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A DECISION PROCEDURE FOR SUSTAINABLE ENERGY MANAGEMENT AND PLANNING BASED ON MULTI CRITERIA DECISION MAKING UNDER FUZZY ENVIRONMENT[1]

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ABSTRACT

This study aims to rank alternative sustainable energy systems and to present the most convenient one utilizing a MCDM methodology based on integration of intuitionistic fuzzy ELECTRE and VIKOR methods. Four experts on sustainable energy have assessed the alternative energy systems, namely biomass, solar and wind energy systems according to sustainability criteria, which are divided into 4 main categories, namely environmental, social, economic and technical. In this scope, experts have specified the values of 16 sub-criteria through linguistic variables which are then representedby intuitionistic fuzzy numbers. The weights of decision makers and criteria with significant contribution on the ranking procedure are specified via Entropy method. The methodology reveals that Solar Energy is the most convenient energy system for Turkey, whereas the ranks of wind and biomass systems change according to different decision making strategies.

***Keywords**: ELECTRE, VIKOR, Intuitionistic Fuzzy Sets, Entropy, Renewable Energy*

***JEL Codes:** C44, D81, Q42.*

SÜRDÜRÜLEBİLİR ENERJİ YÖNETİMİ VE PLANLAMASI İÇİN SEZGİSEL BULANIK ÇEVREDE ÇOK KRİTERLİ KARAR VERME YÖNTEMLERİNE DAYALI BİR KARAR PROSEDÜRÜ

ÖZ

Bu çalışma, alternatif enerji sistemlerini sezgisel bulanık ELECTRE ile VIKOR yöntemlerinin entegrasyonuna dayanan bir yaklaşımı kullanarak sıralamayı ve aralarından en uygununu seçmeyi amaçlamaktadır. Yenilenebilir enerji konusunda uzman dört karar verici, alternatif enerji sistemi

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seçeneklerindengüneş, rüzgâr ve biyokütle sistemlerini sürdürülebilirliğinçevresel,sosyal,ekonomik ve teknik boyutlarını temsil eden 4 ana kriter ve bu kapsamda belirlenen16 alt kritere göre dilsel değişkenler aracılığıyla değerlendirmiştir. Bu dilsel değişkenler daha sonra sezgisel bulanık sayılarla ifade edilmiştir.Kriter ve karar vericilere ilişkin ağırlıklarseçeneklerin sıralanmasında büyük öneme sahiptir. Bu ağırlıklar objektif bir ağırlık belirleme yöntemi olan Entropi Metodu ile belirlenmiştir. Kullanılan yaklaşım, uzman değerlendirmelerine göre Güneş Enerjisi sistemlerinin Türkiye için en uygun enerji sistemi olduğunu ortaya çıkarmakta, Rüzgar ve Biyokütle enerjilerinin sırası ise karar verme stratejisine göre değişmektedir.

Anahtar kelimeler: *Yenilenebilir Enerji, VIKOR,ELECTRE, Entropi, Sezgisel Bulanık Kümeler*

JEL kodları: *C44, D81, Q42.*

1. INTRODUCTION

Energy is one of the most essential needs for economic and social development of all countries that face with the rapidly rising population and technological and industrial advances in recent decades. However, a large part of the world's energy need is currently fulfilled by fossil fuel based energy systems that could not be sustained in case of substantially increasing industrial, agricultural and domestic energy demand. In recent years, global warming, environmental pollution and unbalanced ecosystems threat the human health significantly. Environmental issues, especially air pollution, constitute the most important problems that force the countries in the globalized world to act in a responsible way to each other (Aydin and Esen, 2018). Local and renewable energy is hotline throughout the world due to the type and supply conditions of energy, its high impact on the global competitiveness, budget balance and payment deficit, and its importance on the production processes.Increase in the use of local and renewable energy systems, that are alternative to fossil fuel based energy systems, is important in terms of challenging with environmental pollution, overcoming economic and financial bottlenecks, decreasing the dependency on imported energy and decreasing the fluctuations in the energy prices (Bayrak and Esen, 2014). Using renewable energy systems that use domestic resources brings the potential to provide energy services with low emission levels of greenhouse gases and other air pollutants.

The main renewable energy systems that are widely used throughout the world are solar energy systems, wind energy systems, biomass based fuel and energy systems and geothermal systems. Besides them, several emerging renewable energy systems exist that are used less frequently, namely wave and tidal energy systems, hydropower, hydrogen energy. Due to varying characteristics based on the energy sources they use, one of the most important processes in renewable energy management and planning is the selection of the most convenient renewable energy system alternative considering the specific environmental, economic and social conditions in each country. In Turkey, renewable energy systems have been implemented in recent decades to increase the usage of renewable energy sources for meeting increasing energy demand.

A wide range of renewable resources can be utilized in Turkey to produce clean and sustainable energy. There is a gradually expanding capacity for wind power in Turkey, especially in the Aegean and Marmara regions. Wind energy production capacity in Turkey has increased significantly from 20MW to 4503MW in 13 years, from 2002 to 2015 (Dawood, 2016). Also, because of its advantageous position between the Middle East and Southeast Europe, Turkey has a high potential for solar energy, mainly in Mediterranean regions and South Eastern Anatolia. The potential of solar energy production in Turkey is 977,000 TWh/year, however due to technical limitations production of 6105 TWh/year is possible (Dawood, 2016). Furthermore, there is a high bio energy potential in Turkey. A huge amount of animal waste (more than 85 million tons/year) is generated, which could be used to produce more than 1.8 million tons of oil annually.

Planning sustainable energy systems requires considering a wide range of technical, social, economic and environmental aspects to meet the increasing demand of energy with a perception of sustainable production and consumption. Since energy planning problems are transformed to a more complex structure, a single objective approach might be insufficient to represent the complexity and multiplicity of such problems. The inclusion of multiple aspects, benchmarks, stakeholders and conflicting goals makes it extremely difficult to achieve a renewable energy system with a perspective of sustainability. Multi criteria decision making (MCDM) methods are commonly used to assess the alternatives according to several conflicting criteria. Nowadays, the popularity of using these methods in design and management of energy systems has been increasing rapidly and they are proved to be one of the better tools to overcome such challenges efficiently related to the complexity of the renewable energy planning problems. MCDM has become a prominent tool to solve energy planning problems as it allows the inclusion of all available criteria representing multiple sustainability dimensions and related priorities in the decision making procedure. MCDM methods are used as decision making aids in a wide range of areas including environmental management (Gregory et al., 2012) health care systems (Diaby, Campbell and Goeree, 2013), agricultural management (Hayashi, 2000), transportation, investment planning and product/service ranking, plant location selection (Mokhtarian, Sadi-Nezhad and Makui, 2014), supplier selection (Sevkli, 2010) andhuman resources management (Liu, Qin, Mao and Zhang, 2014). Some of the studies in the literature that use MCDM methods to plan and manage energy systems in Turkey include; (Büyüközkan and Güleryüz, 2017; Çelikbilek and Tüysüz, 2016; Onar, Oztaysi, Otay and Kahraman, 2015; Ü. Şengül, Eren, Shiraz, Gezder and A. B. Şengül, 2015; Ertay, Kahraman and Kaya, 2013; F. E. Boran, K. Boran and Menlik, 2012; Erol and Kılkış, 2012; Kahraman and Kaya, 2010).

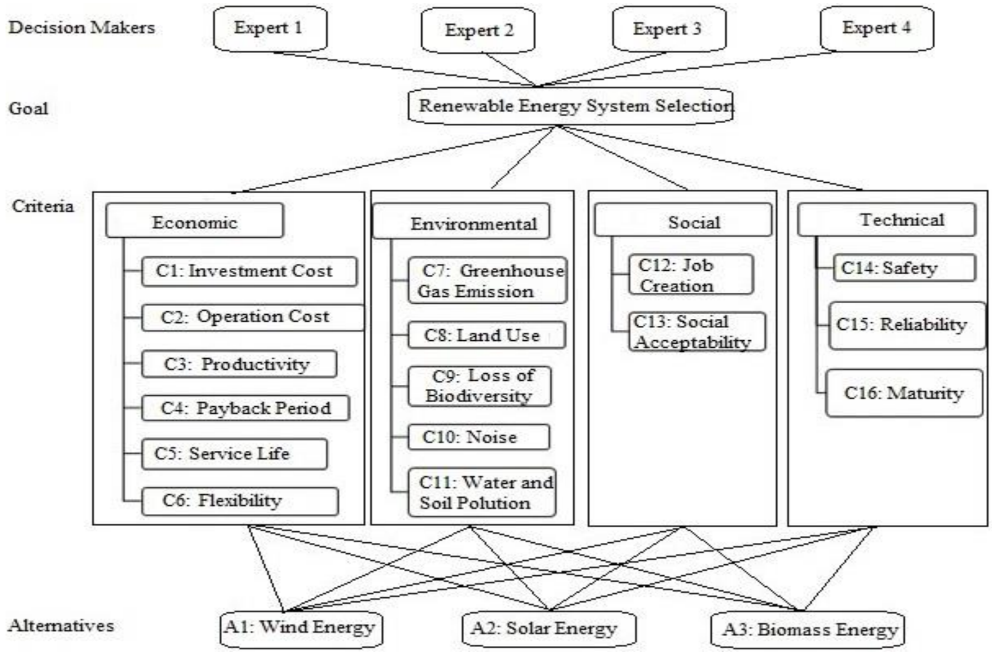
Among MCDM methods, ELECTRE I is a simple, useful methodology, which proposes the most preferable solution based on pair wise comparison of all alternatives. However, it has a disadvantage in terms of providing partial ranking. It is possible for the decision maker to face with the situations in which the superiority of one alternative to another cannot be decided. ELECTRE I method provides a convenient decision making approach to determine the most appropriate alternatives instead of a providing complete ranking list. This shortcoming can be eliminated by integrating VIKOR, which provides complete ranking. Renewable energy system ranking and selection problem is handled using this integrated MCDM model. To this aim, four experts (with academic background) actively studying on renewable and sustainable energy systems have assessed the alternative energy systems, namely biomass, solar and wind energy systems according to multiple sustainability criteria. The criteria are divided into 4 main categories, namely environmental, social, economic and technical criteria. Within these main categories,16 sub-criteria are determined according to a comprehensive literature review and the values of these sub-criteria are decided by the experts using linguistic variables, which then will be expressed by intuitionist fuzzy numbers.

One of the core drivers of this study is to come up with a novel renewable energy system selection model that takes into account different dimensions of sustainability (environmental, economic, social and technical), which makes the methodology developed in this study a generic framework which can be employed to similar decision problems through small modifications in different energy planning cases that involve comparing various options and then determine the most appropriate one efficiently modifying the set of criteria or alternatives. The methodology in this study combines intuitionist fuzzy sets with MCDM for representing the linguistic variables to cope with possible incomplete/ unreliable evaluations that may lead to ill-defined situations. The applicability of this integrated approach is then explored on a case study to make decisions effectively in selecting the most convenient renewable energy system alternative for Turkey. This study is structured as follows. The second part explains the decision problem along with the description of renewable energy system alternatives and criteria. The third section provides information of the integrated MCDM approach that is employed to rank the renewable energy system alternatives and select the most appropriate one among them. The section four presents the results of the case study of renewable energy system selection by using the implementation steps of the proposed methodology. Finally, concluding remarks and guidance for future studies are presented in the last section.

2. PROBLEM DEFINITION

Group decision making problems focus on the evaluation of feasible alternatives by two or more experts with reference to the conflicting criteria and determination of the most convenient one among the alternatives via multi criteria decision making (MCDM) methods. This article deals with the problem of renewable energy system selection in Turkey by utilizing MCDM methodology. The components of MCDM procedure comprises the main objective, alternatives, criteria and DMs. The components may differentiate according to the type and characteristics of the problem handled. Figure 1 shows the components of the problem handled in this article.

Figure 1. Hierarchical structure for the problem of renewable energy system selection



2.1 Determination of the alternatives

The alternatives for renewable energy systems are determined as Wind Energy (A1), Solar Energy (A2) and Biomass Energy (A3), which are among the most widely used renewable energy systems throughout the world. As stated in the introduction section, because of its advantageous geographic position and convenient climatic conditions as well as large amount of agricultural and husbandry waste produced annually, Turkey has a high potential to generate renewable energy from sunlight, wind and biomass sources. In addition, among all renewable energy systems, solar, wind and biomass energy systems have a wider application area in Turkey. Considering these facts, these three renewable energy systems are selected as alternatives to assess in our study.

Solar energy systems utilize a wide range of ever-evolving technologies and conversion processes such as photovoltaic panels, solar heating, solar thermal energy, molten salt power plants, solar architecture, and artificial photosynthesis to make use of the radiant light and heat from the sun that is harnessed to produce thermal and electrical energy that can be utilized in a range of applications for agricultural, industrial, residential purposes. Solar energy is widely utilized in urban planning by solar building design, in transportation vehicles by solar panels and in greenhouses. Wind turbines make use of air flow to produce mechanical power and turn the electric generators. There is a number of wind farms operated throughout the world that consist of many wind turbines which generate electrical energy and transmit to electricity transmission network to which they are connected. All forms of organic materials can be used as biomass resources in renewable energy production. Biomass materials are available on a renewable basis. Various biomass resources and different conversion processes can be utilized in bio energy production.

2.2 Selection of the criteria

Solar, wind and biomass energy systems are promising renewable energy systems as alternative to fossil fuel based systems, which use plentiful, clean, renewable and widely distributed resources, and produces no or minimum environmental pollution during operation. The total impact on the environment are far less problematic than those of nonrenewable energy sources. However, they have also some disadvantages in comparison with non-renewable energy systems. Due to relatively new and immature technology and process options investment and operational costs may be higher than that of fossil fuel based systems. Also, the specific characteristics of different renewable energy systems make some of them more appropriate in certain conditions and locations. Hence, the multiple criteria and the conflicts between these criteria should be considered in selecting the most appropriate system. In addition, different criteria may have varying values and priorities according to the decision makers (DMs) and alternatives. In this study, three alternatives are assessed with reference to the sustainability criteria categorized into 4 main criteria and 16 sub criteria which are determined according to a literature review (Wang, Jing, Zhang and Zhao, 2009). The benefit criteria with positive effect on the evaluation procedure (the higher is the better) are; Productivity (C3), Service Life (C5), Flexibility (C6), Job Creation (C12), Social Acceptability (C13), Safety (C14), Reliability (C15) and Maturity (C16). The cost criteria with negative effect on the evaluation procedure (the lower is the better) are; Investment cost (C1), Operation cost (C2), Payback Period (C4), Greenhouse Gas Emissions (C7), Land Use (C8), Loss of Biodiversity (C9), Noise (C10), Water and Soil Pollution (C11). Each sub criteria are explained in the following.

2.2.1 Economic criteria

Investment cost: Investment cost represents the initial capital cost that comprise land, building and equipment costs as well as construction and project costs.

Operation cost: Operation cost comprise monthly or annual cost of material and services for the energy system operation as well as maintenance costs, employee’s wages and office costs.

Productivity: Productivity is a measure of efficiency of the process. Productivity can be calculated by measuring the amount of output per unit of input. The resource availability and utilization in renewable energy systems has a significant impact on the productivity.

Payback period: Payback period is the period of time to meet the expenses of an investment or to achieve the point that the gains are equal to the expenses. Payback period is usually expressed in years.

Service Life: A system's service life refers to its period of use in service. It has been defined as "a system’s total life in use from the point of sale to the point of discard”. The system can be sold after its service period by its “salvage value”.

Flexibility: Flexibility of a system refers to its adaptability to the changes of market demand in a competitive and volatile business environment.

2.2.2 Environmental criteria

Greenhouse gas emissions: Greenhouse gases are atmospheric gas compounds caused by the production and transportation processes of energy systems. The increase in greenhouse gases leads to a warmer surface of the Earth, which ultimately results in climate change and global warming.

Land use: Land use represents the area used for construction of facilities and equipment for renewable energy systems. Land use represents the total size of the area occupied for development or production of a product or service.

Loss of biodiversity: The extinction of species in a habitat can be defined as loss of biodiversity. Loss of biodiversity is created by production processes due to environmental degradation.

Noise: Noise refers to the noise caused by the production processes in the renewable energy system.

Water and soil pollution: Soil and water pollution are important factors that affect the formation and quality of soil and water bodies. The increase in the pollutants in the soil and water resources in the nature due to the production activities results in water and soil contamination.

2.2.3 Social criteria

Job creation: Job creation represents the quantity of jobs created as a result of renewable energy system construction. This criterion can be investigated as the sum of the following three job categories; direct (immediate or on-site jobs), indirect (jobs created as a result of increase in economic activities) and induced jobs (jobs induced by the increase in the well-being).

Social Acceptability: Social acceptability criterion integrates the factors related to public perceptions on the renewable energy system concerning the aesthetic, recreational and cultural values of the local community in the neighborhood of the system.

2.2.4 Technical criteria

Safety: The system safety criterion refers to the suitability of the energy systemto risk management strategies based on the identification and analysis of hazards, and application of remedial controls.

Reliability: Reliabilityis the ability to operate a system within intended and predetermined conditions (Büyüközkan and Güleryüz, 2017: 151) with little fluctuations in production and supply amounts.

Maturity: Maturity points out technology level of the energy system. Technology may be tested in laboratory, or only employed in pilot plants, may be still progressed, or it is a consolidated technology (Wang et al, 2009).

2.3 Evaluation of the alternatives using intuitionistic fuzzy numbers

In most cases, DM may have difficulty in assessment of the alternatives precisely due to the lack of knowledge, unreliably measured conditions or uncertainties in real life problems. Therefore, this article employs intuitionistic fuzzy sets to cope with these situations resulting in uncertainties.

Intuitionistic fuzzy set (IFS) theory is introduced by Atanassov (1986), whichprovides convenient tools to handle uncertain situations and vagueness since it considers the hesitation degree of the elements in a set. Consider A as an IFS in a finite set X, this set can be defined as follows:

$$A = \{< x, \mu_A(x), v_A(x) > | x \epsilon X\} \tag{1}$$

where $\mu_A(x): X \rightarrow [0, 1]$ indicates membership degree of the element x to the set A, $v_A(x): X \rightarrow [0, 1]$ indicates non-membership degree of the element x to the set A with the condition as follows:

$$0 \leq \mu_A(x) + v_A(x) \leq 1 \quad x \epsilon X \tag{2}$$

Differently from traditional fuzzy sets (Zadeh, 1965), IFS has also a third parameter$\pi_A(x): X \rightarrow [0,1]$ which states the hesitancy degree of the element x to the set A. It is calculated as follows:

$$\pi_A(x) = 1 - \mu_A(x) - v_A(x) \tag{3}$$

IFS theory can be used in MCDM methodology. Consider $C = \{c_1, c_2, \dots, c_n\}$ as the set of criteria and $A = \{A_1, A_2, \dots A_m\}$ the set of alternatives. Alternative A_i is defined as an IFS as follows:

$$A_i = \{< c_j, (\mu_{ij}, v_{ij}, \pi_{ij}) > | c_j \in C\} \tag{4}$$

The elements of IFSs refers to the intuitionistic fuzzy numbers (IFNs). The IFN of $(\mu_{ij}, v_{ij}, \pi_{ij})$ points out the satisfaction level of alternative$i$ according to criterion $j$withμ_{ij}, the non- satisfaction level of alternative$i$according to criterion $j$with v_{ij} and hesitancy for evaluation of alternative$i$according to criterion $j$with π_{ij} where $0 \leq \mu_{ij} + v_{ij} \leq 1$ and $\pi_{ij} = 1 - \mu_{ij} - v_{ij}$ for each alternative and criterion.

In this study, three academicians from Department of Mechanical Engineering and an academician from Department of Industrial Engineering at a public university in Turkey are consulted as DMs of the problem. They have evaluated the alternatives using linguistic variables which can be expressed through IFNs. They have assessed the renewable energy alternatives regarding to the criteria defined in the previous section using the terms “Extremely high”, “very very high”, “very high”, “high”, "medium high", "medium", "medium low", "low", "very low" and "very very low". Then in calculation process, these evaluations are converted into decision matrices using the corresponding IFNs provided in Table 1.

Table 1. Linguistic variables and corresponding IFNs

Linguistic variables	IFNs (μ, v, π)
Extremely good (EG) / extremely high (EH)	(1.00, 0.00, 0.00)
Very very good (VVG) / very very high (VVH)	(0.90, 0.10, 0.00)
Very good (VG) / very high (VH)	(0.80, 0.10, 0.10)
Good (G) / high (H)	(0.70, 0.20, 0.10)
Medium good (MG) / medium high (MH)	(0.60, 0.30, 0.10)
Fair (F) / medium (M)	(0.50, 0.40, 0.10)
Medium bad (MB) / medium low (ML)	(0.40, 0.50, 0.10)
Bad (B) / low (L)	(0.25, 0.60, 0.15)
Very bad (VB) / very low (VL)	(0.10, 0.75, 0.15)
Very very bad (VVB) / very very low (VVL)	(0.10, 0.90, 0.00)

Source: Boran, Genc, Kurt and Akay, (2009).

3. THE METHODOLOGY: IF-ELECTRE INTEGRATED WITH VIKOR

ELECTRE I method, proposed by Roy (1968), is one of the outranking based MCDM methodsto handle the choice problematic which searches for the most preferable alternative among the set of preferred alternatives instead of the ranking problematic which aims in the ranking the alternatives from more preferable to the less preferable. This method is convenient for the problems with a high number of alternatives because of providing partial ranking. On the other hand, VIKOR, introduced by Opricovic (1998), is the MCDM method designed for the determination of the compromise solution closest to the ideal solution, can tackle ranking problematic.

This study employs a MCDM methodology which is Intuitionistic fuzzy ELECTRE integrated with VIKOR in order to determine the most appropriate renewable energy system alternative for Turkey. The procedure of IF-ELECTRE integrated with VIKOR is expressed as follows (Çalı and Balaman, 2018):

Step 1: The procedure starts with the determination of objective, alternatives and criteria known as components of MCDM problems.

$A = \{A_i | A_1, A_2, \dots, A_m\}$ is the set of alternatives for $i = 1,2, \dots m$.

$C = \{c_j | c_1, c_2, \dots, c_n\}$ is the set of criteria for $j = 1,2, \dots n$.

$DM = \{DM_k | DM_1, DM_2, \dots, DM_K\}$ is the set of DMs for $k = 1,2, \dots K$.

$\omega = \{\omega_j | \omega_1, \omega_2, \dots, \omega_n\}$ is the set of criteria weights for $j = 1,2, \dots n$.

$\lambda = \{\lambda_k | \lambda_1, \lambda_2, \dots \lambda_K\}$ is the set of DMs' weights for $k = 1,2, \dots K$.

Step 2: Each DM assesses each alternative regarding to each criterion, therefore the individual decision matrix $X^{(k)}$ for each k-th DM is established as below:

$$X^{(k)} = \begin{bmatrix} x_{11}^{(k)} & \cdots & x_{1n}^{(k)} \\ \vdots & \ddots & \vdots \\ x_{m1}^{(k)} & \cdots & x_{mn}^{(k)} \end{bmatrix} = \begin{bmatrix} (\mu_{11}^{(k)}, v_{11}^{(k)}, \pi_{11}^{(k)}) & \cdots & (\mu_{1n}^{(k)}, v_{1n}^{(k)}, \pi_{1n}^{(k)}) \\ \vdots & \ddots & \vdots \\ (\mu_{m1}^{(k)}, v_{m1}^{(k)}, \pi_{m1}^{(k)}) & \cdots & (\mu_{mn}^{(k)}, v_{mn}^{(k)}, \pi_{mn}^{(k)}) \end{bmatrix} \tag{5}$$

Step 3: Since the knowledge levels of DMs differ from each other, it is essential to reflect the weight of each DM to system. Entropy equations are used for computing the relative importance of DMs. Considering each individual decision matrix $X^{(k)}$as an IFS, the IF-entropy measure (Vlochos and Sergiadis, 2007) is employed to calculate the weights of DMs. The entropy measure $E^{IFS}\left(X^{(k)}\right)$for each individual decision matrix is determined by Equation (6),

$$E^{IFS}\left(X^{(k)}\right) = -\frac{1}{mn\ln 2}\sum_{j=1}^{n}\sum_{i=1}^{m}\left[\mu_{ij}\ln\mu_{ij} + v_{ij}\ln v_{ij} - (1-\pi_{ij})\ln\left(1-\pi_{ij}\right) - \pi_{ij}\ln 2\right] \tag{6}$$

Next, the weight of each DM (for each k = 1, 2…,K) is determined by Equation (7).

$$\lambda_k = \frac{1-E_{LT}^{IFS}\left(X^{(k)}\right)}{\sum_{k=1}^{K}\left(1-E_{LT}^{IFS}\left(X^{(k)}\right)\right)} \text{where } \lambda_k \geq 0,\ k = 1,2,\ldots K \text{ and} \sum_{k=1}^{K}\lambda_k = 1 \tag{7}$$

The smaller entropy measure points out the uncertainty transmitted by $X^{(k)}$ is smaller as well. That is to say, individual decision matrix with smaller uncertainty belongs to the DM with higher importance level.

Step 4: DM’s opinions are aggregated and group decision matrix is formed. The elements of group decision matrix x_{ij} are calculated by IFWA operator (Xu, 2007) in Equation (8),

$$x_{ij} = [1 - \prod_{k=1}^{K}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{K}\left(v_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{K}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{K}(v_{ij}^{(k)})^{\lambda_k} \tag{8}$$

Then, the group decision matrix is expressed as Equation (9).

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} = \begin{bmatrix} (\mu_{11}, v_{11}, \pi_{11}) & \cdots & (\mu_{1n}, v_{1n}, \pi_{1n}) \\ \vdots & \ddots & \vdots \\ (\mu_{m1}, v_{m1}, \pi_{m1}) & \cdots & (\mu_{mn}, v_{mn}, \pi_{mn}) \end{bmatrix} \tag{9}$$

Step 5: This step uses entropy weighting known as one of the objective weighting methods. Entropy weighting can be utilized to calculate the relative importance of criteria (Zeleny, 1976). Determination of criteria weights consists of following steps (Hung and Cheng, 2009). Firstly, IF-entropy measure $E^{IFS}\left(c_j\right)$ for each criterion is calculated by Equation (10) (Vlochos and Sergiadis, 2007).

$$E^{IFS}(c_j) = -\frac{1}{mn\ln 2}\sum_{j=1}^{n}\sum_{i=1}^{m}[\mu_{ij}\ln\mu_{ij} + v_{ij}\ln v_{ij} - (1-\pi_{ij})\ln(1-\pi_{ij}) - \pi_{ij}\ln 2] \tag{10}$$

Next, entropy weight of each criterion ω_j is defined by Equation (11).

$$\omega_j = \frac{1-E_{LT}^{IFS}(c_j)}{\sum_{j=1}^{J}(1-E_{LT}^{IFS}(c_j))} \text{where } \omega_j \geq 0,\ j = 1,2,\dots n \text{ and} \sum_{j=1}^{n}\omega_j = 1 \tag{11}$$

The smaller entropy measure indicates that the performance values of all alternatives regarding to a criterion is less similar, thereby the more information can be transmitted to the system by the corresponding criterion. Consequently, the weight of this criterion is determined as higher value.

Step 6: We define three different concordance and discordance sets based on Wu and Chen (2011). Concordance set comprises the criteria for which an alternative is superior over the other alternative. On the other hand, discordance set comprises the criteria for which an alternative is inferior to the other alternative. According to the levels of superiority and inferiority of the criteria, strong, midrange and weak sets are defined. Let $x_{ij} = (\mu_{ij}, v_{ij}, \pi_{ij})$ as performance score of i-th alternative with reference to j-th criterion.

The strong concordance set C'_{ab} comprises the criteria {j | j = 1,2,…n} for which alternative A_a is preferred to A_b providing the following equation.

$$C'_{ab} = \{j|\mu_{aj} \geq \mu_{bj},\ v_{aj} < v_{bj}\ and\ \pi_{aj} < \pi_{bj}\} \tag{12}$$

The midrange concordance set C''_{ab} comprises the criteria providing the following equation.

$$C''_{ab} = \{j|\mu_{aj} \geq \mu_{bj},\ v_{aj} < v_{bj}\ and\ \pi_{aj} \geq \pi_{bj}\} \tag{13}$$

The weak concordance set C'''_{ab} comprises the criteria providing the following equation.

$$C'''_{ab} = \{j|\mu_{aj} \geq \mu_{bj},\ v_{aj} \geq v_{bj}\} \tag{14}$$

The strong discordance set D'_{ab} comprises the criteria {j | j = 1,2,…n} for which alternative A_a is not preferred to A_b providing the following equation.

$$D'_{ab} = \{j|\mu_{aj} < \mu_{bj},\ v_{aj} \geq v_{bj}\ and\ \pi_{aj} \geq \pi_{bj}\} \tag{15}$$

The midrange discordance set D''_{ab} comprises the criteria providing the following equation.

$$D''_{ab} = \{j|\mu_{aj} < \mu_{bj},\ v_{aj} \geq v_{bj}\ and\ \pi_{aj} < \pi_{bj}\} \tag{16}$$

The weak discordance set D'''_{ab} comprises the criteria providing the following equation.

$$D'''_{ab} = \{j|\mu_{aj} < \mu_{bj},\ v_{aj} < v_{bj}\} \tag{17}$$

It is very important to note that the abovementioned formulations to form the concordance and discordance sets are valid for benefit criteria. When considering cost criteria, the formulations of concordance and discordance sets should be reversed.

Step 7: We determine contribution level of each concordance set to the decision making process by weighting distance approach which is used for identification of the differences between IFSs. The approach in Zhang, Peng, J. Wang and J. Q. Wang (2017) in which weighting distance approach is used to obtain differences between linguistic intuitionistic fuzzy numbers. Firstly, the process starts with specifying total dominance degrees of strong, midrange and weak concordance sets by the following equations.

$$dd' = \sum_{\substack{a,b=1\\a\neq b}}^{m} \sum_{j\in C'_{ab}} \omega_j * d(x_{aj}, x_{bj}) \tag{18}$$

$$dd'' = \sum_{\substack{a,b=1\\a\neq b}}^{m} \sum_{j\in C''_{ab}} \omega_j * d(x_{aj}, x_{bj}) \tag{19}$$

$$dd''' = \sum_{\substack{a,b=1\\a\neq b}}^{m} \sum_{j\in C'''_{ab}} \omega_j * d(x_{aj}, x_{bj}) \tag{20}$$

$\omega_j * d(x_{aj}, x_{bj})$ demonstrates dominance degree of A_a over A_b regarding to j-th criterion in concordance set. For instance, total dominance degree of strong concordance set (dd') considers the superiority degree of the alternatives with reference to the criteria in strong concordance set (C'_{ab}). Here, $d(x_{aj}, x_{bj})$ indicates Euclidean distance measure introduced by Szmidt and Kacprzyk (2000). Let W and Y be IFSs in $\varepsilon = \{\varepsilon_1, \varepsilon_2, \ldots \varepsilon_n\}$, the Euclidean distance $d(W, Y)$ is calculated by Equation (21).

$$d(W,Y) = \sqrt{\frac{1}{2}\sum_{j=1}^{n}\left(\mu_W(\varepsilon_j) - \mu_Y(\varepsilon_j)\right)^2 + \left(v_W(\varepsilon_j) - v_Y(\varepsilon_j)\right)^2 + \left(\pi_W(\varepsilon_j) - \pi_Y(\varepsilon_j)\right)^2}. \tag{21}$$

Finally, the weights of strong $(w_{C'})$, midrange $(w_{C''})$ and weak $(w_{C'''})$ concordance sets can be computed as follows:

$$w_{C'} \ = dd'/(dd' + dd'' + dd''') \tag{22}$$

$$w_{C''} = dd''/(dd' + dd'' + dd''') \tag{23}$$

$$w_{C'''} = dd'''/(dd' + dd'' + dd''') \tag{24}$$

Step 8: Concordance matrix is constructed after computing the concordance indices which are the members of concordance matrix. The following equation adapted from Figueira, Greco, Roy and Slowinski (2010) is utilized to obtain concordance index p_{ab} indicating superiority of A_a over A_b.

$$p_{ab} = w_{C'} * \sum_{j \epsilon C'_{ab}} \omega_j + w_{C''} * \sum_{j \in C''_{ab}} \omega_j + w_{C'''} * \sum_{j \in C'''_{ab}} \omega_j \tag{25}$$

Then, the concordance matrix is formed as follows:

$$P = \begin{bmatrix} - & p_{12} & \cdots & \cdots & p_{1m} \\ p_{21} & - & p_{23} & \cdots & p_{2m} \\ \cdots & \cdots & - & \cdots & \cdots \\ p_{(m-1)1} & \cdots & \cdots & - & p_{(m-1)m} \\ p_{m1} & p_{m2} & \cdots & p_{m(m-1)} & - \end{bmatrix} \tag{26}$$

Step 9: Discordance matrix is established after computing their elements called as discordance indices which reflect the inferiority degree of the alternatives according to each other. The following equation adapted from Zhang et al. (2017) calculates the discordance index t_{ab}.

$$t_{ab} = \frac{\max_{j \in D'_{ab} \cup D''_{ab} \cup D'''_{ab}} \omega_j * d(x_{aj}, x_{bj})}{\max_{j \in C} d(x_{aj}, x_{bj})} \tag{27}$$

The discordance matrix can then be defined as follows:

$$T = \begin{bmatrix} - & t_{12} & \cdots & \cdots & t_{1m} \\ t_{21} & - & t_{23} & \cdots & t_{2m} \\ \cdots & \cdots & - & \cdots & \cdots \\ t_{(m-1)1} & \cdots & \cdots & - & t_{(m-1)m} \\ t_{m1} & t_{m2} & \cdots & t_{m(m-1)} & - \end{bmatrix} \tag{28}$$

Step 10: VIKOR method is integrated to the methodology to provide complete ranking list in this step. According to Opricovic and Tzeng (2007), the main idea behind discordance concept of ELECTRE and individual regret value (R) in VIKOR are similar as well as the main idea behind concordance concept of ELECTRE and group utility value (Q) in VIKOR are similar. They presented aggregating discordance index and aggregating concordance index to obtain complete ranking when ELECTRE methodology is utilized. Zandi and Roghanian (2013) adapted this equations to the system utilized fuzzy sets. We have adapted this equations to the system based on IFSs.

The formulation related to aggregating discordance index of alternative A_a is as below:

$$t_a = R_a / C \tag{29}$$

where $C = \max_j \omega_j$ and $t_a = \max_i t_{ai}\; i \neq ai = \{1,2, \dots m\}$

The formulation related to the aggregating concordance index of alternative A_a is as below:

$$p_a = 1 - S_a \qquad (30).$$

where $p_a = \sum_{i \neq a}^{m} p_{ai} / (m-1)andp_{ai} = w_{C'} * \sum_{j \epsilon C'_{ai}} \omega_j + w_{C''} * \sum_{j \epsilon C''_{ai}} \omega_j + w_{C'''} * \sum_{j \epsilon C'''_{ai}} \omega_j$ and alternatives $i = \{1,2, \dots m\}$ and criteria $j = \{1,2, \dots n\}$.

As a result, the values R and the values S of each alternative i is computed by Equation (23) and Equation (24), respectively.

$$R_i = t_i * C \qquad \forall i \tag{31}$$

$$S_i = 1 - p_i \qquad \forall i \tag{32}$$

Step 11: The Q values for each alternative indicating degree of closeness to ideal point are calculated by Equation (25) which integrates the values of R_i and the values of S_i at the ratio determined by DM with value of γ (the weight for maximum group utility strategy) and the value of $(1-\gamma)$ (the weight for minimum individual regret strategy). For maximum group utility strategy (min S), the weight is assigned as $(\gamma > 0.5)$. For minimum individual regret of opponent (min R) is determined as $(\gamma < 0.5)$. For consensus the weight is determined as 0.5.

$$Q_i = \gamma * \frac{S_i - S^*}{S^- - S^*} + (1-\gamma) * \left(\frac{R_i - R^*}{R^- - R^*}\right) \qquad \forall i \tag{33}$$

where $S^- = max\ S_i$; $S^* = min\ S_i$; $R^- = maxR_i$; $R^* = minR_i$

Step 12: The alternatives are sorted according to ascending order of the values S, R and Q; thereby three different ranking lists are proposed. The alternative with minimum Q value refers to compromise solution provided that the undermentioned conditions are satisfied:

Condition 1: Suppose that A_1 is the first and A_2 is the second regarding to the ascending order of Q. Alternative A_1 has a meaningful advantage over the alternative A_2 by providing Equation (26).

$$Q(A_2) - Q(A_1) \geq DQ \;\text{ where } DQ = 1 / (m-1) \tag{34}$$

Condition 2: The compromise solution A_1 has acceptable stability in decision making provided that it is in the first position both in ascending order of S values and in ascending order of R values.

If alternativeA_1 does not satisfy one of the conditions, then a set of compromise solutions is presented. Provided that Condition 2 is not satisfied, A_1 and A_2 are regarded as the compromise solutions. Provided that Condition 1 is not satisfied, A_1, A_1,…A_m are regarded as the compromise solutions where $Q(A_m) - Q(A_1) < DQ$ and $DQ = 1 / (m - 1)$.

4. IMPLEMENTATION AND RESULTS

The procedure of IF-ELECTRE integrated with VIKOR is implemented in this section to the renewable energy selection case and the results are explained step by step.

Step 1: We have explained the goal, alternatives and criteria of the problem of this paper in Section 2.

Step 2: Four experts (DMs) have evaluated solar energy, wind energy and biomass energy systems with reference to all the criteria explained in Section 2 employing linguistic variables. The evaluations of DMs can be seen in Table 2. This table includes the performance scores of the alternatives in linguistic variables, but the individual matrices can be obtained by converting linguistic variables into IFNs through Table 1.

Step 3: The weight of each DM is calculated based on Entropy method. Firstly, entropy measures are computed by Equation (6) through individual decision matrices obtained in previous step. Then, the entropy weight for each DM is determined by Equation (7). The entropy values of DMs are obtained as 0.804, 0.768, 0.688 and 0.753, respectively. The entropy weights of DMs (DM1, DM2, DM3 and DM4) are calculated as 0.198, 0.235, 0.316 and 0.251, respectively. As a result, it can be inferred that the evaluations of third expert have a little bit higher effect on the calculation process.

Table 2. DM's (experts) Evaluations for Each Alternative Based on Linguistic Variables

	A1				A2				A3			
Criteria	DM1	DM2	DM3	DM4	DM1	DM2	DM3	DM4	DM1	DM2	DM3	DM4
C1	H	ML	VH	VH	H	MH	H	VH	MH	VH	ML	VH
C2	MH	MH	H	VH	MH	MH	H	M	VH	MH	MH	H
C3	H	MH	VH	MH	VH	M	VH	H	MH	M	H	ML
C4	ML	M	VVH	H	ML	VH	VVH	MH	ML	M	VH	MH
C5	VH	MH	MH	H	MH	MH	MH	VH	VH	MH	VVH	VH
C6	M	VH	H	ML	M	VH	H	ML	VH	M	VVH	VVH
C7	VL	VVL	VVL	VVL	VL	VVL	VVL	VVL	M	L	MH	ML
C8	L	ML	VH	L	ML	VH	VH	MH	MH	ML	VL	H
C9	H	ML	L	VH	M	ML	L	VH	VH	VL	VVL	ML
C10	M	VVH	ML	VVH	ML	L	ML	M	ML	VL	L	M
C11	VL	VL	VVL	ML	VL	VL	VVL	ML	L	M	VL	VVL
C12	L	M	M	M	L	M	M	H	MH	M	M	VH
C13	H	VH	MH	VVH	VVH	VH	MH	VVH	H	VH	VH	VH
C14	VH	VH	VH	ML	VH	VH	VH	H	ML	VH	VH	H
C15	MH	MH	MH	MH	MH	VH	MH	VH	VH	H	VH	H

C16	H	VH	H	MH	VH	VH	H	VH	MH	VH	VVH	H

Table 3. Aggregated Decision Matrix

	Criteria			
	C1	C2	C3	C4
Alternatives	(μ, v, π)	(μ, v, π)	(μ, v, π)	(μ, v, π)
A1	(0.719, 0.167, 0.113)	(0.692, 0.200, 0.106)	(0.696, 0.195, 0.107)	(0.725, 0.226, 0.047)
A2	(0.710, 0.184, 0.105)	(0.613, 0.283, 0.102)	(0.725, 0.164, 0.109)	(0.762, 0.181, 0.056)
A3	(0.675, 0.206, 0.117)	(0.675, 0.218, 0.106)	(0.573, 0.320, 0.105)	(0.633, 0.250, 0.115)
	C5	C6	C7	C8
	(μ, v, π)	(μ, v, π)	(μ, v, π)	(μ, v, π)
A1	(0.675, 0.218, 0.106)	(0.641, 0.245, 0.113)	(0.099, 0.868, 0.031)	(0.531, 0.326, 0.142)
A2	(0.663, 0.227, 0.108)	(0.641, 0.245, 0.113)	(0.099, 0.868, 0.031)	(0.704, 0.181, 0.114)
A3	(0.810, 0.129, 0.059)	(0.832, 0.138, 0.028)	(0.463, 0.424, 0.111)	(0.470, 0.408, 0.120)
	C9	C10	C11	C12
	(μ, v, π)	(μ, v, π)	(μ, v, π)	(μ, v, π)
A1	(0.573, 0.295, 0.131)	(0.757, 0.218, 0.023)	(0.186, 0.717, 0.095)	(0.458, 0.433, 0.108)
A2	(0.500, 0.384, 0.114)	(0.313, 0.594, 0.092)	(0.186, 0.717, 0.095)	(0.523, 0.364, 0.112)
A3	(0.396, 0.481, 0.122)	(0.323, 0.550, 0.125)	(0.243, 0.647, 0.108)	(0.619, 0.266, 0.113)
	C13	C14	C15	C16
	(μ, v, π)	(μ, v, π)	(μ, v, π)	(μ, v, π)
A1	(0.773, 0.162, 0.064)	(0.736, 0.149, 0.113)	(0.599, 0.300, 0.100)	(0.706, 0.188, 0.105)
A2	(0.882, 0.099, 0.017)	(0.778, 0.118, 0.102)	(0.714, 0.175, 0.109)	(0.750, 0.141, 0.107)
A3	(0.783, 0.114, 0.102)	(0.724, 0.163, 0.111)	(0.756, 0.140, 0.103)	(0.796, 0.147, 0.056)

Step 4: The aggregated IF-decision matrix is constructed by Equation (8). Table 3 shows the aggregation result, in other words, group decision matrix.

Step 5: Entropy method is used to obtain the weights of the criteria. The entropy value of each criterion is specified by Equation (10) and the entropy weight (ω) of each criterion is determined by Equation (11). The results are depicted in Table 4. According this table, it can be observed that C13(Social Acceptability) as a social criterion, C7 (Greenhouse Gas Emission) as an environmental criterion, C14 (Safety)as a technical criterion and C1 (Investment Cost) as an economic criterion play an important role in the calculation process since they have higher entropy weights than weights of the others in associated groups.

Table 4. Calculated Entropy Value and Entropy Weight for Each Criterion

	Criteria							
	C1	C2	C3	C4	C5	C6	C7	C8
Entropy value	0.768	0.841	0.819	0.800	0.755	0.779	0.663	0.907
Entropy weight	0.070	0.048	0.055	0.060	0.074	0.066	0.101	0.028
	C9	C10	C11	C12	C13	C14	C15	C16
Entropy value	0.972	0.888	0.794	0.958	0.589	0.675	0.779	0.695
Entropy weight	0.008	0.034	0.062	0.013	0.124	0.098	0.067	0.092

Step 6: The strong, midrange and weak concordance sets are formed by using Equations (12), (13) and (14), respectively. The strong, midrange and weak discordance sets are formed by using Equations (15), (16) and (17), respectively. The concordance and discordance sets are obtained as depicted in Table 5.

For instance, the position (1, 2) in top left cell of Table 5 indicates the strong concordance set C'_{12} = {5, 8}. It means that A1 is superior to A2 with reference to C5 and C8 strongly.

Table 5. The Strong, Midrange, Weak Concordance and Discordance Sets

	Strong C'_{ab}				Strong D'_{ab}		
	A1	A2	A3		A1	A2	A3
A1	-	{5, 8}	{∅}	A1	-	{10,13,14}	{1,4,5,6,10,16}
A2	{10,13,14}	-	{13, 14}	A2		-	{1,4,5,6,8,9,15}
A3	{1,4,5,6,10, 16}	{1,4,5,6,8, 9,15}	-	A3	{∅}	{13,14}	-
	Midrange C''_{ab}				Midrange D''_{ab}		
	A1	A2	A3		A1	A2	A3
A1	-	{4}	{3,7,11,14}	A1	-	{1,2,3,9,12,15, 16}	{2,8,9,12,13,15}
A2	{1,2,3,9,12, 15,16}	-	{2,3,7,10,11}	A2	{4}	-	{12}
A3	{2,8,9,12,13 ,15}	{12}	-	A3	{3,7,11,14}	{2,3,7,10,11}	
	Weak C'''_{ab}				Weak D'''_{ab}		
	A1	A2	A3		A1	A2	A3
A1	-	{6}	{∅}	A1	-	{7,11}	{∅}
A2	{6}	-	{∅}	A2	{7,11}	-	{16}
A3	{∅}	{1,6}	-	A3	{∅}	{∅}	-

Step 7: The weights of strong, midrange and weak concordance sets are computed by Equations (18-24). The results are as follows; the weight of strong concordance set $w_{C'}$ is 0.460, the weight of midrange concordance set $w_{C''}$ is 0.535 and the weight of weak concordance set $w_{C'''}$ is 0.014.

Step 8: Next, we have used Equation (25) in order to obtain concordance indices. Therefore, the concordance matrix P is established. For instance, the concordance index p_{12} is calculated as follows:

$$p_{12} = w_{C'} * (\omega_5 + \omega_8) + w_{C''} * (\omega_4) + w_{C'''} * (\omega_6)$$

$$p_{12} = 0.460*(0.074 + 0.028) + 0.535*(0.060) + 0.014*(0.066) = 0.079$$

$$P = \begin{bmatrix} 0.0 & 0.079 & 0.166 \\ 0.303 & 0.0 & 0.259 \\ 0.333 & 0.179 & 0.0 \end{bmatrix}$$

Step 9: Using Equation (27), we have computed each of discordance index. Therefore, the discordance matrix T is constructed.

$$T = \begin{bmatrix} 0.0 & 0.0336 & 0.0323 \\ 0.0108 & 0.0 & 0.0270 \\ 0.1016 & 0.1016 & 0.0 \end{bmatrix}$$

Step 10: The individual regret value for each alternative denoted by R_i is computed by Equations (29) and (31). For instance, individual regret value for the first alternative is determined as follows:

Firstly, the maximum value among weights of criteria is determined as 0.124 ($C = \max \omega_j$).

The aggregating discordance index of first alternative is computed as 0.0336 by specifying the maximum value among the discordance indices of the first alternative ($t_a = \max t_{ai}$).

Thereby, the individual regret value for the first alternative is calculated as 0.004 ($R_i = t_i * C$ = 0.124*0.0336).

The group utility value for each alternative denoted by R_i is computed by Equations (30) and (32). For instance, the group utility value for the first alternative is calculated as follows:

$p_1 = (p_{12} + p_{13})/2$, p_1 = (0.079 + 0.166)/2 = 0.123. $S_1 = 1 - p_1$ = 1 – 0.123 =0.877

All of the determined group utility and individual regret values are provided in Table 6.

Step 11: Next, Q values are calculated for each alternative based on Equation (25). The calculated Q values according to consensus strategy ($\gamma = 0.5$) for each renewable energy system alternative is shown in Table 6.

Step 12: We have sorted the values of Q, R and S in ascending order. It is revealed that since Solar Energy alternative is in the first position of each ranking list and satisfies two conditions (meaningful advantage and acceptable stability), hence it is compromise solution. When the weight for maximum group utility strategy γ is assigned as 1, it means that only S values are considered, in other words, only group utility of the "majority" (the closeness the value of criteria to best value) has impact in the determination of the ranking list. In this situation, the ranking is obtained as Solar > Biomass > Wind. When γ is assigned as 0, it means that only R values are considered, in other words, only the unsatisfied criteria have influence on specifying the ranking list. In this situation, the ranking is determined as Solar > Wind > Biomass. If it is assigned equal weight for both strategies ($\gamma = 0.5$), in other words, the consensus for maximum group utility and minimum individual regret is considered, the ranking is obtained as Solar > Wind > Biomass. Consequently, Solar Energy is proposed as the most convenient renewable energy system for Turkey.

Table 6. The Results of MCDM Methodology

	Renewable Energy Systems			
	Wind	Solar	Biomass	Result of ranking
Q ($\gamma = 0.5$)	0.544	0.0	0.578	Solar > Wind > Biomass
S	0.877	0.718	0.743	Solar > Biomass > Wind
R	0.004	0.003	0.012	Solar > Wind > Biomass

5. CONCLUSIONS

Renewable energy systems, which are alternative systems to traditional non-renewable systems for fossil fuel based energy production, are considered as a part of the solution to the world wide increasing energy needs in parallel with the increasing world population and technological advances, depletion and high prices of non-renewable energy sources as well as environmental pollution caused by the use of non-renewable energy sources. However, utilizing renewable sources for energy production imposes using relatively new and immature energy conversion technologies, hence to compete with fossil fuel based energy systems effective design and management methodologies should be developed and employed that significantly improve the economic, social, technical and environmental viability of renewable energy production. Considering this fact, this study aims in developing a decision making procedure to select the most appropriate renewable energy system for Turkey. To this aim, a hybrid MCDM methodology is used, which integrates ELECTRE I method with VIKOR method under intuitionistic fussy environment. The evaluations from four experts in the field of renewable energy systems corresponding to 16 economic, environmental, social and technical sustainability criteria are considered to rank 3 renewable energy system alternatives. As a result, solar energy system is selected as the most appropriate system alternative according to 16 criteria and two of three decision strategies.

Although the MCDM procedure used in this study utilizes objective weighting approaches to assign weights to criteria and decision makers instead of assigning these weights subjectively, it should be noted that the ranking of alternatives may change due to inclusion of new criteria and removing or modification of the existing criteria set. Also, the ranking may change in case of the existence of different decision makers, since each expert has his/her own perspective about the values associated with each criterion. Although the methodology is applied to renewable energy system selection case in this study, it is generic and can be adapted to varying energy management cases that include ranking and selection of multiple technologies, processes or equipment by modifying the criteria set and alternatives.

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