodology based on type-2 fuzzy sets. Appl Soft Comput 2015;27:399–410.
[4] Zadeh LA. Fuzzy sets. Inf Control 1965;8:338–53.
[5] Zadeh LA. The concept of a linguistic variable and its application to approximate reasoning – 1. Inf Sci 1975;8:199–249.
[6] Mendel JM, John RIB. Type-2 fuzzy sets made simple. IEEE Trans Fuzzy Syst 2002;10:117–27.
[7] Torra V. Hesitant fuzzy sets. Int J Intell Syst 2010;25:529–39.
[8] Kabak M, Dagdeviren M. Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology. Energy Convers Manag 2014;79:25–33.
[9] Turkish Republic Ministry of Energy and Natural Resources, 2015-2019Strategic Plan, ⟨http://www.enerji.gov.tr/tr-TR/Stratejik-Plan⟩, 04.01.2015.
[10] Mahmutoglu M. Türkiye Elektrik Sektöründe Yenilenebilir Enerjinin Rolü [Master's Thesis]. Ankara (in Turkish): Gazi University, Institute of Social Sciences; 2013.
[11] Turkish Republic Ministry of Energy and Natural Resources, ⟨http://www.enerji.gov.tr/⟩, 10.02.2017.
[12] Kahraman C, Kaya I. A fuzzy multicriteria methodology for selection among energy alternatives. Expert Syst Appl 2010;37:6270–81.
[13] Cebi S, Ilbahar E, Atasoy A. A fuzzy information axiom based method to determine the optimal location for a biomass power plant: a case study in Aegean Region of Turkey. Energy 2016;116:894–907.
[14] Ghosh S, Chakraborty T, Saha S, Majumder M, Pal M. Development of the location suitability index for wave energy production by ANN and MCDM techniques. Renew Sustain Energy Rev 2016;59:1017–28.
[15] Alkan MA. Türkiye'deki yenilenebilir enerji kaynaklarinin eğitimi ve öğretimi [Master's Thesis]. Afyon (in Turkish): Afyon Kocatepe University, Instıtute of Science; 2009.
[16] Haralambopoulos DA, Polatidis H. Renewable energy projects: structuring a multicriteria group decision-making framework. Renew Energy 2003;28:961–73.
[17] Beccali M, Cellura M, Mistretta M. Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. Renew Energy 2003;28:2063–87.
[18] Nigim K, Munier N, Green J. Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources. Renew Energy 2004;29:1775–91.
[19] Madlener R, Kowalski K, Stagl S. New ways for the integrated appraisal of national energy scenarios: the case of renewable energy use in Austria. Energy Policy 2007;35:6060–74.

[20] Kowalski K, Stagl S, Madlener R, Omann I. Sustainable energy futures: methodological challenges in combining scenarios and participatory multi-criteria analysis. Eur J Oper Res 2009;197:1063–74.
[21] Amer M, Daim T. Selection of renewable energy technologies for a developing country: a case of Pakistan. Energy Sustain Dev 2011;15:420–35.
[22] Yazdani-Chamzini A, Fouladgar MM, Zavadskas EK, Moini SHH. Selecting the optimal renewable energy using multi criteria decision making. J Bus Econ Manag 2013;14:957–78.
[23] Troldborg M, Heslop S, Hough RL. Assessing the sustainability of renewable energy technologies using multi criteria analysis: suitability of approach for national scale assessments and associated uncertainties. Renew Sustain Energy Rev 2014;39:1173–84.
[24] Kahraman C, Kaya I, Cebi S. A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process. Energy 2009;34:1603–16.
[25] Kahraman C, Cebi S, Kaya I. Selection among renewable energy alternatives using fuzzy Axiomatic design: the case of Turkey. J Comput Sci 2010;16:82–102.
[26] Kaya T, Kahraman C. Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHS methodology: the case of Istanbul. Energy 2010;35:2517–27.
[27] Sadeghi A, Larimian T, Molabashi A. Evaluation of renewable energy sources for generating electricity in province of Yazd: a fuzzy MCDM approach. Procedia - Social Behav Sci 2012;62:1095–9.
[28] Manzardo A, Ren J, Mazzi A, Scipioni A. A grey-based group decision-making methodology for the selection of hydrogen technologies in life cycle sustainability perspective. Int J Hydrog Energy 2012;37:17663–70.
[29] Ertay T, Kahraman C, Kaya I. Evaluation of renewable energy alternatives using MACBETH and fuzzy AHP multicriteria methods: the case of Turkey. Technol Econ Dev Econ 2013;19:38–62.
[30] Tasri A, Susilawati A. Selection among renewable energy alternatives based on a fuzzy analytic hierarchy process in Indonesia. Sustain Energy Technol Assess 2014;7:34–44.
[31] Buyukozkan G, Guleryuz S. A new GDM based AHP framework with linguistic interval fuzzy preference relations for renewable energy planning. J Intell Fuzzy Syst 2014;27:3181–95.
[32] Balin A, Baraçli H. A fuzzy multi-criteria decision making methodology based upon the interval type-2 fuzzy sets for evaluating renewable energy alternatives in Turkey. Technol Econ Dev Econ. ⟨http://dx.doi.org/10.3846/20294913.2015.1056276⟩.
[33] Adhikary P, Roy PK, Mazumdar A. Optimal renewable energy project selection: a multi-criteria optimization technique approach. Glob J Pure Appl Math 2015;11(5):3319–29.
[34] Buyukozkan G, Guleryuz S. An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey. Int J Prod Econ 2016;182:435–48.
[35] Al Garni H, Kassem A, Awasthi A, Komljenoviç D, Al-Haddad K. A multicriteria decision making approach for evaluating renewable power generation sources in Suudi Arabia. Sustain Energy Technol Assess 2016;16:137–50.
[36] Celikbilek Y, Tuysuz F. An integrated grey based multi-criteria decision making approach for the evaluation of renewable energy sources. Energy 2016;115:1246–58.
[37] Suganthi L, Iniyan S, Samuel AA. Applications of fuzzy logic in renewable energy systems – a review. Renew Sustain Energy Rev 2015;48:585–607.
[38] Kumar A, Sah B, Singh AR, Deng Y, He X, Kumar P, Bansal RC. A review of multi criteria decision making towards sustainable renewable energy development. Renew Sustain Energy Rev 2017;69:596–609.
[39] Wang W, Liu X, Qin Y. Multiple-attribute group decision making models under interval type-2 fuzzy environment. Knowl Based Syst 2012;30:121–8.
[40] Kahraman C, Oztaysi B, Sarı IU, Turanoglu E. Fuzzy analytic hierarchy process with interval type-2 fuzzy sets. Knowl Based Syst 2014;59:48–57.
[41] Erdogan M, Kaya I. A combined fuzzy approach to determine the best region for a nuclear power plant in Turkey. Appl Soft Comput 2016;39:84–93.
[42] Saaty TL. The analytic hierarchy process. McGraw Hill; 1980.
[43] Cevik Onar S, Oztaysi B, Kahraman C. Strategic decision selection using hesitant fuzzy TOPSIS and type-2 fuzzy AHP: a case study. Int J Comput Intell Syst 2014;7:1002–21.
[44] Peng J, Wang J, Wang J, Yang L, Chen X. An extension of ELECTRE to multi-criteria decision making problems with multi-hesitant fuzzy sets. Inf Sci 2015;307:113–26.
[45] Çevik Onar S, Büyüközkan G, Öztayşi B, Kahraman C. A new hesitant fuzzy QFD approach: an application to computer workstation selection. Appl Soft Comput 2016;46:1–16.
[46] Zhang N, Wei G. Extension of VIKOR method for decision making problem based on hesitant fuzzy set. Appl Math Model 2013;37:4938–47.
[47] Xu Z, Xia M. Distance and similarity measures for hesitant fuzzy sets. Inf Sci 2011;181:2128–38.
[48] Xu Z, Zhang X. Hesitant fuzzy multi attribute decision making based on TOPSIS with incomplete weight information. Knowl Based Syst 2013;52:53–64.
[49] Zeng S, Balezentis A, Su W. The multi-criteria hesitant fuzzy group decision making with MULTIMOORA method. Econ Comput Econ Cybern Stud Res 2013;47:171–84.
[50] Chen N, Xu Z, Xia M. The ELECTRE I decision making method based on hesitant fuzzy sets. Int J Inf Technol Decis Mak 2015;14:621–57.
[51] Liu H, Rodriguez RM. A fuzzy envelope for hesitant fuzzy linguistic term set and its application to multicriteria decision making. Inf Sci 2014;258:220–38.
[52] Chen N, Xu Z. Hesitant fuzzy ELECTRE II approach: a new way to handle multi-criteria decision making problems. Inf Sci 2015;292:175–97.
[53] Wang J, Wang J, Zhang H, Chen X. Multi-criteria decision making based on hesitant fuzzy linguistic term sets: an outranking approach. Knowl-Based Syst 2015;86:224–36.
[54] Liao H, Xu S, Zeng X. Hesitant fuzzy linguistic VIKOR method and its application in qulitative multiple criteria decision making 2015;23(5):1343–55.
[55] Yavuz M, Oztaysi B, Cevik Onar S, Kahraman C. Multi-criteria evaluation of alternative fuel vehicles via a hierarchical hesitant fuzzy linguistic model. Expert Syst Appl 2015;42:2835–48.
[56] Aktas A, Kabak M. A model proposal for locating wind turbines. Procedia Comput Sci 2016;102:426–33.
[57] Wu S, Liu H, Wang L. Hesitant fuzzy integrated MCDM approach for quality function deployment: a case study in electric vehicle". Int J Prod Res 2016:1–14.
[58] Senvar O, Otay I, Bolturk E. Hospital site selection via hesitant fuzzy TOPSIS. IFAC-Pap 2016;49(12):1140–5.
[59] Adem A, Dağdeviren M. A life insurance policy selection via hesitant fuzzy linguistic decision making model. Procedia Comput Sci 2016;102:398–405.
[60] Gou X, Xu Z, Liao H. Hesitant fuzzy linguistic entropy and cross entropy measures and alternative queuing method for multiple criteria decision making. Inf Sci 2017;388–389:225–46.
[61] Kılıc M, Kaya I. The prioritisation of provinces for public grants allocation by a decision-making methodology based on type-2 fuzzy sets. Urban Stud. 2016;53:755–74.