Research Article

Using Intuitionistic Fuzzy TOPSIS in Site Selection of Wind Power Plants in Turkey

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The reduction of energy resources and the increase in environmental consciousness have recently increased the interest in renewable energy sources. Wind energy is from renewable energy sources, which are used in many countries. Turkey has a lot alternative wind energy plants thanks to its favorable geographical location. Where the wind power plant is to be established is a complex and important decisive factor. It is very important to select the appropriate wind power plant site to take advantage of wind energy and reduce costs. In this study, we aimed to reach the solution of wind energy plant site selection. For this purpose 4 alternative wind power plant locations have been identified. To evaluate the alternatives, 10 criteria in four dimensions including wind potential, location, cost, and social benefits are selected. Since the Multicriterion Decision Making (MCDM) methods are often used in problem of location selection from past to present, TOPSIS method combined with intuitionistic fuzzy set (IFS) has been used to achieve this goal. The main purpose of the TOPSIS method is to rank the alternatives in the worst way. The IFS are used to reflect approval, rejection, and hesitation of decision makers by dealing with real life uncertainty, imprecision, vagueness, and linguistic human decisions. Finally, a numerical example is applied for wind power plant site selection. In order to demonstrate the effectiveness of IFS, the problem is solved by the Fuzzy TOPSIS method using the same data. Then, the obtained results are compared with the IFS method to show the effectiveness of the proposed method.

1. Introduction

Increased living standards have also increased the need for energy. The shortage of fossil fuels and the negative effects on the environment have created a need for clean energy [1]. Radioactive waste generated by nuclear power plants and security problems, especially the explosion of nuclear power plants in Japan Fukushima, triggered the tendency for renewable energy sources [2].

The use of renewable energy sources ensures sustainable development. Reducing the use of fossil fuels and energy imports, achieving national targets by increasing employment and competitiveness, and eliminating climate change and environmental problems are benefits of renewable energy sources [8].

Wind energy, which is the oldest energy source [3], is caused by the difference in pressure that occurs when the

earth's surface is exposed to different solar rays [4]. Wind energy, which provides high usability, reliability, and clean energy, is one of the fastest growing renewable energy sources all over the world [9]. Wind energy is abundant, useful, and economical [1] compared to limited, expensive, and defective hydrocarbon based energy [5].

The increase of the urban population and the development of industry increased Turkey's energy needs [4]. Thanks to its geographical location, Turkey has an alternative renewable energy, especially wind energy [7]. It is important to establish where the power plant is to take advantage of this energy at the maximum level [5]. Political, social, environmental, cultural, and economic criteria should be considered in addition to the technical requirements for wind power plant site selection [10].

Multicriterion Decision Making (MCDM) methods are often used to solve wind power plant site selection problem

including complex criterion [9]. MCDM methods widely used in solution of this problem are Analytic Network Process (ANP), Analytic Hierarchy Process (AHP), Elimination and Choice Translating Reality (ELECTRE), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [6].

In this study, the Intuitionistic Fuzzy TOPSIS (IFT) approach is proposed for the solution of the problem of wind power plant site selection. The most commonly used method for ranking alternatives based on criterion is TOPSIS [11]. The alternative chosen from all alternatives is the closest to the positive ideal solution, in other words the farthest away from the negative ideal solution. Positive ideal solution maximizes the benefit criterion and minimizes the cost criterion. It is the inverse for the negative ideal solution [12]. The IFS is used to deal with real life uncertainty, imprecision, vagueness, and linguistic human decisions. Also, it provides reflection of approval, rejection, and hesitation of decision makers [13].

In numerical example, 3 alternatives were selected for the wind power plant and the results of the literature survey were sorted according to the 10 election decisions determined. These criteria are gathered in 4 dimensions. Wind potential includes wind speed and wind density criterion. Location consists of surface characteristics, proximity, power distribution network, and natural disaster occurrence. In dimension of cost, there are land purchase cost and initial and annual maintenance. Finally, social benefits cover cultural and environmental concerns and employment.

The rest of this article is organized as follows: In Section 2, a literature search of the wind power site selection is given. Then the IFTOPSIS method is given in Section 3. In Section 4 this approach is illustrated with a numerical example. The conclusion and comment of the problem are given in Section 5.

2. Literature Review

Increasing global warming and increased energy demand have led countries to use renewable energy sources. This study is about wind energy from renewable energy sources. Criterion and method for wind energy site selection have been determined by literature survey. Summaries of the literature study are given in Tables 1 and 2.

The work in [4] represents the importance of renewable energy sources and Turkey has a high potential for wind energy. The wind energy potential map has been examined and potential places in Amasra, Bandırma, Bozcaada, and Çanakkale have been selected. For site selection, surface characteristic, proximity, cost, and wind characteristic were chosen as the criteria for selection. Choquet integral method, which enables interaction between criteria and evaluates quantitative and qualitative data at the same time, is applied. Çanakkale was found as the most suitable alternative.

The authors of [3] have used an integrated hierarchical Data Envelopment Analysis (DEA) method for wind plant location optimization in their work and have implemented it in Iran. A total of 125 locations in 25 cities and 5 regions in each city were evaluated. In order to determine the best region at the first level of location optimization, land

cost, population and human labor, and distances of power distribution networks indicators with social and technical structure were selected. At the second level in order to prioritize the cities used indicators, which have technical and geographical characteristics: intensity of natural disasters, quantity of proper topographical areas, quantity of proper geological areas, and average wind blow.

The authors of [6] have established a decision mechanism for SWHPS (solar-wind hybrid power station) site selection using AHP method. For the 49.5 MW SWHPS installation in China, the assessment committee chose business benefits, socioeconomic needs, and performances as subtargets and benefit, accessibility, environment, risk, and resource as evaluation features. Five alternative SWHPS sites are selected using the Geographic Information System (GIS) and grid map. As a result, alternative A site was chosen as the most suitable site.

The authors of [2] develop strategies for the selection of an offshore wind farm, in the coastal regions of South Korea's Jeju Island. The settlement criteria are divided into four categories: conservation areas and environmental protection, energy resources and economy, marine ecology and human activities, and marine environment. They have developed 4 scenarios for alternative site selection by utilizing GIS. In the scenario where 4 categories were taken into consideration, fewer suitable areas were found than other scenarios. But consideration of all categories will help to reduce the number of social conflicts among stakeholders and environmental issues by providing a sustainable and eco-friendly offshore wind farm.

The authors of [7] have done a study on site selection for wind energy plants. They choose Western Turkey as application area. The application consists of two stages: first stage is elimination of unfavorable stages and second stage is examination of existing ones. Alternative land areas are treated as grids of the same size, each large enough to build a wind turbine. GIS have been used to apply the elimination criterion and restrictions. Besides, Multiple Criterion Decision Analysis (MCDA) is then used to rank and sort the grids via the evaluation criterion specified. The problem has been assessed in 13 areas where several grids are assembled to evaluate larger areas of space to build wind farms instead of individual turbines. In all MCDA methods used, areas 3, 5, 8, and 12 are emphasized.

The authors of [5] used an integrated fuzzy-DEA approach in this study to decide on wind farm locations. They used the Basic Component Analysis (BCA) and Numerical Taxonomy (NT) methods to validate the results of the DEA model. The model was tested on 25 candidate cities in Iran with 5 regions in each city. In addition, 20 other cities are considered to be consumers of energy produced. The results show the importance of the proximity of consumers in the establishment of wind farms.

The authors of [1] evaluated the possibility of establishing wind farms in the province of Ardabil in northwestern Iran by combining ANP and Decision Making Experiment and Evaluation Laboratories (DEMATEL) methods in a GIS environment. Using the 13 layers of information according to three main criteria, environment, technical, and economical,

TABLE 1: Criterion from literature review.

Researchers	Methodology	Distance	Cost	Energy Resources	Wind Characteristics	Elevation	Slope	Proximity	Environmental Risks	Human Labor
Azadeh, Ghaderi, & Nasrollahi [3]	DEA	✓	✓						✓	✓
Cebi, S. & Kahraman [4]	AHP/Choquet Integral		✓		✓			✓	✓	
Ali Azadeh & Armin Rahimi-Golkhanda & Mohsen Moghaddam [5]	DEA	✓	✓						✓	✓
Ali Azizi & Bahram Malekmohammadi & Hamid Reza Jafari & Hossein Nasiri & Vahid Amini Parsa, [1]	ANP/Dematel/GIS					✓	✓		✓	✓
Yunna Wu & Shuai Geng [6]	AHP		✓	✓	✓				✓	
Kazim Baris Atici & Ahmet Bahadir Simsek & Aydin Ulucan & Mustafa Umur Tosun, [7]	MCDA/GIS	✓		✓		✓	✓			
Taeyun Kim & Jeong-II Park & Junho Maeng, [2]	AHP/GIS		✓	✓					✓	✓

TABLE 2: Literature review on renewable energy location selection.

Authors	Title of the Study	Article Name
Azadeh, Ghaderi, & Nasrollahi [3]	Location optimization of wind plants in Iran by an integrated hierarchical Data Envelopment Analysis.	Renewable Energy
Cebi, S. & Kahraman [4]	Using Multi Attribute Choquet Integral in Site Selection of Wind Energy Plants: The case of Turkey	Journal of Multiple-Valued Logic & Soft Computing
Ali Azadeh & ArminRahimi-Golkhanda & Mohsen Moghaddam (2013)	Location optimization of wind plants in Iran by an integrated hierarchical data envelopment analysis.	Renewable Energy
Ali Azizi & Bahram Malekmohammadi & Hamid Reza Jafari & Hossein Nasiri & Vahid Amini Parsa, [1]	Land suitability assessment for wind power plant site selection using ANP-DEMATEL in a GIS environment: case study of Ardabil province, Iran.	Environ Monit Assess
Yunna Wu & ShuaiGeng [6]	Multi-criterion decision making on selection of solar–wind hybrid power station location	A case of China Energy Conversion and Management
KazimBarisAtici & Ahmet BahadirSimsek & Aydin Ulucan & Mustafa UmurTosun, [7]	A GIS-based Multiple Criterion Decision Analysis approach for wind power plant site selection.	Utilities Policy
Taeyun Kim & Jeong-II Park & JunhoMaeng, [2]	Offshore wind farm site selection study around Jeju Island, South Korea.	Renewable Energy

a land suitability map was established. Then, it is reclassified according to the 5 equal-rate divisions from the most suitable areas that are least suitable. The results show that 6.68% of Ardabil province is most suitable for wind turbines.

3. Methodology

MCDM techniques are often used because mathematical and heuristic methods are inadequate in dealing with qualitative factors in the solution of the problem of location selection that has come up to date from the past and is still valid [4]. The MCDM methods are useful in reflecting the judgments of decision makers and in dealing with the complexity in the decision process [7].

The TOPSIS method of the MCDM techniques is proposed for solving the problem of wind power plant site selection. This section briefly reviews the intuitionistic fuzzy set and TOPSIS method.

3.1. Intuitionistic Fuzzy Set. Human decisions in real life problems involve uncertainty and ambiguity. In 1965, the fuzzy set theory was proposed by Zadeh to deal with this ambiguity and uncertainty [14]. The intuitionistic fuzzy set (A-IFS), which is generalized to the fuzzy set and characterized by a membership function and a nonmember function, was first introduced in 1986 by Atanassov. IFS has been applied to many different fields, including logic programming, medical diagnosis, decision making, evaluation function, and preference relation [15].

In this section a few definitions and operations of IFS are introduced.

Let X be fixed. IFS A in X can be defined as

$$X = \{s, \mu_x(s), \nu_x(s) \mid s \in S\}, \quad (1)$$

where

$$\mu_x(s) : \mu_x(s) \in [0, 1], \quad S \longrightarrow [0, 1] \quad (2)$$

$$\nu_x(s) : \nu_x(s) \in [0, 1], \quad S \longrightarrow [0, 1] \quad (3)$$

$\mu_x(s)$ and $\nu_x(s)$ are degrees of membership and nonmembership function, respectively, satisfying the following equation:

$$0 \leq \mu_x(s) + \nu_x(s) \leq 1 \quad \forall s \in S, \quad R \longrightarrow [0, 1] \quad (4)$$

For the IFS A in X , $\pi_x(s)$ is defined as the intuitionistic index. It is the measurement of the hesitation degree.

$$\pi_x(s) = 1 - \mu_x(s) - \nu_x(s). \quad (5)$$

Let A and B be IFS of the set S ; then the multiplication operators are, correspondingly,

$$\begin{aligned} X + Y \\ = \{ \mu_x(s) * \mu_y(s), \nu_x(s) + \nu_y(s) - \nu_x(s) * \nu_y(s) \mid s \in S \} \end{aligned} \quad (6)$$

3.2. Intuitionistic Fuzzy TOPSIS. The TOPSIS, first introduced by Hwang and Yoon in 1981, is the most common method of ranking alternatives based on the selection criterion. The basic idea of the TOPSIS method is to rank the alternatives from best to worst. The best solution among the alternatives in the obtained order is the closest one to the positive ideal solution at the same time as the farthest negative solution [16].

Fuzzy numbers are used to deal with real life uncertainty, imprecision, vagueness, and linguistic human decisions. The intuitionistic fuzzy sets better reflect the decision makers' approval, rejection, and hesitation [17].

TABLE 3: Linguistic terms for rating DMs.

Linguistic terms	IFNs
Very Important	(0.80, 0.10)
Important	(0.50, 0.20)
Medium	(0.50, 0.50)
Bad	(0.30, 0.50)
Very Bad	(0.20, 0.70)

In this section, we present an Intuitionistic Fuzzy TOPSIS model introduced by [13] for the evaluation of the alternatives. The order of m alternatives is based on n criterion. $A = \{A_1, A_2, \dots, A_m\}$ is set of alternatives, $C = \{C_1, C_2, \dots, C_n\}$ is set of criteria, and $L = \{l_1, l_2, \dots, l_l\}$ represents set of decision makers.

Now we replace the algorithm with a seven-step procedure as follows.

Step 1 (calculate the weights of DMs). The importance of the DMs is represented as linguistic terms (Table 3).

$DI = [\mu_l, \nu_l, \pi_l]$ is the intuitionistic fuzzy number for l th DM ranking. The weight of DM can be determined by the following formula:

$$\lambda_l = \frac{[\mu_l + \pi_l (\mu_l / (\mu_l + \nu_l))]}{\sum_{l=1}^k [\mu_l + \pi_l (\mu_l / (\mu_l + \nu_l))]} \quad (7)$$

where

$$\lambda_l \in [0, 1] \text{ and } \sum_{l=1}^k \lambda_l = 1 \quad (8)$$

Step 2 (calculate the weights of criterion). All criteria can not be regarded as having equal qualification. W represents a set of importance levels. In order to achieve W , all DM views on the importance of each criterion need to be integrated.

Let $w_j^k = (\mu_j^k, \nu_j^k, \pi_j^k)$ represent intuitionistic fuzzy number about the X_j criterion of the k th decision maker. The intuitionistic fuzzy weighted averaging (IFWA) operator is used to calculate the weights of the criterion. The IFWA operator is developed by Xu (2007).

$$\begin{aligned} w_j &= \text{IFWA}_{\lambda} (w_j^{(1)}, w_j^{(2)}, \dots, w_j^{(l)}) = \lambda_1 w_j^{(1)} \oplus \lambda_2 w_j^{(2)} \\ &\oplus \dots \oplus \lambda_k w_j^{(k)} = \left[1 - \prod_{l=1}^k (1 - \mu_{ij}^{(l)})^{\lambda_l}, \right. \\ &\left. \prod_{l=1}^k (\nu_{ij}^{(l)})^{\lambda_l}, \prod_{l=1}^k (1 - \mu_{ij}^{(l)})^{\lambda_l} - \prod_{l=1}^k (1 - \nu_{ij}^{(l)})^{\lambda_l} \right] \end{aligned} \quad (9)$$

The importance of criterion is represented as linguistic terms (Table 4).

Step 3 (construct intuitionistic fuzzy decision matrix (IFDM)). To arrive at a precise conclusion, each view from a group of DMs must be combined into a single view to form the aggregated intuitionistic fuzzy decision matrix (AIFDM) model.

TABLE 4: Linguistic terms for rating criterion.

Linguistic terms	IFNs
Very Important	(0.90, 0.10)
Important	(0.75, 0.20)
Medium	(0.50, 0.45)
Unimportant	(0.35, 0.60)
Very Unimportant	(0.10, 0.90)

Let $R^{(l)} = (r_{ij}^{(l)})_{m \times n}$ be the IFDM of each DM.
 $\lambda = \{\lambda_1, \lambda_2, \lambda_3, \dots, \lambda_k\}$ is the weight of the DM.

$$R = (r_{ij})_{m' \times n'} \quad (10)$$

where

$$\begin{aligned} r_{ij} &= \text{IFWA}_{\lambda} (r_{ij}^{(1)}, r_{ij}^{(2)}, \dots, r_{ij}^{(k)}) = \lambda_1 r_{ij}^{(1)} \oplus \lambda_2 r_{ij}^{(2)} \oplus \dots \\ &\oplus \lambda_k r_{ij}^{(k)} = \left[1 - \prod_{l=1}^k (1 - \mu_{ij}^{(l)})^{\lambda_l}, \right. \\ &\left. \prod_{l=1}^k (\nu_{ij}^{(l)})^{\lambda_l}, \prod_{l=1}^k (1 - \mu_{ij}^{(l)})^{\lambda_l} - \prod_{l=1}^k (1 - \nu_{ij}^{(l)})^{\lambda_l} \right] \end{aligned} \quad (11)$$

Step 4 (the calculation of aggregated weighted intuitionistic fuzzy decision matrix (AWIFDM)). The aggregated weighted intuitionistic fuzzy decision matrix is calculated by combining W and R .

$$R \oplus W = (\mu'_{ij}, \nu'_{ij}) \quad (12)$$

$$= \{ \langle x, \mu_{ij} * \mu_j, \nu_{ij} + \nu_j - \nu_{ij} * \nu_j \rangle \}$$

$$\pi'_{ij} = 1 - \mu_{ij} * \mu_j - \nu_{ij} - \nu_j + \nu_{ij} * \nu_j \quad (13)$$

Step 5 (calculate intuitionistic fuzzy positive and negative ideal solution). Let J_1 be benefit criterion and J_2 be cost criterion. A^+ represents intuitionistic fuzzy positive ideal solution and A^- represents intuitionistic fuzzy negative ideal solution. Then A^+ and A^- are calculated as

$$A^+ = (r_1^+, r_2^+, \dots, r_n^+), \quad (14)$$

$$r_j^+ = (\mu_j^+, \nu_j^+, \pi_j^+), \quad j = 1, 2, \dots, n$$

$$A^- = (r_1^-, r_2^-, \dots, r_n^-), \quad (15)$$

$$r_j^- = (\mu_j^-, \nu_j^-, \pi_j^-), \quad j = 1, 2, \dots, n$$

where

$$\mu_j^* = \left\{ \left(\max_i \{ \mu'_{ij} \} j \in J_1 \right), \left(\min_i \{ \mu'_{ij} \} j \in J_2 \right) \right\}, \quad (16)$$

$$v_j^* = \left\{ \left(\min_i \{ v'_{ij} \} j \in J_1 \right), \left(\max_i \{ v'_{ij} \} j \in J_2 \right) \right\}, \quad (17)$$

$$\pi_j^* = \left\{ \left(1 - \max_i \{ \mu'_{ij} \} - \min_i \{ v'_{ij} \} j \in J_1 \right), \right. \\ \left. \left(1 - \min_i \{ \mu'_{ij} \} - \max_i \{ v'_{ij} \} j \in J_2 \right), \right\} \quad (18)$$

$$\mu_j^- = \left\{ \left(\min_i \{ \mu'_{ij} \} j \in J_1 \right), \left(\max_i \{ \mu'_{ij} \} j \in J_2 \right) \right\}, \quad (19)$$

$$v_j^- = \left\{ \left(\max_i \{ v'_{ij} \} j \in J_1 \right), \left(\min_i \{ v'_{ij} \} j \in J_2 \right) \right\}, \quad (20)$$

$$\pi_j^- = \left\{ \left(1 - \min_i \{ \mu'_{ij} \} - \max_i \{ v'_{ij} \} j \in J_1 \right), \right. \\ \left. \left(1 - \max_i \{ \mu'_{ij} \} - \min_i \{ v'_{ij} \} j \in J_2 \right), \right\} \quad (21)$$

Step 6 (obtain the separation measures between the alternatives). In this paper, the normalized Euclidean distance proposed by Szmidt and Kacprzyk (2000) is used for measure separation between alternatives on intuitionistic fuzzy set. S_i^* and S_i^- , the separation measures of each alternative, are calculated for intuitionistic fuzzy positive ideal and negative ideal solutions, respectively.

$$S_i^* = \sqrt{\frac{1}{2n} \sum_{j=1}^n \left[(\mu'_{ij} - \mu_j^*)^2 + (v'_{ij} - v_j^*)^2 + (\pi'_{ij} - \pi_j^*)^2 \right]}, \quad (22)$$

$$S_i^- = \sqrt{\frac{1}{2n} \sum_{j=1}^n \left[(\mu'_{ij} - \mu_j^-)^2 + (v'_{ij} - v_j^-)^2 + (\pi'_{ij} - \pi_j^-)^2 \right]}, \quad (23)$$

Step 7 (determine the final ranking). The relative closeness coefficient of an alternative A_i with respect to the intuitionistic fuzzy positive ideal solution A^* is defined as follows:

$$CC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, \quad \text{where } 0 \leq C_i^* \leq 1. \quad (24)$$

After the relative closeness coefficient of each alternative is determined, alternatives are ranked according to descending order of CC_i^* .

4. Case Study

In this section, the IFTOPSIS method for selection of appropriate wind power plant site is applied in a numerical example. It is shown in Figure 1. A decision maker group consisting of three experts was formed for this reason. Decision maker 1 is a geographer, decision maker 2 is a

map engineer, and decision maker 3 is an energy engineer. Çanakkale, İzmir, Samsun, and Mersin are selected as the alternative for wind power plant location. Three decision makers evaluate these alternatives and for selection of an appropriate alternative we will use selection criterion given in Table 6. Ten criteria are considered as follows.

Wind speed (C1): this includes a high average wind speed and the ability to provide the maximum benefit from the wind.

Wind density (C2): it is the kinetic energy measure produced by wind, unit square meter and time.

Surface characteristic (C3): this includes geological conditions such as soil structure and infrastructure conditions and topographic conditions such as geographical direction, elevation of the plant, and slope which are properties to be taken into consideration in the site selection.

Proximity (C4): due to some factors such as noise pollution, healthcare, aesthetics, and safety, the wind power plant should be away from areas such as urban areas, water resource, main roads, protected areas, and airports.

Power distribution network (C5): to prevent energy losses, the plant must be installed in areas close to the consumers.

Natural disaster occurrence (C6): this criterion is aimed at establishing the plant in places where safe and natural disasters are less experienced.

Land purchase cost (C7): this criterion refers to the purchase cost of the place where the plant will be established.

Initial and annual maintenance cost (C8): installation and annual maintenance costs are the criteria that should not be ignored.

Cultural and environmental concerns (C9): the plant to be installed must not be allowed to harm the environment and the historical heritage.

Employment (C10): being close to the available human labor of the plant is important in terms of employee accommodation and salaries.

4.1. Application of Intuitionistic Fuzzy TOPSIS Method. In this section, Intuitionistic Fuzzy TOPSIS model is applied for the evaluation of the alternatives.

In Step 1, the linguistic terms in Table 3 and (7) are used to calculate the weight of the decision makers and the results in Table 7 were obtained.

In the second step, the opinions of the decision makers about the criterion weight are calculated as shown in Table 10 using Table 4 and (9).

Decision makers were asked to evaluate each alternative using linguistic terms in Table 5 for each criterion and Table 8 was generated. Using (11), Table 11 is calculated, so that the decisions of DMs are collected into a single decision.

FIGURE 1: Alternative assessment based on criterion.

TABLE 5: Linguistic terms for rating the alternatives.

Linguistic terms	IFNs
Very Good (VG)	[1.00, 0.00, 0.00]
Good (G)	[0.85, 0.05, 0.10]
Moderately Good (MG)	[0.70, 0.20, 0.10]
Fair (F)	[0.50, 0.50, 0.00]
Moderately Poor (Mp)	[0.40, 0.50, 0.10]
Poor (P)	[0.25, 0.60, 0.15]
Very Poor (VP)	[0.00, 0.90, 0.10]

TABLE 6: The dimension and criterion of wind power plant site selection.

Target	Dimension	Criterion
Wind power plant site selection	Wind Potential	Wind speed
		Wind density
	Location	Surface characteristic
		Proximity
		Power distribution network
		Natural disaster occurrence
	Cost	Land purchase cost
		Initial and annual maintenance cost
	Social Benefits	Cultural end environmental concerns
		Employment

By combining the criterion weights and the aggregated intuitionistic fuzzy decision matrix with the help of (12) and (13), an aggregated weighted intuitionistic fuzzy decision matrix is obtained in Table 12.

TABLE 7: The importance and weights of decision makers' opinions.

	DM1	DM2	DM3
Linguistic terms	Very Important	Important	Medium
λ	0,42	0,34	0,24

In Step 5 from AIFMD, A^+ is calculated by using (16), (17), and (18) and A^- is calculated by using (19), (20), and (21). A^+ and A^- are shown that in Table 13 and in Table 14, respectively.

To calculate S^* (22) is used, to calculate S^- (23) is used, and to calculate CC_i^* (24) is used. S^* and S^- represent separation measurement and CC_i^* shows ranking of alternatives. S^*S^- and CC_i^* values for the alternatives are determined and presented in Table 15.

4.2. Application of Fuzzy TOPSIS Method. In this section, the data used in the solution phase of the Intuitionistic Fuzzy TOPSIS model (decision makers opinions, importance weight of the criterion) were also used in Fuzzy TOPSIS application. As a result of this evaluation, the results obtained by the two different approaches under the same data will be compared and the effectiveness and solution results of the proposed Intuitionistic Fuzzy TOPSIS model will be evaluated.

After obtaining fuzzy ratings from Tables 9 and 10 normalized fuzzy decision matrix determined is shown in Table 16.

By combining the criterion weights and the aggregated Intuitionistic fuzzy decision matrix, aggregated weighted intuitionistic fuzzy decision matrix is obtained. After that, fuzzy positive ideal solution (A^+) and negative ideal solution (A^-) obtained according to the aggregated weighted intuitionistic fuzzy decision matrix are presented in Tables 17 and 18, respectively.

TABLE 8: Importance of alternative based on opinion of DMs.

Decision-Makers (DMs)	Alternative	Criterion									
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
DM1	Mersin	MG	G	MP	MG	MG	MG	G	MP	F	P
	Çanakkale	VG	VG	G	VG	G	MP	MG	MG	MP	MP
	İzmir	VG	VG	F	G	VG	F	F	G	MG	MG
	Samsun	G	F	MG	MP	F	G	VG	F	P	F
DM2	Mersin	MG	G	F	F	F	G	VG	F	MP	P
	Çanakkale	VG	VG	MG	MG	VG	F	MG	G	G	MG
	İzmir	G	G	G	G	G	MP	F	MG	MG	F
	Samsun	MG	MG	MP	MP	MG	MG	G	MP	F	MP
DM3	Mersin	F	MG	MP	MP	F	F	G	F	MP	P
	Çanakkale	VG	VG	MG	G	G	MP	MG	G	MG	F
	İzmir	G	VG	G	MG	VG	P	MP	MG	F	G
	Samsun	MG	F	F	F	MG	MG	F	VG	P	MG

TABLE 9: The importance weight of the criterion.

Criterion	DM1	DM2	DM3
C1	I	VI	I
C2	VI	VI	VI
C3	I	M	M
C4	M	U	M
C5	M	I	M
C6	I	I	M
C7	VI	I	VI
C8	U	M	I
C9	VU	U	U
C10	M	U	U

TABLE 10: Weight of criterion.

C1	(0.82,0.16,0.03)
C2	(0.90,0.10,0.00)
C3	(0.63,0.32,0.05)
C4	(0.45,0.50,0.05)
C5	(0.60,0.34,0.05)
C6	(0.70,0.24,0.05)
C7	(0.86,0.13,0.01)
C8	(0.53,0.42,0.05)
C9	(0.25,0.71,0.03)
C10	(0.42,0.53,0.05)

The calculation of distance (S^* and S^-) of each alternative from A^+ and A^- is determined. Then, by using the (S^* and S^-) values closeness coefficient (CC_i^*) of each alternative is calculated and shown in Table 19. According to the obtained results, Çanakkale is the best alternative and Samsun is the worst alternative.

4.3. Comparison of Intuitionistic Fuzzy TOPSIS with Fuzzy TOPSIS Method. In this section, the results obtained by two different methods will be compared. As Table 20 and

FIGURE 2: Comparison of two different methods results.

Figure 2 show the results obtained by Intuitionistic Fuzzy TOPSIS method and Fuzzy TOPSIS method, according to the Intuitionistic Fuzzy TOPSIS method the most important alternative is Izmir. Later, Çanakkale, Mersin, and Samsun are listed, respectively. According to the results obtained by Fuzzy TOPSIS method, Çanakkale is the most important alternative, followed by Mersin, İzmir, and Samsun, respectively.

Given the results obtained, it is clear how effective the weighting of decision makers' opinions is on the outcome, which demonstrates the effectiveness of the proposed method.

5. Conclusion

Many reasons, such as reduced resources, increased environmental problems, and energy need, have led the world to trend to renewable energy. The wind energy is from renewable energy that develops rapidly all around the world. To get the maximum benefit from wind energy, where the

TABLE II: R matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	(0.66,0.25,0.09)	(0.82,0.07,0.11)	(0.44,0.50,0.06)	(0.58,0.34,0.08)	(0.60,0.34,0.06)	(0.73,0.16,0.11)	(1.00,0.00,0.00)	(0.46,0.50,0.04)	(0.44,0.50,0.06)	(0.25,0.60,0.15)
A2	(1.00,0.00,0.00)	(1.00,0.00,0.00)	(0.78,0.11,0.11)	(1.00,0.00,0.00)	(1.00,0.00,0.00)	(0.44,0.50,0.06)	(0.70,0.20,0.10)	(0.80,0.09,0.11)	(0.68,0.18,0.13)	(0.55,0.37,0.09)
A3	(1.00,0.00,0.00)	(1.00,0.00,0.00)	(0.75,0.13,0.12)	(0.82,0.07,0.11)	(1.00,0.00,0.00)	(0.41,0.52,0.06)	(0.48,0.50,0.02)	(0.78,0.11,0.11)	(0.66,0.25,0.09)	(0.70,0.20,0.11)
A4	(0.78,0.11,0.11)	(0.58,0.37,0.05)	(0.57,0.34,0.09)	(0.43,0.50,0.07)	(0.63,0.29,0.08)	(0.78,0.11,0.11)	(1.00,0.00,0.00)	(1.00,0.00,0.00)	(0.35,0.56,0.09)	(0.53,0.40,0.07)

TABLE 12: Aggregated weighted intuitionistic fuzzy decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	(0.540,0.368,0.092)	(0.741,0.163,0.097)	(0.273,0.660,0.067)	(0.262,0.668,0.070)	(0.361,0.566,0.073)	(0.516,0.361,0.123)	(0.863,0.127,0.010)	(0.243,0.709,0.048)	(0.113,0.856,0.031)	(0.104,0.813,0.083)
A2	(0.817,0.158,0.025)	(0.900,0.100,0.000)	(0.486,0.396,0.118)	(0.453,0.496,0.050)	(0.605,0.342,0.053)	(0.307,0.621,0.071)	(0.604,0.301,0.094)	(0.421,0.470,0.108)	(0.174,0.764,0.062)	(0.228,0.703,0.069)
A3	(0.817,0.158,0.025)	(0.900,0.100,0.000)	(0.471,0.410,0.120)	(0.373,0.531,0.096)	(0.605,0.342,0.053)	(0.292,0.638,0.070)	(0.412,0.563,0.024)	(0.409,0.483,0.108)	(0.168,0.783,0.048)	(0.292,0.623,0.085)
A4	(0.634,0.252,0.114)	(0.522,0.430,0.049)	(0.357,0.551,0.091)	(0.193,0.748,0.059)	(0.380,0.535,0.085)	(0.547,0.328,0.126)	(0.863,0.127,0.010)	(0.527,0.418,0.055)	(0.088,0.874,0.038)	(0.221,0.720,0.059)

TABLE 13: A^+ .

C1	(0.817,0.158,0.025)
C2	(0.900,0.100,0.000)
C3	(0.486,0.396,0.118)
C4	(0.453,0.496,0.050)
C5	(0.605,0.342,0.053)
C6	(0.547,0.328,0.126)
C7	(0.412,0.563,0.024)
C8	(0.243,0.709,0.048)
C9	(0.174,0.764,0.062)
C10	(0.292,0.623,0.085)

TABLE 14: A^- .

C1	(0.540,0.368,0.092)
C2	(0.522,0.430,0.049)
C3	(0.273,0.660,0.067)
C4	(0.193,0.748,0.059)
C5	(0.361,0.566,0.073)
C6	(0.292,0.638,0.070)
C7	(0.863,0.127,0.010)
C8	(0.527,0.418,0.055)
C9	(0.088,0.874,0.038)
C10	(0.104,0.813,0.083)

TABLE 15: Separation measures and the relative closeness coefficient of each alternative.

Alternatives	S^+	S^-	CC_i^*
Mersin	0,2166	0,1466	0,4036
Çanakkale	0,1342	0,2131	0,6135
İzmir	0,1136	0,2425	0,6811
Samsun	0,2409	0,1075	0,3086

plant is installed is a very important decision that needs to be taken. In addition to cost, many factors such as sustainability and the environment must be considered. Therefore, the wind power station site selection problem should be considered as MCDM problem.

In this paper, to solve problem of wind power plant site selection, the TOPSIS method is used and combined with the intuitionistic fuzzy number which is reflecting the judgments of decision makers and dealing with the complexity in the decision process, so that more accurate results can be achieved. Wind potential, location, cost, and social benefits were defined as dimension of criterion and the ten selected criteria were collected under these dimensions. The weights of the criterion importance were decided in the establishment of the wind power plant and the selection was made in this direction. The alternatives evaluated based on these criteria are Mersin, Çanakkale, İzmir, and Samsun. The results have shown that İzmir is the best alternative for wind power site.

Also Çanakkale, Mersin, and Samsun follow it, respectively. Thus which alternative is most appropriate is determined.

For the future research, the other MCDM methodologies like ELECTRE, PROMETHEE, etc. can be used for wind power site selection and the obtained results can be compared with ours. Furthermore, a comprehensive study can be carried out by identifying other main criteria and separating them with subcriterion.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

TABLE 16: R matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	(4.61, 2.18, 0.49)	(7.24, 0.90, 0.90)	(2.84, 3.27, 0.44)	(3.49, 2.62, 0.44)	(5.38, 3.79, 0.32)	(4.25, 1.56, 0.41)	(6.97, 0.26, 0.52)	(3.13, 3.35, 0.22)	(2.55, 2.94, 0.39)	(1.32, 3.17, 0.79)
A2	(7.28, 0.00, 0.00)	(9.05, 0.00, 0.00)	(4.91, 0.98, 0.65)	(5.56, 0.55, 0.44)	(8.54, 0.32, 0.63)	(2.70, 3.11, 0.41)	(5.42, 1.55, 0.77)	(5.37, 0.67, 0.67)	(3.82, 1.47, 0.59)	(2.82, 2.11, 0.35)
A3	(6.55, 0.24, 0.49)	(8.59, 0.15, 0.30)	(4.80, 1.31, 0.44)	(5.24, 0.65, 0.65)	(9.01, 0.16, 0.32)	(2.38, 3.32, 0.52)	(3.61, 3.87, 0.26)	(5.03, 1.01, 0.67)	(3.73, 1.77, 0.39)	(3.61, 1.32, 0.35)
A4	(5.46, 1.09, 0.73)	(5.13, 3.62, 0.30)	(3.49, 2.62, 0.44)	(2.84, 3.27, 0.44)	(6.01, 2.85, 0.63)	(4.67, 0.93, 0.62)	(6.07, 1.42, 0.26)	(4.25, 2.24, 0.22)	(1.96, 3.33, 0.59)	(2.82, 2.11, 0.35)

TABLE 17: A^+ positive distance of alternatives.

ALTERNATIVES	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0,726	0,550	0,433	0,331	0,733	0,173	0,153	0,393	0,143	0,319
A2	0,115	0,121	0,244	0,451	0,407	0,682	0,457	0,374	0,442	0,217
A3	0,223	0,178	0,211	0,436	0,414	0,570	0,966	0,332	0,372	0,328
A4	0,499	1,176	0,304	0,412	0,615	0,872	0,280	0,251	0,158	0,217

TABLE 18: A^- negative distance of alternatives.

ALTERNATIVES	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0,115	0,634	0,244	0,357	0,414	0,441	0,966	0,374	0,352	0,328
A2	0,726	1,176	0,433	0,412	0,638	0,191	0,523	0,393	0,158	0,251
A3	0,529	1,040	0,411	0,363	0,733	0,193	0,153	0,337	0,165	0,319
A4	0,238	0,121	0,222	0,451	0,332	0,536	0,708	0,294	0,442	0,251

TABLE 19: Separation measures and the relative closeness coefficient of each alternative.

Alternatives	S^+	S^-	CC_i^*	Ranking
A1 - Mersin	3,9545	4,2258	0,517	2
A2 - Çanakkale	3,5102	4,9020	0,583	1
A3 - İzmir	4,0305	4,2441	0,513	3
A4 - Samsun	4,7853	3,5938	0,429	4

TABLE 20: Comparison of the relative closeness coefficient of two methods.

Alternatives	Intuitionistic Fuzzy TOPSIS CC_i	Ranking	Fuzzy TOPSIS CC_i	Ranking
A1 - Mersin	0,4036	3	0,517	2
A2 - Çanakkale	0,6135	2	0,583	1
A3 - İzmir	0,6811	1	0,513	3
A4 - Samsun	0,3086	4	0,429	4

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