Renewable Energy 75 (2015) 617–625

Contents lists available at ScienceDirect

Renewable Energy

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

Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey

Ümran Şengül [a, *], Miraç Eren [b], Seyedhadi Eslamian Shiraz [c], Volkan Gezder [d], Ahmet Bilal Şengül [e]

[a] Department of Business Administration, Faculty of Economics and Administrative Sciences at Çanakkale, Çanakkale Onsekiz Mart University, Terzioglu Kampusu, 17020 Çanakkale, Turkey
[b] Department of Econometric, Faculty of Economics and Administrative Sciences, Atatürk University 25240 Erzurum, Turkey
[c] Department of Management, University College of Nabi Akram (UCNA), Tabriz, İran
[d] SHW 8, Regional Directorate, Directorate of Dams and HPS, Erzurum, Turkey
[e] Department of Mechanical Engineering, Faculty of Engineering, Çanakkale Onsekiz Mart University, Terzioğlu Kampusu, 17020 Çanakkale, Turkey

ARTICLE INFO

Article history:
Received 1 November 2013
Accepted 19 October 2014
Available online

Keywords:
Renewable energy supply systems
Multi-criteria decision making
Fuzzy TOPSIS
Interval shannon's entropy

ABSTRACT

Multi-Criteria Decision Making (MCDM) techniques are gaining popularity in energy supply systems. The aim of this paper is to develop the multi-criteria decision support framework for ranking renewable energy supply systems in Turkey. Given the selection of renewable energy supply systems involves many conflicting criteria, multi criteria decision methods (Fuzzy TOPSIS) were employed for the analysis. The Interval Shannon's Entropy methodology was used to determine weight values of the criteria. In this study, $\alpha = 0.1$, 0.5 and 0.9 values based sensitivity analysis were performed. Three α-cutting levels were identical to the sequence of alternatives. According to result, the first criterion in preference ranking of renewable energy sources in Turkey is the Amount of Energy Produced, followed by the ranking systems Land use, Operation and maintenance cost, Installed capacity, Efficiency, Payback period, Investment cost, Job creation, and Value of CO_2 emission. Thus the multi-criteria analysis showed that the *Hydro Power Station* is determined to be the most renewable energy supply system in Turkey. Additionally, the *Geothermal Power Station, Regulator* and *Wind Power Station* are determined to be the second, third and fourth, respectively. The government of Turkey should invest, in order of priority, in these systems. The government should also evaluate the projects, which are related to these renewable energy resources.

1. Introduction

The growing trade opportunities with the increase in population, urbanization and industrialization around the world are gradually increasing the demand for natural resources and energy. The world's population has increased by 2.5 times since 1950, and the energy demand has increased seven-fold. Compared to the present, in 2030, it is expected to increase in a ratio ranging from 40 to 50% of the energy consumption worldwide, and to increase higher than 100% of this consumption in Turkey [1].

The simplest definition of energy is the ability to do a job, and that it is the source of life. In nature, energy is directly obtained from primary energy sources: coal, oil, natural gas, uranium, biomass, geothermal, hydro, solar and wind. These energy sources, oil, natural gas and coal, are of fossil origin. The others are renewable energy sources. Renewable energy is available without the need for any production processes. It is of non-fossil origin, has less harmful emissions, is renewed with a continuous cycle, and is present in nature as ready to use: water, wind, solar, geothermal, biomass, biofuels, wave, current and tidal energy, refers to energy sources as hydrogen [2]. Electricity, which is a secondary energy source, is produced by converting fossil fuels and renewable energy sources [3]. Considering the primary sources of energy, electric energy which is equivalent to 230 million barrels of oil energy is consumed in the world every day. About 200 million barrels of this electrical energy are fossil fuels. In the energy sector, petroleum, natural gas and coal are considered together, with the hydrocarbon weighted [4].

Safe, sustainable energy to provide cheap, efficient use, should reduce greenhouse gas emissions. The transition to the new and

* Corresponding author. Tel.: +90 286 218 0018 2869; fax: +90 286 218 3807.
E-mail addresses: umransengul@comu.edu.tr (Ü. Şengül), mirac.eren@atauni.edu.tr (M. Eren), hadi.eslamian@gmail.com (S. Eslamian Shiraz), volkangezder@dsi.gov.tr (V. Gezder), absengul@yahoo.com (A.B. Şengül).

http://dx.doi.org/10.1016/j.renene.2014.10.045
0960-1481/

renewable energy sources from fossil sources, is an important issue that should be getting the attention of the world especially in Turkey. The first of the targets of the 2010–2014 strategy of the Ministry of Energy and Natural Resources (MENR) in Turkey is security of the energy supply. The first objective that is planned is to achieve these targets in the form of "giving priority to domestic resources to ensure the diversification of sources". In order to ensure diversification of the energy supply, the intent is the maximum use of local and renewable energy sources in electricity production. In addition, this should be aimed at studies towards the reduction of energy intensity, the provision of the security of the energy supply, the reduction of risks arising from dependence, and increasing the efficiency of the struggle against climate change. Consequently, Turkey became a party to the United Nations Framework Convention on Climate Change in 2004, submitted its own first national declaration in 2007, and participated in the Kyoto Protocol on 5 February 2009 [5].

In 2011, Turkey had obtained 2.33% from renewable energy sources, 1.7% from liquid fuels, 22.8% from hydroelectric, 28.2% from coal, 44.7% from natural gas all self-produced [5]. The main objective for renewable energy sources of the Ministry of Energy is to ensure that a level of 30% of the share of electricity production is from these resources in 2023. The renewable energy sources which are primary energy sources, and the status of Turkey in terms of these energy resources are provided below.

1.1. Hydro-power

Hydroelectric power plants have been set up for electricity production from water itself. Electricity can be produced on rivers with small power (1 MW-100 MW) from hydroelectric power plants, and with great power from dams [6]. Turkey, compared to European countries which significantly consume their hydraulic potential, is a leader in Europe with hydraulic potential for 129 billion kWh/year [7]. The technically feasible hydro-power potential in Turkey is 21,600 gWh/year (State Water Works-(SWW), 2010). In 2011, the primary energy production in Turkey was 228431.02 kWh. and 22.8% of this production was met by hydraulic [8].

1.2. Geothermal energy

It is a clean source of energy for electricity generation because it is naturally occurring, and is not derived as a result of burning unlike thermal power plants. Turkey is the seventh richest country in the world in geothermal potential for its direct use and for electricity generation [9]. In addition, geothermal potential in Turkey is 31,500 MW, and 1500 MW of geothermal energy potential is suitable for the production of electrical energy. The installed capacity of geothermal energy by the end of 2009 was 77,2 MW [5].

1.3. Wind energy

Wind energy is made up of air masses encountering different temperature ranges. Wind turbines convert the wind energy into electricity. There is wind energy potential of at least 5000 MW in the regions where Turkey's annual wind speed is 8.5 m/s or higher, and at least 48000 MW in the regions where it is 7.0 m/s or higher. By the end of 2009, installed wind power in Turkey reached 802.8 MW [5].

1.4. Solar energy

Solar energy is a renewable energy source coming from the sun and containing values ranging from 0 to 1100 W/m^2 on the earth's surface [10]. It is in the stage of development due to the high cost of electricity generation, and covering wide areas with solar panels. Due to its geographical location, Turkey is a country of high potential for solar energy. Turkey's solar energy potential is 380 billion kWh/year.

1.5. Biofuel energy

Biofuel includes all kinds of fuel obtained from living organisms. Bio-fuels are classified as biodiesel, bioethanol, biogas and biomass [5]. Biomass energy potential in Turkey is 16,920 KTEP [3].

1.6. Hydrogen energy

Hydrogen energy is not a natural fuel. It is a synthetic fuel produced from different raw materials such as water, fossil fuels and biomass, taking advantage of the primary energy sources [3]. Hydrogen, compared to petroleum fuels, is a 33% more efficient fuel. However, due to the high cost of use, is not very widespread [5]. Since it is not at a level for consumption, the data could not be obtained for generating electricity from biofuel, solar energy and hydrogen energy in Turkey. In this regard, solar, biofuel and hydrogen energy, among renewable alternatives, have not been evaluated in this study.

Multi-Criteria Decision Making (MCDM) techniques are methods that provide the ordering or grouping of alternatives, making a choice between alternatives by the evaluation of multiple decision criteria [12]. The decision-making process determining the best energy alternatives is multidimensional, made up of a number of aspects at different levels, such as economic, technical, environmental, political, and social. From this perspective, an MCDM approach to decision making appears to be the most appropriate tool to understand all the different perspectives involved, and to support those concerned with the decision-making process by creating a set of relationships between the various alternatives [9].

In the literature, there are many studies where MCDM techniques were used in ranking renewable energy alternatives.

Pohekar and Ramachandran [13] included sustainable energy planning MCDM methods examined in more than 90 publications. According to the study, these methods are very widely used: AHP, PROMETHEE and ELECTRE. Abu-Taha [14] created a study dividing the methods of MCDM into two categories, including multi-objective decision making (MODM) and multi-attribute decision making (MADM). He presented a review of 90+ published papers of MCDM analysis in the renewable energy field. This work demonstrated that multi-criteria analyses could provide a technical-scientific decision-making support tool that was able to justify its choices clearly and consistently, especially in the renewable energy sector.

Cristóbal [11] has shown how the method can be used in the selection of a renewable energy investment project. In order to do this, the method is applied to the Plan de Energias Renovables (Renewable Energy Plan) launched by the Spanish Government in 2005. It described the use of the Compromise Ranking Method, also known as the VIKOR method, in the selection of a Renewable Energy project. Wang, et. Al. [15], reviewed literature on the corresponding methods in different stages of MCDM for sustainable energy, i.e., criteria selection, criteria weighting, evaluation, and final aggregation. The criteria of energy supply systems are summarized from technical, economic, environmental and social aspects. In the study by Kaya & Kahraman [16] two cases are suggested. First, they determined the best renewable energy alternatives for Istanbul by using an integrated VIKOR-AHP methodology. Second, a selection among alternative energy production sites in this city was made using the same approach. In the study by Kaya & Kahraman [17], the decision-makers' opinions on the relative importance of the selection criteria were determined using a Fuzzy AHP procedure. Afterward, a modified Fuzzy TOPSIS methodology was proposed to make a multi criteria selection among energy alternatives. Georgopoulou et al. [18], in their studies, used the-ELECTRE method, which is a multi-criteria decision-making method. In practice, in Greece and on the island, 15 criteria were taken into account for eight energy-efficient alternatives. Haralambopoulos and Polatidis [19], in their study, used the PROMETHE II method for ranking renewable energy projects. This study was applied to geothermal resources on the island of Chios. Polatidis and Haralambopoulos [20], in their study, on local renewable energy sources in Greece made recommendations for planning and investors. In this study, the views of investors, and local stakeholders, mayors, local councilors, presidents, local media, civil society organizations, local development corporations and regional authorities were taken into account. Polatidis and Haralambopoulos [21], in a study consisting of six chapters, described the fields that can be used and connections between the primary renewable energy and multi-criteria decision methods. In this study, they compared the use of renewable energy in the field of MCDM techniques.

Dicorato et al. [22], in their study, investigated the efficiency of energy sources with a linear programming-based optimization model. That paper, researched renewable energy sources on different continents, and the energy sources were compared. As a result of the tests made in that study, recommending the use of less environmentally damaging energy (such as hydro and wind power), it was suggested that this was the least costly of these energies. Menegaki [23] examined the literature on the assessment of renewable energy, and identified four basic elements for a choice of renewable energy. Önüt et al. [24], in their study, took into consideration fuel oil, coal, electricity, LPG and NG (Natural Gas), which is the most common energy source in the manufacturing industry. The ANP method was used to determine which of these resources was best in the manufacturing industry. They ranked NG, LPG, coal and fuel oil alternatives. Streimikiene et al. [25] presented MULTIMOORA and TOPSIS from the multi-criteria decision support framework for choosing the most sustainable electricity production technologies. They stated that the future of sustainable energy resources, is water and solar thermal.

Decision-making will often be based on “expert judgments” and/or “stakeholder values”. The decision-making may be influenced by subjectivity because of the weight the expert gives to the criteria when comparing them. This expert subjectivity constitutes the main drawback of decision-making. Sensitivity analysis have been undertaken in order to determine the effect of this drawback. Some of the studies are: Pang and Bai [37] who developed a supplier evaluation approach based on the Analytic Network Process (ANP) in a fuzzy environment. The criteria values are linguistic, and linguistic values are expressed as triangular fuzzy numbers. For sensitivity analysis of the weight of criteria, the weight of one criterion is exchanged with the weight of another, while all other criteria weights remain unchanged. Nguyen et al. [38] have applied a hybrid approach of the fuzzy ANP and COPRAS-G on the machine selection problem. The values that they use in making the machine selection are linguistic. Linguistic values are expressed as triangular fuzzy numbers. To determine the robustness of the rankings of alternatives they did the sensitivity analysis in the same way as Pang and Bai. There are 12 criteria in decision problems. They chose to switch the weight of 2 of the 12 criteria of a set. Therefore 66 different calculations must be implemented for the sensitivity analysis. In an effort to deal with subjectivity in criterion weights contributing to potential uncertainty, Feizizadeh et al. have suggested integrating the Monte Carlo Simulation with the conventional AHP [39]. However, criteria are quantitative data in our study. No expert opinion or stakeholder has been consulted in the data obtained. The data are definite and interval data obtained from the official site of the Republic of Turkey Ministry of Energy and Natural Resources (RTMENR), the Turkish Electricity Transmission Company (TETC), the Turkish Electricity Distribution Company (TEDC), the General Directorate of State Hydraulic Works (GDSHW), the Turkey Coal Enterprises (TCE) etc. and from literature. These data were taken as triangular fuzzy numbers. The data are used for alpha (α) cutting levels to make sensitivity analysis of fuzzy data. These data were taken as triangular fuzzy numbers. It is used for alpha (α) cutting levels to do sensitivity analysis of fuzzy data. α is an arbitrary value and in a triangular fuzzy number can be expressed with α-cutting level sets (confidence interval) [32]. In this study, $\alpha = 0.1$, 0.5 and 0.9 values based sensitivity analysis were performed. Three α-cutting levels were identical to the sequence of alternatives.

This aim of this paper is to develop the multi-criteria decision support framework for ranking the Renewable Energy Supply Systems (RESS) in Turkey. The paper is organized as follows. Section 2 presents the determination for RESS criteria. Section 3 introduces research methodology, including *Fuzzy sets and Fuzzy numbers*, *Interval Shannon's Entropy based on α-level sets*, and *the Fuzzy TOPSIS method*. Section 4 presents the results of the comparison of RESS in Turkey. Finally, Section 5 concludes this study.

The results of this research can provide energy policymakers and decision makers with the optimal alternatives for resource allocation in Turkey. They should invest, in order of priority, in RESS. They can also evaluate the projects which are related to these renewable energy sources.

2. Determination for renewable energy supply systems criteria

Wang et al. [15], determined the used of criteria to evaluate the energy supply systems in the literature. The criteria are summarized Table 1.

Abu-Taha [14], suggested the MCDM technique, which used a selection of renewable energy sources. According to the study, in relation to renewable energy sources, MCDM techniques most commonly used in the fields of renewable energy planning and

Table 1
The typical evaluation criteria of energy supply systems.

Aspects	Criteria
Technical	Efficiency
	Exergy efficiency
	Primary energy ratio
	Safety
	Reliability
	Maturity
Economic	Investment cost
	Operation and maintenance cost
	Fuel cost
	Electric cost
	Net present value
	Payback period
	Service life
	Equivalent annnual cost
Environmental	NO_x emission
	CO_2 emission
	CO emission
	SO_2 emission
	Particles emission
	Non-methane volatile organic compounds
	Land use
Social	Social acceptability
	Joc creation
	Social benefits

Table 2
Criteria taken into account to select the best renewable energy policy.

Main criteria	Sub-criteria	Unit
Technical	Efficiency (C_7)	billion kWh for 2011
	Installed capacity (C_8)	MW for 2012
	Amount of energy produced (C_9)	billion kWh for 2011
Economic	Investment cost (C_1)	cent/kWh
	Operation and maintenance cost (C_2)	cent/kWh
	Payback period (C_4)	year
Environmental	Land use (C_3)	km^2/1000 MW
	Value of CO_2 emission (C_5)	$/year
Social	Job creation (C_6)	person/MW

policy, renewable energy evaluation, project selection and the environment respectively, were AHP/ANP, PROMETHEE, ELECTRE, VIKOR, TOPSIS, SWA, SIMUS, UTADIS and value tress. In addition, some studies have been made of these techniques in a Fuzzy environment.

Based on data from various official institutions, quantitative criteria are derived from the data in Table 2, and renewable energy sources can produce electricity and have the potential in Turkey (Table 3).

2.1. Description of criteria

In this subsection, the criteria that will be used to evaluate RESS with potential in Turkey are explained briefly. While some criteria have a positive impact in decision-making problems, others have a negative impact. In this study, the criteria with a positive impact are the values of CO_2 emission (C_5), Job Criterion (C_6), Efficiency (C_7), Installed capacity (C_8), and Amount of energy produced (C_9). The criteria with negative impact are the values of Investment cost (C_1), Operation and maintenance cost (C_2), Land use (C_3), and Payback period (C_4).

2.1.1. Investment cost

Investment cost comprises all costs relating to: the purchase of mechanical equipment, technological installations, construction of roads and connections to the national grid, engineering services, drilling and other incidental construction work. Labor costs and costs for equipment maintenance are not included in the investment costs [15]. The 2009 data are given in Table 4 [5].

2.1.2. Operation and maintenance cost

Operating and maintenance costs are the cost values of materials other than fuel for the operation and management of power plant after it is installed [3]. Operation and maintenance costs consists of two parts, including employee wages, and the funds spent for the energy, products and services for the energy system operation [15], (Table 5) [26].

Table 3
Alternatives for renewable energy policy.

Alternative	Abbreviated name
Regulator (5MW < P[a] <100 MW)	R
Hydro Power Station (100 MW < P < 1000 MW)	HPS
Wind Power Station	WPS
Geothermal Power Station	GPS

[a] Power.

Table 4
Investment cost values of renewable energy supply systems in Turkey.

	R	HPS	WPS	GPS
Investment cost (cent/kWh)	0.677–1.104	2.5152–4.0249	2.1452–2.3684	0.1443–0.1689

Table 5
Operating and maintenance cost values of renewable energy supply systems in Turkey.

	R	HPS	WPS	GPS
Operation and maintenance cost (cent/kWh)	0.5–2.0	0.5–2.0	0.086–0.095	0.003–0.003

2.1.3. Land use

The energy system occupies some land. The environment and landscape are affected directly by the land occupied by the energy systems [15]. This criterion is a value of type km^2 of the area occupied by the establishment of a 1000 MW power plant, and its data are given in Table 6 [3].

2.1.4. Payback period

The study payback period used was the electrical entity financing period. The payback period of an energy project refers to the period of time required for the return on an investment to "repay" the sum of the original investment [15], and its data are given in Table 7 [26].

2.1.5. Value of CO_2 emissions

The carbon market representing all of the greenhouse gases is an important tool in reducing harmful emissions with the condition of work in accordance with the market rules. To reduce the emissions of the carbon market, penalizing those who release more than the limit imposed by rewarding those who have less emissions, is working to reduce the amount of emissions [27], (Table 8) [3].

2.1.6. Job creation

Energy supply systems employ many people during their life cycle, from construction and operation until decommissioning [15]. This criterion is considered to be the employment potential of the energy supply systems and its data are given in Table 9 [5].

2.1.7. Efficiency

Efficiency refers to how much useful energy we can obtain from an energy. Efficient energy use is essential in slowing the energy

Table 6
Values of land use of renewable energy supply systems in Turkey.

	R	HPS	WPS	GPS
Land use (km^2/1000 MW)	33	750	100	18

Table 7
Payback period of renewable energy supply systems in Turkey.

	R	HPS	WPS	GPS
Payback period (year)	1–3	5–10	0.5–1	1.5–2

Table 8
CO_2 emission value of renewable energy supply systems in Turkey.

	R	HPS	WPS	GPS
Value of CO_2 emission ($/year)	26302793.3	26302793.3	16612290.5	49836871.510

Table 9
Employment potential of renewable energy supply systems in Turkey.

	R	HPS	WPS	GPS
Job creation (person/MW)	0.56–0.92	0.56–0.92	0.25–0.42	0.10–0.33

Table 10
Turkey's renewable energy potential [a]

Energy type	Usage purpose	Natural capacity	Technical	Economical
Solar energy	Electric (billion kWh)	977000	6105	305
	Thermal (Mtoe)	80000	500	25
Hydro power	Electric (billion kWh)	430	215	124.5
Wind energy (land)	Electric (billion kWh)	400	110	50
Wind energy (off shore)	Electric (billion kWh)	–	180	–
Wave energy	Electric (billion kWh)	150	18	–
Geothermal energy	Electric (109 kWh)	–	–	1.4
	Thermal (Mtoe)	31500	7500	2843
Biomass energy	Total (Mtoe)	120	50	32

[a] In Table 10 values, the technical and economic potential are taken into consideration.

demand growth. It is the most used technical criteria to evaluate energy systems [15]. In this study, effectiveness, the country's energy supplied to meet requirement potential is assessed, and its data is given in Table 10 [28].

2.1.8. Installed capacity

This criterion is evaluated with the installed capacity according to sources in Turkey. Table 11 gives the distribution of sources for 53.910 MW of installed capacity as of April 2012 [5].

2.1.9. Amount of energy produced

According to the sources, electricity generation values are considered under this criterion. It shows that 228.4 billion kWh of electricity was produced in Turkey at the end of 2011 (Table 12) [5].

3. Research methodology

In this paper, the weights of each criterion are calculated using Fuzzy Shannon's Entropy. After that, Fuzzy TOPSIS is utilized to rank the alternatives.

3.1. Fuzzy sets and Fuzzy numbers

The natural language to express perception or judgment is always subjective, uncertain or vague [29]. Fuzzy set theory, which was introduced by Zadeh [30] to deal with problems in which a source of vagueness is involved, has been utilized for incorporating imprecise data into the decision framework. A Fuzzy set $\tilde{A}$ can be defined mathematically by a membership function $\mu_{\tilde{A}}(X)$, which assigns each element x in the universe of discourse X a real number in the interval [0,1] [31]. The triangular membership function is defined by three parameters. These parameters (l,m,u) of the triangular membership function take the shape of the components shown Fig. 1.

Table 12
Electricity production by source in Turkey.

Resources	*R*	HPS	WPS	GPS	Oil	Coal	Natural gas
Amount of energy that produced (%)	1.59	21.21	2.07	0.29	1.67	27.89	44.71
Amount of energy that produced (billion kWh)	3.632	48.444	4.728	0.662	3.814	63.701	102.118

$$\mu_{\tilde{A}}(x;l,\ m,\ u)=\begin{cases} l\ \le x\le m\ , & \dfrac{(x-l)}{(m-l)} \\ m\ \le x\le u\ , & \dfrac{(u-x)}{(u-m)} \\ x>u \text{ or } x<l, & 0 \end{cases} \tag{1}$$

$\mu_A(m)=1$ to be m on the top of the triangular Fuzzy number, where m is the l and u which is not necessarily the midpoint [32]. In this study, the interval of data is the criteria value, taken as triangular Fuzzy numbers.

A-cutting process can be applied to fuzzy numbers. Membership of an A-cutting set, A_α, is established from the members not less than α. α is an arbitrary value and in a triangular fuzzy number can be expressed with α-cutting level sets (confidence interval) [32].

3.2. Interval Shannon's entropy based on α-level sets

The concept of Shannon's entropy [33] has a dominant role in information theory. This concept has been developed in different scientific fields, such as physics, social sciences, etc. [34]. Hosseinzadeh, Lotfi and Fallahnejad (2010) extend the Shannon entropy for the interval data cases. The structure of the alternative performance matrix in the interval data case is created. This is where the matrix, $[x_{ij}^l, x_{ij}^u]$ is the rating of the alternative i with respect to the criterion j, $[w_j^l, w_j^u]$ is the weight of criterion j (Table 13).

The steps of Shannon's Entropy explained for these interval data as follow [35].

Step 1: The normalized value p_{ij}^l and p_{ij}^u are calculated as:

$$p_{ij}^l=\frac{x_{ij}^l}{\sum_{i=1}^m x_{ij}^u},\quad p_{ij}^l=\frac{x_{ij}^u}{\sum_{i=1}^m x_{ij}^u},\quad i=1,\dots,m,\ \ j=1,\dots,n \tag{2}$$

Step 2: Lower bound h_i^l and upper bound h_i^u of interval entropy can be obtained by:

$$h_j^l=\min\left\{-h_0\sum_{i=1}^m p_{ij}^l\cdot \ln p_{ij}^l, -h_0\sum_{i=1}^m p_{ij}^u\cdot \ln p_{ij}^u\right\},\quad j=1,\dots,n \tag{3}$$

Table 11
According to the sources, the power of the board of Turkey (MW).

Resources	*R*	HPS	WPS	GPS	Oil	Coal	Natural gas	Others[a]
Installed power (%)	7.0	26	3.5	0.2	2.5	23	30,4	8
Installed power (MW)	3774	13747	1887	108	1348	12345	16389	4313

[a] Others include: multi-fuel liquid (gas and liquid),renewable + waste.

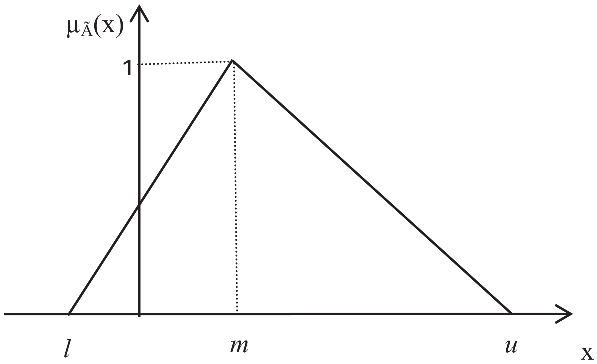

Fig. 1. A triangular fuzzy number $\tilde{A}$.

$$h_j^u = \max\left\{-h_0\sum_{i=1}^{m} p_{ij}^l \cdot \ln p_{ij}^l, -h_0\sum_{i=1}^{m} p_{ij}^u \cdot \ln p_{ij}^u\right\}, \quad j = 1, \ldots, n \tag{4}$$

where h_0 is equal to $(\ln m)^{-1}$, and $p_{ij}^l \cdot \ln p_{ij}^l$ or $p_{ij}^u \cdot \ln p_{ij}^u$ is defined as 0 if $p_{ij}^l = 0$ or $p_{ij}^u = 0$.

Step 3: Set the lower and the upper bound of the interval of diversification d_i^l and d_i^u as the degree of deversification as follows:

$$d_j^l = 1 - h_j^u, \quad d_j^u = 1 - h_j^l, \quad j = 1, \ldots, n \tag{5}$$

Step 4: Lower bound w_i^l and upper bound w_i^u of interval weight can be obtained by:

$$w_j^l = \frac{d_i^l}{\sum_{s=1}^{n} d_s^u}, \quad w_j^u = \frac{d_i^u}{\sum_{s=1}^{n} d_s^l}, \quad j = 1, \ldots, n \tag{6}$$

The $\alpha-$*level sets* can also be expressed in the following interval form:

$$\left[(x_{ij})_\alpha^l, (x_{ij})_\alpha^u\right] = \left[\min_{x_{ij}}\left\{x_{ij}\in R|\mu_{x_{ij}}(x_{ij}) \geq \alpha\right\}, \max_{x_{ij}} \times \left\{x_{ij}\in R|\mu_{x_{ij}}(x_{ij}) \geq \alpha\right\}\right] \tag{7}$$

where $0 < \alpha \leq 1$. In this study, $\alpha = 0.1$, 0.5 and 0.9 values based sensitivity analysis was performed.

3.3. The Fuzzy TOPSIS method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a linear weighting technique which was first proposed in its crisp version. Since then, this method has been widely adopted to solve MCDM problems in many different fields [36]. TOPSIS views an MCDM problem with m alternatives as a geometric system and m points in the n-dimensional space. This method is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution, and the longest distance from the negative ideal solution. TOPSIS defines an index called similarity to the positive-ideal solution and the remoteness from the negative-ideal solution. Then the method chooses an alternative with the maximum similarity to the positive-ideal solution [31]. The distances may be either summed up in the Euclidean sense or pondered, hence prioritizing one of the two distances [36]. It is often difficult for a decision-maker to assign a precise performance rating to an alternative for the attributes under consideration. The merit of a using a Fuzzy approach is to assign the relative importance of the attributes using Fuzzy numbers instead of precise numbers [31]. In this study, the interval values are triangular Fuzzy numbers. To find the middle value of a Fuzzy number, the lower bound and upper bound of the interval data are averaged arithmetically.

Fuzzy TOPSIS mathematics concept adapted from Wang and Chang [29].

Step 1: Determine the weighting of evaluation criteria

Criteria weights are determined by the *Interval Shannon's entropy*. For sensitivity analysis of criteria weights $\alpha = 0.1$, 0.5 and 0.9 have been calculated.

Step 2: Construct the Fuzzy matrix

$$\tilde{D} = \begin{matrix} & C_1 & C_2 & \ldots & C_n \\ A_1 & \tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\ A_2 & \tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A_m & \tilde{x}_{m1} & \tilde{x}_{m2} & \vdots & \tilde{x}_{mn} \end{matrix}, \quad i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n \tag{8}$$

where $\tilde{x}_{ij}$ is the rating of alternative A_i with respect to criterion C_j evaluated by data from official sites.

Step 3: Normalize the Fuzzy decision matrix

The normalized Fuzzy decision matrix denoted by $\tilde{R}$ is shown as following formula:

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n}, \quad i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots n \tag{9}$$

where

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{c_j^+}, \frac{m_{ij}}{c_j^+}, \frac{u_{ij}}{c_j^+}\right), \quad c_j^+ = \max_i c_{ij} \tag{10}$$

Step 4: Construct weighted mormalized Fuzzy decision matrix

The weighted normalized decision matrix $\tilde{V}$ is defines as.

$$\tilde{V} = [\tilde{v}_{ij}]_{m\times n}, \quad i = 1, 2, \ldots m; \quad j = 1, 2, \ldots, n \tag{11}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j \tag{12}$$

where $\tilde{w}_j$ represents the importance weight of criterion C_j.

Step 5: Determine the Fuzzy positive-ideal solution (FPIS) and Fuzzy negative-ideal solution (FNIS)

Table 13
Structure of the alternative performance when data are intervalled.

	Criterion 1	Criterion 2	…	Criterion n
Alternative 1	$[x_{11}^l, x_{11}^u]$	$[x_{12}^l, x_{12}^u]$	…	$[x_{1n}^l, x_{1n}^u]$
Alternative 2	$[x_{21}^l, x_{21}^u]$	$[x_{22}^l, x_{22}^u]$	…	$[x_{2n}^l, x_{2n}^u]$
⋮	⋮	⋮	…	⋮
Alternative m	$[x_{m1}^l, x_{m1}^u]$	$[x_{m2}^l, x_{m2}^u]$	…	$[x_{mn}^l, x_{mn}^u]$
	$[w_1^l, x_1^u]$	$[x_2^l, x_2^u]$		$[x_n^l, x_n^u]$

Because the positive triangular Fuzzy numbers are included in the interval [0,1], the Fuzzy positive ideal reference point (*FPIS*,A^+) and Fuzzy negative ideal reference point (*FNIS*, A^-) hence can be defined as.

$$A^+ = \left(\tilde{v}_1^+, \tilde{v}_2^+, \ldots, \tilde{v}_n^+\right) \tag{13}$$

$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\right) \tag{14}$$

where $\tilde{v}_1^+ = (1,1,1)$ and $\tilde{v}_1^- = (0,0,0)$, $j = 1,2,\ldots,n$.

Step 6: Calculate the distances of each alternative from FPIS and FNIS

The distances (d_i^+ and d_i^-) of each alternative A^+ from and A^- can be currently calculated by the area compensation method.

$$d_i^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij},\ \tilde{v}_j^+\right),\quad i = 1,2,\ldots,m;\quad j = 1,2,\ldots,n \tag{15}$$

$$d_i^- = \sum\nolimits_{j=1}^{n} d\left(\tilde{v}_{ij},\ \tilde{v}_j^-\right),\quad i = 1,2,\ldots,m;\quad j = 1,2,\ldots,n \tag{16}$$

Step 7: Obtain the closeness coefficient and rank the order of alternatives

Once the closeness coefficient is determined, the ranking order of all alternatives can be obtained, allowing the decision-makers to select the most feasible alternative. The closeness coefficient of each alternative is calculated as.

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-},\quad i = 1,2,\ldots,m \tag{17}$$

4. Results of the multi-criteria assessment

The determination of the correct energy policy effects many economic, social and environmental events in our country. In this paper the most appropriate renewable energy policy alternative in Turkey is selected by a Fuzzy multi-criteria decision - making technique. Through literature investigation and the study of other papers that are related to energy policy selection, nine criteria are finally selected. These criteria include investment cost (C_1), operation and maintenance cost (C_2), land use (C_3), payback period (C_4), value of CO_2 emissions (C_5), job creation (C_6), efficiency (C_7), installed capacity (C_8) and amount of energy that is produced (C_9). In addition, there are four alternatives, including Regulator (R), Hydro Power Station (HPS), Wind Power Station (WPS) and Geothermal Power Station (GPS).

4.1. Interval Shannon's Entropy

The Interval Shannon's Entropy methodology was used to determine the weight values of the criteria. The aggregate decision matrix for Shannon's Entropy can be seen in Table 14.

For the sensitivity analysis of the criteria weights $\alpha = 0.1$, $\alpha = 0.5$ and $\alpha = 0.9$ have been calculated. According to Eq. (2), we normalized the interval decision matrix. The normalized interval decision matrix is shown in Table 15.

Then, we calculated the lower bound h_i^l and upper bound h_i^u of the criteria based on Eq. (3) and Eq. (4). After that, the degrees of diversification were calculated using Eq. (5), as shown in Table 16.

Table 14
Aggregate decision matrix for Interval Shannon's Entropy.

	C_1	C_2	C_3	…	C_9
R	[0.677,1.104]	[0.5–2.0]	[33,33]	…	[3.631,3.631]
HPS	[2.515,4.024]	[0.5–2.0]	[750,750]	…	[48.444,48.444]
WPS	[2.145,2.368]	[0.086–0.095]	[100,100]	…	[4.723,4.723]
GPS	[0.144,0.169]	[0.003–0.003]	[18,18]	…	[0.662,0.662]

4.2. Fuzzy TOPSIS

The weights of the criteria were calculated using Interval Shannon's Entropy. Then, the Fuzzy decision matrix was created using Table 14. The Fuzzy decision matrix is shown in Table 18.

By following the Fuzzy TOPSIS procedural steps and calculations, the ranking of renewable energy policy is gained. The results and final ranking for $\alpha = 0.1$, $\alpha = 0.5$ and $\alpha = 0.9$ are shown Table 19.

According to Table 19, the "HPS (Hydro Power Station)" is determined to be the best renewable energy policy alternative for Turkey today. The ranking of renewable energy alternatives is determined as follows: GPS (Geothermal Power Station), Regulator, and WPS (Wind Power Station).

5. Discussion and conclusion

Providing cheap, good quality, on time and safely of energy is one of the priority issues of country management. In this study, Turkey has a potential to produce electricity from renewable energy supply systems listed under the criteria defined by the literature. The proposed Fuzzy TOPSIS allows the ranking of interval data. This method is based on different utility functions, and thus enables assessment of alternatives against multiple criteria in an integrated manner. Criteria that are necessary for performance rankings of renewable energy supply systems were determined from literature. Criteria data were obtained from the literature and from official sites in Turkey. 24 criteria for the ranking of energy sources have been identified in the literature (Table 1). However, it has not been possible to apply all of these 24 criteria on Turkey's renewable energy supply systems. We identified 9 criteria that can be obtained from four groups where the 24 criteria are found (technical, economics, environmental, social) (Table 2). It is possible to use expert opinion for the criteria for which data cannot be obtained. However, the aim of this study is to do analysis with quantitative data only, without recourse to expert opinion. All the criteria data have been taken as triangular fuzzy numbers, due to the value of some of them being interval values. Alpha (α) cutting levels are used to do sensitivity analysis of fuzzy data. In this study,

Table 15
The normalized interval decision matrix.

$\alpha = 0.1$	C_1	C_2	C_3	…	C_9
R	[0.092, 0.143]	[0.146,0.488]	[0.037,0.037]	…	[0.063,0.063]
HPS	[0.343, 0.523]	[0.146,0.488]	[0.832,0.832]	…	[0.843,0.843]
WPS	[0.285, 0.312]	[0.022,0.024]	[0.111,0.111]	…	[0.082,0.082]
GPS	[0.019, 0.022]	[0.001,0.001]	[0.020,0.020]	…	[0.012,0.012]
$\alpha = 0.5$	C_1	C_2	C_3	…	C_9
R	[0.110,0.140]	[0.262,0.486]	[0.037,0.037]	…	[0.063,0.063]
HPS	[0.406,0.512]	[0.262,0.486]	[0.832,0.832]	…	[0.843,0.843]
WPS	[0.309,0.325]	[0.026,0.028]	[0.111,0.111]	…	[0.082,0.082]
GPS	[0.021,0.023]	[0.001,0.001]	[0.020,0.020]	…	[0.012,0.012]
$\alpha = 0.9$	C_1	C_2	C_3	…	C_9
R	[0.130,0.136]	[0.428,0.483]	[0.037,0.037]	…	[0.063,0.063]
HPS	[0.478,0.501]	[0.428,0.483]	[0.832,0.832]	…	[0.843,0.843]
WPS	[0.336,0.339]	[0.033,0.033]	[0.111,0.111]	…	[0.082,0.082]
GPS	[0.023,0.024]	[0.001,0.001]	[0.020,0.020]	…	[0.012,0.012]

Table 16
The values h_i^l,h_i^u,d_i^l andd_i^u.

	$\alpha = 0.1$		$\alpha = 0.5$		$\alpha = 0.9$	
	$[h_i^l,h_i^u]$	$[d_i^l,d_i^u]$	$[h_i^l,h_i^u]$	$[d_i^l,d_i^u]$	$[h_i^l,h_i^u]$	$[d_i^l,d_i^u]$
C_1	[0.231,0.263]	[0.231,0.263]	[0.760,0.772]	[0.228,0.240]	[0.773,0.774]	[0.226,0.227]
C_2	[0.469,0.574]	[0.426,0.531]	[0.580,0.582]	[0.418,0.420]	[0.594,0.610]	[0.390,0.406]
C_3	[0.430,0430]	[0.570,0.570]	[0.430,0.430]	[0.570,0570]	[0.430,0.430]	[0.570,0.570]
C_4	[0.646,0.751]	[0.249,0.354]	[0.713,0.753]	[0.247,0.287]	[0.751,0.755]	[0.245,0.249]
C_5	[0.942,0.942]	[0.058,0.058]	[0.942,0.942]	[0.058,0.058]	[0.942,0.942]	[0.058,0.058]
C_6	[0.753,0.931]	[0.069,0.247]	[0.836,0.926]	[0.074,0.164]	[0.903,0.919]	[0.081,0.097]
C_7	[0.646,0.730]	[0.270,0.354]	[0.700,0.730]	[0.270,0.300]	[0.728,0.730]	[0.270,0.272]
C_8	[0.591,0.591]	[0.409,0.409]	[0.591,0.591]	[0.409,0.409]	[0.591,0.591]	[0.409,0.409]
C_9	[0.415,0.415]	[0.585,0.585]	[0.415,0.415]	[0.585,0.585]	[0.415,0.415]	[0.585,0.585]

Table 17
The interval and crisp weight of criteria.

	$\alpha = 0.1$		$\alpha = 0.5$		$\alpha = 0.9$	
	$[w_i^l,w_i^u]$	$[w_i]$	$[w_i^l,w_i^u]$	$[w_i]$	$[w_i^l,w_i^u]$	$[w_i]$
C_1	[0.069,0.092]	0.080	[0.075,0.084]	0.080	[0.079,0.080]	0.079
C_2	[0.126,0.185]	0.156	[0.138,0.147]	0.142	[0.136,0.143]	0.140
C_3	[0.169,0.199]	0.184	[0.188,0.199]	0.194	[0.199,0.201]	0.200
C_4	[0.074,0.124]	0.099	[0.081,0.100]	0.091	[0.085,0.088]	0.087
C_5	[0.017,0.020]	0.019	[0.019,0.020]	0.020	[0.020,0.020]	0.020
C_6	[0.020,0.086]	0.053	[0.024,0.058]	0.041	[0.028,0.034]	0.031
C_7	[0.080,0.123]	0.102	[0.089,0.105]	0.097	[0.094,0.096]	0.095
C_8	[0.121,0.143]	0.132	[0.135,0.143]	0.139	[0.142,0.144]	0.143
C_9	[0.174,0.204]	0.189	[0.193,0.205]	0.199	[0.204,0.206]	0.205

$\alpha = 0.1$, 0.5 and 0.9 values based sensitivity analysis were performed. Interval Shannon's Entropy methodology was used to determine weight values of the criteria. Three α-cutting levels were approximately identical to the sequence of criteria (Table 17). The results are given in Table 20.

According to Table 20, the first criterion in preference ranking of renewable energy sources in Turkey is the Amount of Energy Produced, followed by the ranking systems Land use, Operation and maintenance cost, Installed capacity, Efficiency, Payback period, Investment cost, Job creation, and Value of CO_2 emission. According to these results, the first necessary condition for the selection of renewable energy sources in Turkey is the amount of energy production. This criterion has a positive effect. Therefore when this criterion is increased, it must be increased in an alternative also. Table 12 shows the amount of energy production in year 2011. As is seen, the highest energy production amount from renewable energy is HPS (48,444 billion kWh). This level of production increases the desirability of HPS. Indeed, in the first of its decisions for renewable energy supply safety, the State Planning Organization of Turkey Republic (SPOTR) declared that “all of the HPS potential which it will technically and economically be possible to use, shall be used to produce electric power until 2023”. The second highest ranking criteria is “land use”. This criterion has a negative impact, therefore a lower value is preferred in an alternative. Land use of the renewable energy supply system is shown in Table 6. Referring to Table 6, the lower land use from renewable energy alternatives is GPS (18 km^2/1000 MW). GPS is ranked second in the results. In the second of its decisions for renewable energy supply safety the State Planning Organization of Turkey Republic (SPOTR) declared that “All of 600 MW JES potential (77.2 MW of installed capacity in 2009) is to be processed that is determined suitable for the production of electrical energy until 2023”. The third decision is to reach 20,000 MW (the installed capacity of 802.8 MW in 2009) of wind power installed capacity until 2023. The present study supports the decision taken by the ministry. Thus the multi-criteria analysis showed that the *Hydro Power Station* is determined to be the most renewable energy supply system in Turkey. Additionally, the *Geothermal Power Station*, *Regulator* and *Wind Power Station* are determined to be the second, third and fourth, respectively. The government of Turkey should invest, in order of priority, in these systems. The government should also evaluate the projects, which are related to these renewable energy resources. Thus, investment priorities can be planned according to ranking in Table 19, both according to the seasonal variability of renewable energy supply and in accordance to geographical conditions. Also, investment in a balanced policy according to ranking in Table 19 in terms of energy supply security is possible. In addition, we are planning to carry out

Table 18
Construct the Fuzzy matrix.

	C_1	C_2	C_3	…	C_9
R	(0.677, 0.891, 1.104)	(0.500, 1.250, 2.000)	(33,33,33)	…	(3.632,3.362,3.362)
HPS	(2.515, 3.270, 4.024)	(0.500, 1.250, 2.000)	(750,750,750)	…	(48.444,48.444,48.444)
WPS	(2.145, 2.257, 2.368)	(0.086, 0.090, 0.095)	(100,100,100)	…	(4.728,4.728,4.728)
GPS	(0.144, 0.157, 0.169)	(0.003, 0.003, 0.003)	(18,18,18)	…	(0.662,0.662,0.662)

Table 19
The comparasions results for renewable energy supply systems.

	$\alpha = 0.1$				$\alpha = 0.5$				$\alpha = 0.9$			
	d^+	d^-	CC	Rank	d^+	d^-	CC	Rank	d^+	d^-	CC	Rank
R	8.730	0.275	0.031	**3**	8.735	0.269	0.030	**3**	8.740	0.265	0.029	**3**
HPS	8.531	0.473	0.052	**1**	8.527	0.476	0.053	**1**	8.526	0.477	0.053	**1**
WPS	8.775	0.231	0.026	**4**	8.734	0.221	0.025	**4**	8.789	0.216	0.024	**4**
GPS	8.534	0.468	0.052	**2**	8.541	0.460	0.051	**2**	8.541	0.460	0.051	**2**

Table 20
Criteria weights according to the Interval Shannon's Entropy methodology.

Definition of criteria	Weight	Unit
Amount of energy produced (C_9)	0.189	billion kWh for 2011
Land use (C_3)	0.184	km^2/1000 MW
Operation and maintenance cost (C_2)	0.156	cent/kWh
Installed capacity (C_8)	0.132	MW for 2012
Efficiency (C_7)	0.102	billion kWh for 2011
Payback period (C_4)	0.099	year
Investment cost (C_1)	0.080	cent/kWh
Job creation (C_6)	0.053	person/MW
Value of CO_2 emission (C_5)	0.019	$/year

further studies with energy supply system rankings in Turkey, by using the Fuzzy VIKOR.

References

[1] Satman A. Turkey's energy vision. In: Geothermal Energy Seminar, 30 kasım-2 aralık, aydın turkey; 2005. http://www.mmo.org.tr/resimler/dosya_ekler/8188c7e9965c217_ek.pdf.
[2] Irkıçatal BO. Renewable Energy Sources, Energy Market Regulatory Authority, http://web.ogm.gov.tr/diger/iklim/Dokumanlar/Biyoenerji%20%C3%87al%C4%B1%C5%9Ftay%C4%B1/CalistaySunumlari/EPDK%20Sunum%20BET%C3%9CL.pdf, [accessed 17.04.13].
[3] Şeker V. Modeling and analysis of renewable energy sources with ANP in electricity generation of Turkey. Unpublished M.Sc. Thesis. Ankara,Turkey: Gazi University; 2010.
[4] Satman A. Turkey's fossil resources (Petroleum, natural Gas and coal) and assessment their potential. Strategic Res Study Cent 2011;9(16):178–203.
[5] MENR in Turkey. Energy investors handbook. 2012. http://www.epdk.gov.tr/documents/strateji/rapor_yayin/yatirimciel_kitabi/Sgb_Rapor_Yayin_Yatirimciel_Kitabi_Tr_2012_y6Xj7FNVt7F6.pdf [accessed 02.04.13].
[6] Atış I, Ay H, Çaylıdemirci M. Renewable energy sources and unit cost Analysis. Development Bank Publication of Turkey; 2010. p. 58.
[7] Sezer HR. Turkey's electricity system technical and economic impacts of renewable energy sources and EU applications. Turkeys Electricity Transmission Corporation, Research Planning CoordinationDepartment; 2005. http://www.emo.org.tr/ekler/6a4d89ba25627b2_ek.pdf [accessed 10.04.13].
[8] Türkyılmaz O, Özgiresun C. Turkey view of Energy. Turkey Chamber of Mechanical Engineers Report. 2012.
[9] Kahraman C, Kaya İ. A Fuzzy multicriteria methodology for selection among energy alternatives. Expert Syst Appl 2010;37:6270–81.
[10] Çakır MT. Wind energy potential of Turkey and its place in EU Countries. Politeknik J 2010;13(4):287–93.
[11] San Cristóbal JR. Multi-criteria decision-making in the selection of a renewable energy project in spain: The Vikor method. Renew Energy 2011;36(2):498–502.
[12] Atıcı KB, Ulucan A. Multi criteria decision analysis approaches in Energy projects evaluation process and Turkey applications. Hacattepe Univ Fac Econ Adm Sci J 2009;27(1):161–86.
[13] Pohekar SD, Ramachandran M. Application of multi-criteria decision making to sustainable energy planning-A review. Renew Sustain Energy Rev 2004;8:365–81.
[14] Abu-Taha R. Multi-criteria applications in renewable energy analysis: a literature review. In: Technology Management in the Energy Smart World (PICMET), Proceedings of PICMET, 11; 2011. p. 1–8.
[15] Wang JJ, Jing YY, Zhang CF, Zhao JH. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew Sustain Energy Rev 2009;13(9):2263–78.
[16] Kaya T, Kahraman C. Multicriteria renewable energy planning using an integrated Fuzzy VIKOR & AHP methodology: the case of Istanbul. Energy 2010;35(6):2517–27.
[17] Kaya T, Kahraman C. Multicriteria decision making in energy planning using a modified Fuzzy TOPSIS methodology. Expert Syst Appl 2011;38(6):6577–85.
[18] Georgopoulou E, Lalas D, Papagiannakis LA. multicriteria decision aid approach for energy planning problems: the case of renewable energy option. Eur J Oper Res 1997;103:38–54.
[19] Haralambopoulos DA, Polatidis H. Renewable energy projects: structuring a multicriteria group decision-making framework. Renew Energy 2003;28:961–73.
[20] Polatidis H, Haralambopoulos DA. Local renewable energy planning: a participatory multi-criteria approach. Energy Sources 2004;26:1253–64.
[21] Polatidis H, Haralambopoulos DA. Selecting an appropriate multi-criteria decision analysis technique for renewable energy planning. Energy Sources Part B 2006;1:181–93.
[22] Dicorato M, Forte G, Trovato M. Environmental-constrained energy planning using energy-efficiency and distributed-generation facilities. Renew Energy 2008;33:1297–313.
[23] Menegaki A. Valuation for renewable energy: a comparative review. Renew Sustain Energy Rev 2008;12:2422–37.
[24] Önüt S, Tuzkaya UR, Saadet N. Multiple criteria evaluation of current energy resources for Turkish manufacturing industry. Energy Convers Manag 2008;49:1480–92.
[25] Streimikiene D, Balezentis T, Krisciukaitiene I, Belezentis A. Prioritizing sustainable elecricity production technologies: MCDM approach. Renew Sustain Energy Rev 2012;16:3302–11.
[26] Tuncer G, Eskibalcı MF. Evaluation studies of energy raw material potential of Turkey. Istanbul Univ Eng Fac J Earth Sci 2003;16(1):81–92.
[27] Renewable Energy Directorate in Turkey, 2013, http://www.eie.gov.tr/iklim_deg/emisyon_ticareti.aspx, [accessed 11.04.13].
[28] Toklu E, Güney MS, Işık M, Comaklı O, Kaygusuz K. Energy production, consumption, policies and recent developments in Turkey. Renew Sustain Energy Rev 2010;14:1172–86.
[29] Wang TC, Chang TH. Application of TOPSIS in evaluating initial training aircraft under a Fuzzy environment. Expert Syst Appl 2007;33:870–80.
[30] Zadeh LA. Fuzzy sets. Inform Control 1965;8:338–53.
[31] Chaghooshi AJ, Fathi MR, Kashef M. Integration of Fuzzy Shannon's entropy with Fuzzy TOPSIS for industrial robotic system selection. J Ind Eng Manag 2012;5(1):102–14.
[32] Baykal N, Beyan T. Principles and fundamentals of Fuzzy Logic. 1st ed. Ankara: Bıçaklar Bookstore; 2004.
[33] Shannon CE. A mathematical theory of communication. Bell Syst Tech J 1948;27:379–423.
[34] Ghorbani M, Arabzad SM, Bahrami M. Implementing Shannon entropy, SWOT and mathematical programming for supplier selection and order allocation. Int J Supply Chain Manag 2010;1(1):43–7.
[35] Hosseinzadeh Lotfi F, Fallahnejad R. Imprecise Shannon's entropy and multi attribute decision making. Entropy 2010;12:53–62.
[36] Bottani E, Rizzi A. A Fuzzy TOPSIS methodology to support outsourcing of logistics services. Supply Chain Management. An Int J 2006;11(4):294–308.
[37] Pang B, Bai S. An integrated fuzzy synthetic evaluation approach for supplier selection based on analytic network process. J Intell Manuf 2013;24:163–74.
[38] Nugeyen HT, Dawal SZM, Nukman Y, Aoyama H. A hybrid approach for fuzzy multi-attribute decision making in machine tool selection with consideration of the interactions of attributes. Expert Syst Appl 2014;41:3078–90.
[39] Feizizadeh B, Jankowski P, Blaschke T. A GIS based spatially-explicit sensitivity and uncertainty analysis approach for multi-criteria decision analysis. Comput Geosci 2014;64:81–95.