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THE SELECTION OF TERRESTRIAL RENEWABLE ENERGY POWER PLANTS IN AN INTUITIONISTIC FUZZY ENVIRONMENT: THE CASE OF TURKEY

Asst. Prof. Fulya ZARALI
Kayseri University, Develi Hüseyin Şahin VS, Kayseri, Turkey, *(fzarali@kayseri.edu.tr)*

ABSTRACT

Energy is recognised as an important indicator of economic development in a globalising world and is of vital importance to countries. In order to ensure sustainable development in a society, it is necessary to have abundant energy resources. These energy resources must be obtained at a reasonable cost and used for all the needs of society without causing any negative social impact. Power plants are recognized as the heart of the electricity generation industry in all countries with continuous operation. They are believed to have a critical and decisive role in the survival of industry and the economy. Therefore, they are certainly one of the most important pillars of development in a country. For this purpose, the selection of terrestrial renewable energy plants has been made in this study. Nowadays, the rapid increase in the world's population and industrialisation increase the need for energy. Energy needs are generally supplied from fossil fuel sources. Due to the decrease in fossil fuel resources in our country and in the world and the damage they cause to the environment, the importance of renewable energy sources has increased. The selection of energy sources is seen as a multi-criteria group decision making problem since alternatives (energy sources) are evaluated by multiple decision makers according to criteria. In this study, terrestrial renewable energy plants are ranked using the intuitionistic fuzzy WASPAS approach. Economic, environmental, technical, and social criteria are taken into account when determining the best terrestrial renewable energy plants for Turkey. As a result of the modelling, solar power plants are determined as the most suitable renewable energy source.

Keywords: *Renewable Energy, Power Plants, Decision Problem, MCDM.*

SEZGİSEL BULANIK ORTAMDA KARASAL YENİLENEBİLİR ENERJİ SANTRALİ SEÇİMİNDE TÜRKİYE ÖRNEĞİ

ÖZET

Enerji, küreselleşen dünyada ekonomik kalkınmanın önemli bir göstergesi olarak kabul edilmektedir ve ülkeler için hayati bir öneme sahiptir. Bir toplumda sürdürülebilir kalkınmayı sağlamak için bol enerji kaynaklarına sahip olmak gerekir. Bu enerji kaynakları makul bir maliyetle elde edilmeli ve herhangi bir olumsuz sosyal etkiye neden olmadan toplumun tüm ihtiyaçları için kullanılmalıdır. Enerji santralleri, sürekli faaliyet gösteren tüm ülkelerde elektrik üretim endüstrisinin kalbi olarak kabul edilmektedir. Sanayinin ve ekonominin ayakta kalmasında kritik ve belirleyici bir role sahip olduklarına inanılmaktadır. Bu nedenle, kesinlikle bir ülkedeki kalkınmanın en önemli esaslarından birisidir. Bu amaçla bu çalışmada karasal yenilenebilir enerji santrallerinin seçimi yapılmıştır. Günümüzde dünya nüfusundaki hızlı artış ve sanayileşme enerji ihtiyacını artırmaktadır. Enerji ihitiyacı genellikle fosil kaynaklı enerji kaynaklarından temin edilmektedir. Ülkemizde ve dünyada fosil kaynakların azalması ve çevreye verdikleri zarardan dolayı yenilenebilir enerji kaynaklarının önemini artırmıştır. Enerji

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kaynaklarının seçimi, alternatiflerin (enerji kaynağının) kriterlere göre birden çok karar verici tarafından değerlendirilmesinden ötürü çok kriterli grup karar verme problemi olarak görülmektedir. Bu çalışmada, karasal yenilenebilir enerji santralleri, sezgisel bulanık WASPAS yaklaşımı kullanılarak sıralanmıştır. Türkiye için en iyi karasal yenilenebilir enerji tesisleri belirlenirken ekonomik, çevresel, teknik ve sosyal kriterler dikkate alınmaktadır. Yapılan modelleme sonucunda güneş enerjisi santrali en uygun yenilenebilir enerji santrali olarak belirlenmiştir.

Anahtar Kelimeler: *Yenilenebilir Enerji, Enerji Santralleri, Karar Problemi, ÇKKV.*

1. Introduction

The need for energy is rising now due to industrialization and the fast growing world population, and it is anticipated that this demand will rise by 56% by 2040. (Damgaci et al., 2017:629). This demand is mostly met by traditional energy sources called fossil fuels, such as coal, oil, and natural gas. These resources, which are used intensively in power plants for electricity generation, produce carbon and other greenhouse gases and contribute to global warming. In order to reduce carbon emissions and combat global warming, it is important to move away from fossil fuels and switch to renewable energy sources (Rahman et al., 2022:1-2). In addition, it can be said that expanding the use of renewable energy sources is a widely accepted policy for countries. Increasing energy efficiency, establishing low carbon technology and building efficient renewable energy power plants that minimise negative impacts on the environment are important within the scope of this policy. Whether in developed or developing countries, power plants are recognised as the beating heart of industry. One of the most significant pillars of national development, power plants are seen to be crucial for maintaining the existence of the economy and industries. There is a need for more renewable energy power plants in order to ensure the security of energy supply, to meet the increasing energy demands of the country, and to eliminate the negative impacts on the environment (Katal & Fazelpour, 2018:163-164).

As in the world, energy demand is constantly increasing in Turkey as well. Studies to predict future energy requirements have shown that these requirements will continue to increase in the coming years. In addition, the relative inadequacy of the country's domestic resources in terms of oil and natural gas makes it necessary to import oil and natural gas. Renewable energy sources in Turkey have been identified as a key factor in addressing the growing energy challenge for Turkey (Kabak & Dadeviren, 2014). For this purpose, targets for the energy sector have been set for 2023 in Turkey. It is aimed to obtain 30% of electricity consumption from renewable energy sources within the framework of these targets. The 2023 targets include mobilizing Turkey's total hydroelectric energy potential (approximately 36 GW) for electricity generation; increasing the installed capacity of wind energy to 20 GW; and reaching a 600 MW geothermal energy capacity. In solar energy, it is aimed to reach an installed capacity of 3 GW (Erdal, 2012:175-176). This underlines the necessity of investing in renewable energy plants. Choosing the right renewable energy power plant provides economic benefits, local job opportunities, and energy security while reducing environmental impacts and resource waste. Selecting the best renewable energy power plants is a complex and important decision-making process. In the literature, multi-criteria decision making (MCDM) models are widely presented to address complex issues with various decision factors (Yazdani et al., 2020:36). The objective is for decision-makers to select the best renewable energy power plants from a set of choices according to their specific decision-making conditions. Sometimes, however, no alternative fulfils all criteria to the highest degree (Gaoa et al., 2020:2). In this selection problem, the most appropriate and optimal solution that meets the specified needs and criteria should be found. In this and similar selection and ranking problems, it is difficult for decision makers to determine the importance of the criteria, to evaluate the alternatives according to the criteria, and to express them precisely with clear data. Atanassov's (1986) intuitionistic fuzzy (IF) sets are a suitable solution to deal with these obstacles and have been applied to numerous decision-making situations in an uncertain environment. It has been demonstrated that IF sets are particularly helpful for handling ambiguity and uncertainty (Memari et al., 2019:10). In this study, the WASPAS approach integrated with the IF set was chosen for this purpose. The WASPAS method is one of the utility theory-based approaches called "weighted sum product evaluation" by Zavadskas et al. (2012). It combines the weighted sum model (WSM) and the weighted product model (WPM). The WASPAS approach provides a more reliable evaluation and ranking of alternatives (Mishra & Rani, 2019:2). Therefore, it is preferred in this study.

This study evaluates the most suitable terrestrial renewable energy plants for Turkey in terms of economic, environmental, social, and technological aspects. Not every decision maker may be familiar with all the characteristics of all the criteria when evaluating terrestrial renewable energy power plants. As a result of this situation, decisions are made in an uncertain environment. IF sets are one of the most effective methods for decision making in uncertain environments. For this purpose, in this study, an extended MCDM method with IF sets is used. The proposed method aims to effectively evaluate terrestrial renewable energy power plants. Furthermore, the proposed methodology aims to help researchers to better understand the problem of terrestrial renewable energy power plant selection and to support governments, investors, decision makers, and all those interested in investing in renewable energy in selecting a renewable energy source or system that provides the highest economic, environmental, social, and technological efficiency. It is hoped that this study will contribute to the literature in various ways. Most of the research on the selection of renewable energy power plants is modelled with MCDM and fuzzy MCDM methods. There are only a few studies that use MCDM methods integrated with IFsets. This study aims to fill this gap. In addition, the WASPAS method extended with IFnumbers has been used for the first time in the selection of terrestrial renewable energy power plants, which constitutes the originality of this study.

The rest of the paper is organized as follows. A summary of the literature is given in Section 2. The IF-WASPAS approach is described in Section 3. The application of the proposed method is presented in Section 4. The results of the sensitivity analysis and comparative analysis are presented in Section 5. Discussion and conclusion are given in Section 6.

2. Literature Review

When we look at the literature, we find that various studies on renewable energy have been done and are still being done around the globe. The selection of renewable energy sources usually employs MCDM or fuzzy MCDM techniques. The objective of the studies is to rank or pick the best renewable energy options based on technical, economic, political, social, and environmental factors. There are fewer publications on the selection of renewable energy power plants than there are on the selection of renewable energy sources.

In the literature on the choice of renewable energy power plants, a synopsis of the research done with MCDM is offered. Özkale et al. (2017) chose renewable energy power plants for Turkey using the PROMETHEE technique. Among the alternatives of wind, hydroelectric, solar, biomass, and geothermal power plants, they determined that the hydroelectric power plant was the most suitable one. In their study, Katal & Fazelpour (2018) evaluated the power plants located in different regions of Iran. The hydroelectric power plant was selected as the most suitable power plant using the VIKOR technique of selection. Tolga & Turgut (2018) used the fuzzy TODIM method to evaluate renewable energy power plants in Turkey. In their studies, they determined that the solar energy power plant was the best option among solar, wind, hydroelectric, and LFG (landfill gas) power plants. Incekara (2018) used the AHP method to evaluate power plant investments in Turkey. Wind power plants were determined to be the best investment among coal, nuclear, natural gas, hydraulic, wind, geothermal, biomass, and solar power plants in the study. Gözde (2020) chose the best renewable energy power plant for Eskişehir province. In the study, selection was made for wind, solar, hydroelectric, geothermal, and biomass power plants for Eskişehir. As selection techniques, SAW, WPM, WASPAS, ARAS, GIA, MULTIMOORA, TOPSIS, VIKOR, COPRAS, EDAS, and ELECRE were employed. The best renewable energy power facility was determined to be a wind power plant.

If we summarize the studies on the selection of renewable energy alternatives related to MCDM, Kahraman et al. (2009) used the fuzzy analytic hierarchy process and fuzzy axiomatic design approaches to find the best renewable energy source for Turkey. They have selected wind energy as the most suited renewable energy source out of solar, wind, hydropower, biomass, and geothermal energy sources. Amer & Daim (2011) listed renewable energy sources for Pakistan using the AHP method. The study used biomass energy, wind energy, solar photovoltaic energy, and solar thermal energy as alternatives. The most suitable renewable energy source has been identified as biomass. Sadeghi et al. (2012) used the fuzzy TOPSIS method in conjunction with the fuzzy analytical hierarchy process method to assess Iran's renewable energy options. Between solar, geothermal, hydroelectric, and wind energy, they determined that solar energy was the most suitable renewable energy source. Ertay et al. (2013) used fuzzy AHP and MACBETH methods to evaluate renewable energy technologies in Turkey. Among solar, wind, hydroelectric, and geothermal energy sources, they determined that solar energy was the most efficient renewable energy source. Balin & Baraçli (2015) applied the interval type-2 fuzzy AHP and TOPSIS method to rank renewable energy sources for Turkey. They identified wind energy as the most suitable renewable energy source among solar, biomass, geothermal, geothermal, hydraulic, wind, and hydrogen energy sources. Çelikbilek & Tüysüz (2016) evaluated renewable energy resources using a gray-based MCDM methodology integrating DEMATEL, ANP, and VIKOR methods. The study presents an MCDM approach for the evaluation of renewable energy alternatives, which are solar, wind, hydroelectric, geothermal, and biomass energies for use in energy planning. Büyüközkan & Güleryüz (2016a) ranked energy alternatives for Turkey using the fuzzy TOPSIS method integrated with the fuzzy analytic hierarchy process (FAHP). Among wind energy, solar energy, biomass energy, conventional energy (coal, oil, etc.), combined heat and power, nuclear energy, and hydraulic energy alternatives, nuclear energy ranked first as the most suitable energy alternative. Büyüközkan & Güleryüz (2016b) presented an integrated MCDM model combining DEMATEL and ANP methods to determine the most suitable renewable energy source for Turkey. Among wind, solar, geothermal, biomass, and hydraulic energy, wind energy was found to be the most suitable renewable energy source. Lee & Chang (2018) used WSM, VIKOR, TOPSIS, and ELECTRE methods to evaluate renewable energy technologies in Taiwan. They determined hydroelectric energy sources as the most suitable energy sources among solar, wind, biomass, hydroelectric, and geothermal energy sources. Rani et al. (2019) used the VIKOR method to select the most appropriate renewable energy source. In the study, wind, solar, geothermal, biomass, and hydroelectric energy are analyzed as renewable energy sources. As a result of the study, it was determined that wind power plants are the most suitable renewable energy source for India. Zhang et al. (2019) conducted renewable energy source selection for China with the extended TODIM method with 2D uncertain linguistic variables. Among the renewable energy sources: wind, solar photovoltaic, biomass power, hydroelectric energy sources, wind energy was selected as the best alternative. Alizadeh et al. (2020) proposed a hybrid decision-making model using BOCR model and ANP model for the evaluation of renewable energy technologies in Iran. They identified solar energy as the best renewable energy source among wind, solar, hydroelectric, biomass and geothermal energy sources. Derse & Yontar (2020) used TOPSIS method integrated with SWARA to select the most appropriate renewable energy source. In the study, wind energy, solar energy, biomass energy, hydrogen energy, wave energy, hydroelectric energy and geothermal energy are analyzed as renewable energy sources. As a result of the study, it is determined that hydroelectric power plant is the most suitable renewable energy source for Turkey. Karakul (2020) ranked renewable energy sources in Turkey using the Fuzzy Analytic Hierarchy Process method. Renewable energy sources are biomass, solar, hydraulic, geothermal, and wind energy. As a result of the study, it was determined that solar energy is the most suitable renewable energy source for Turkey. Karaaslan & Aydın (2020) used AHP, COPRAS, and MULTIMOORA methods to rank wind, solar, geothermal, biomass, and hydroelectric energy sources for Turkey. As a result of the study, the most suitable energy source for Turkey was the hydroelectric energy source. In their study, Bilgiç et al. (2021) determined the most suitable renewable energy source for the Central Anatolia region with the Best Worst Method—BWM method. In their study, they determined solar energy, wind energy, hydroelectric energy, geothermal energy, and biomass energy as renewable energy sources and selected solar energy as the best renewable energy source. In their study, Bilgili et al. (2022) made a renewable energy source selection for Turkey in terms of sustainable development. They selected solar energy as the best renewable energy source among wind, solar, geothermal, biomass, wave, and hydrogen energy with the IF-TOPSIS method.

When we examine the literature, we see that MCDM or Fuzzy MCDM methods are used in the selection of renewable energy sources and power plants. Uncertainty applications in these studies are generally based on classical fuzzy set theory. In this study, a different MCDM method integrated with a IFset is proposed for the selection of terrestrial renewable energy plants. In the literature on renewable energy resource selection, there are very few studies with IFset-integrated MCDM methods. This paper contributes to the literature on power plant selection and IF sets. A case study for Turkey is presented to evaluate the validity of the proposed approach. It is expected that this study will be useful for investors and researchers to better understand the power plant selection problem and help investors make more reliable investment decisions in the field of renewable energy.

3. Methodology

3.1. IF Set Theory

Decision-making has emerged as one of the fastest growing academic areas dealing with real-world difficulties as a result of greater competitiveness. MCDM is an important part of the decision-making process since it allows you to rank possibilities based on a variety of criteria and then select the best one. Because the criteria differ, there may not be a single solution that meets all of them at the same time. Numerous MCDM strategies have been developed to produce more reasonable decision findings. Due to the ambiguity and complexity of human thought, fuzzy sets (FSs) were first proposed by Zadeh (1965) and have recently drawn more interest from decision experts in the field of decision making. Later, IF sets are added to the category of FSs (Atanassov, 1986). Atanassov (1986) introduced IF sets, which are quite helpful for coping with the uncertainty of MCDM scenarios (Mishra & Rani, 2018:1048). Where Atanassov's IF sets theory and Zadeh's FS theory diverge is in the degree of membership. In the traditional FS theory, only the membership degree is defined; in the IF set theory, the non-membership degree is also defined. Degrees of membership and non-membership fall into the [0,1] range. When viewed from this angle, the sum of membership and non-membership degrees is equal to one in classical FS theory. However, according to IF sets theory, the sum of these two variables may be less than 1, but it equals 1 when a third component termed hesitancy degree is taken into account (Yıldırım & Çiftçi, 2021:778).

The IF set *A* in *X* is expressed as $A=\{(x,\mu_A(x),\upsilon_A(x))|\,x\in\}$ when *X* is a non-empty set. It defined the degree of belonging of the element χ to the set *A* as $\mu_A(x)$, the degree of non-belonging as $\upsilon_A(x)$, and the hesitation index as $\pi_A(x)$ in IF set theory. The total of the degrees of belonging and not belonging, according to IF set theory, takes a value in the range [0,1]. 0 ≤ $\mu_A(x)+\upsilon_A(x)$ ≤ 1. The level of hesitation is whether any element belongs to set or not. The equation is used to calculate it (Tırmıkçıoğlu,2021:1333-1334).

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

Definition 1: Let $=(\mu_x,\upsilon_x)$ and $B=(\mu_y,\upsilon_y)$ be two IF numbers (IFN) with parameters and λ a constant number greater than zero. Operations with IFN are given below.

$$A\oplus B=(\mu_x+\mu_y-\mu_x.\mu_y,\upsilon_x.\upsilon_y) \tag{2}$$

$$A\otimes B=(\mu_x.\mu_y,\upsilon_x+\upsilon_y-\upsilon_x.\upsilon_y) \tag{3}$$

$$\lambda.A=(1-(1-\mu_x)^{\lambda},\upsilon_x^{\lambda}),\lambda>0 \tag{4}$$

$$A^{\lambda}=(\mu_x^{\lambda},1-(1-\upsilon_x)^{\lambda}),\lambda>0 \tag{5}$$

Definition 2: Below are the score and accuracy functions for the IFN A and B.

$$S(A_1)=\mu_1+\mu_1(1-\mu_1-\upsilon_1) \tag{6}$$

$$S(B_2) = \mu_2 + \mu_2(1 - \mu_2 - \upsilon_2) \tag{7}$$

$$H(A_1) = \mu_1 + \upsilon_1 \tag{8}$$

$$H(B_2) = \mu_2 + \upsilon_2 \tag{9}$$

3.2. IF-WASPAS Method

One of the new utility theory-based approaches, the weighted aggregate product assessment (WASPAS) method, was developed by Zavadskas et al. (2012). This technique combines the weighted sum model (WSM) and the weighted product model (WPM). This strategy has been expanded under many fuzzy theories (Mishra & Rani, 2018:1048). It is utilized in this work by fusing IFN with it. With the aid of linguistic considerations and the aid of IFN, it is believed that the decision-maker would be able to successfully navigate the ambiguity of the decision-making process, such as uncertainty and lack of knowledge.

Different techniques have been presented to be created by researchers, and WSM, one of the precursors of MCDM methods, has been employed in a variety of decision challenges as an approach that allows the weights of criteria to be reflected in the choice problem. In its simplest version, the WSM is created by multiplying the performance scores of each decision-problem choice by the weight of the pertinent criterion. In contrast, the WPM employs the exponentiation of the weights to provide a single score that is similar to the performance scores of the alternatives depending on the criteria (Tırmıkçıoglu, 2021:1333). The WASPAS approach is a model that advocates using both of these models simultaneously and has been proposed in the literature. Assuming that the scores of the alternatives may be on various scales depending on the criteria in the choice problem under discussion, the WASPAS technique starts by normalizing the decision matrix (Yıldırım & Çiftçi, 2021:782).

Below are the steps of the WASPAS approach combined with the IFN. (Tırmıkcıoglu, 2021:1334-1335; Günter, 2019:19-20)

Step 1: Determine the linguistic variables to be evaluated and the related IFN values in the decision-making model

Step 2: Determine the weights of the decision makers. Assume the decision group consists of one decision maker. Decision-makers' importance is viewed as linguistic concepts articulated within the context of IFN. To rate the kth decision maker, let $E_k = [\mu_k, \upsilon_k, \pi_k]$ be an IFN. The weight of the kth decision maker can then be determined using the equation:

$$\lambda_k = \frac{\left(\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + \upsilon_k}\right)\right)}{\sum_{k=1}^{l} \mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + \upsilon_k}\right)}$$

$$\text{and } \sum_{k=1}^{l} \lambda_k = 1 \tag{10}$$

Step 3: The decision makers analyze the decision making model's criteria using linguistic variables and their IFcounterparts.

Step 4: The decision makers' criteria evaluations are combined with the IFweighted arithmetic mean operator ($IFWA_{\lambda}$) using importance weights ($\lambda 1, \lambda 2, \ldots, \lambda k$).

$$IFWA_{\lambda} = \begin{bmatrix} 1-\Pi_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda k}, \Pi_{k=1}^{l}\left(\upsilon_{ij}^{(k)}\right)^{\lambda k}, \Pi_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda k} \\ -\Pi_{k=1}^{l}\left(\upsilon_{ij}^{(k)}\right)^{\lambda k} \end{bmatrix} \tag{11}$$

Step 5. The combined IFcriterion values are defuzzified by the score function defined for the IFN:

$$w_j = \mu_j + \mu_j\left(1-\mu_j-\upsilon_j\right)\left(J=1,....,n\right) \tag{12}$$

Step 6: The criteria weights are computed by normalizing the found criteria score values:

$$\bar{w}_j = \frac{w_j}{\sum_{j=1}^{n} w_j} j = 1,....,n; 0 < \bar{w}_j < 1; \sum_{j=1}^{n} \bar{w}_j = 1 \tag{13}$$

Step 7: Alternatives are evaluated by each decision maker using the predetermined criteria, and the results are combined to form the combined decision matrix Y.

$\bar{Y}_{ij}^{k} = \left(\mu_{ij}^{(k)}, \upsilon_{ij}^{(k)}, \pi_{ij}^{(k)}\right)\left(k=1,....,l\right)$ (k. the decision-maker j. in accordance with the criterion i. IFevaluation of alternatives;

$$\bar{Y}_{ij} = \left[1-\Pi_{k=1}^{l}\left(1-\mu_{j}^{(k)}\right)^{\lambda k}, \Pi_{k=1}^{l}\left(\upsilon_{j}^{(k)}\right)^{\lambda k}\right] \tag{14}$$

$$\bar{Y}^{(k)} = \left(\bar{Y}_{ij}^{k}\right)_{mxn} = \begin{pmatrix} \bar{Y}_{11}^{k} & \cdots & \bar{Y}_{1n}^{k} \\ \vdots & \ddots & \vdots \\ \bar{Y}_{m1}^{k} & \cdots & \bar{Y}_{mn}^{k} \end{pmatrix}$$

$$\bar{Y} = \left(\bar{Y}_{ij}\right)_{mxn} = \begin{pmatrix} \bar{Y}_{11} & \cdots & \bar{Y}_{1n} \\ \vdots & \ddots & \vdots \\ \bar{Y}_{m1} & \cdots & \bar{Y}_{mn} \end{pmatrix}$$

Step 8: The $\bar{Z} = \left(\bar{z}_{ij}\right)_{mxn}$ combined normalized decision matrix is formed by normalizing the combined decision matrix. The benefit and cost criteria are represented by B and C, respectively, in the normalized decision matrix:

$$\bar{z}_{ij} = \begin{Bmatrix} \left(\mu_{\bar{x}ij}, \upsilon_{\bar{x}ij}\right) J \in B \\ \left(\upsilon_{\bar{x}ij}, \mu_{\bar{x}ij}\right) J \in C \end{Bmatrix} \tag{15}$$

Step 9: Using the weighted aggregate model, the relative relevance values of the alternatives are calculated. The IFWA operator is used to calculate the value.

$$\bar{Q}_i^{(1)} = \sum_{j=1}^{n} \bar{z}_{ij} * \bar{w}_j \tag{16}$$

$$IFWA_w = [1 - \Pi_{k=1}^{l}(1-\mu_j)^{wj}, \Pi_{k=1}^{l}(\upsilon_{ij})^{wj}] \tag{17}$$

Step 10: The weighted product model of the alternatives is used to calculate relative importance values. The IFWG operator is used to calculate the $\bar{Q}_i^{(2)}$ value.

$$\bar{Q}_i^{(2)} = \Pi_{j=1}^{n} \bar{z}_{ij}^{\bar{w}j} \tag{18}$$

$$IFWG_w = [\Pi_{k=1}^{l}(\mu_j)^{wj}, 1 - \Pi_{k=1}^{l}(1-\upsilon_{ij})^{wj}] \tag{19}$$

Step 11. The Q_i value for each alternative is calculated

$$Q_i = \lambda.(\bar{Q}_i^{(1)}) + (1-\lambda)\bar{Q}_i^{(2)} \tag{20}$$

$0 < \lambda < 1$ using the equation. The λ value is set at 0.5 in this study.

Step 12: Sort the relative values from greatest to smallest using the values from the score function. The selection with the highest score value is the best one.

4. Application

In this section, terrestrial renewable energy power plants are selected for Turkey to demonstrate the applicability and effectiveness of the proposed approach. Solar energy, wind energy, landfill gas, and geothermal power plants are the selected terrestrial renewable energy plants. Below are the descriptions of the alternative renewable energy plants.

Solar Energy (SE): Solar energy has long been recognized as clean energy, i.e., energy that does not emit carbon dioxide (Rahman et al., 2022:3). Solar energy refers to the radiation emitted by the sun as a result of fusion events occurring within the sun. Although only 50 per cent of solar radiation falls on Earth, it has a very high energy potential. The energy brought by radiation can be converted into electrical energy using devices known as solar panels or solar cells, commonly known as photovoltaic systems. (Turgut, 2017:28)

Wind energy (WE): Wind energy is recognised as a safe and environmentally benign form of energy. It is one of the oldest renewable energy facilities. With the help of a turbine, it utilises the speed of the wind to generate electrical energy (Rahman et al., 2022:6). Among electricity generation facilities, wind power plants are the most popular choice due to their low environmental impact, fast installation times, lower investment prices compared to other energy sources, and ease and speed of conversion into electrical energy (Ylmaz & Öziç, 2018:530).

Landfill gas energy (LG): Landfill gas energy is generated from garbage collected in the landfills of large settlements. In addition to solving the garbage problem of the settlements, this technology allows the energy needs of the settlements to be met. The methane gas in the garbage dumped in landfills is extracted from the garbage using a special mechanism and then burned in gas engines to generate energy. After hydroelectric power plants, landfill gas power generation plants are the most cost-effective energy source among renewable technologies (Çelebi et. al., 2017:696).

Geothermal Energy (GE): Geothermal resources are hot water and steam that are produced by heat stored in the earth's different depths, whose temperature values are consistently higher than the area's average atmospheric temperature and which may contain more different minerals, salts, and gases than the typical surface. Energy is generated from medium- and low-temperature liquid-weighted geothermal resources using geothermal power plant methods. (Arda & Çavşi, 2018:47).

After the selection of the alternatives, four main criteria and eight sub-criteria are determined from the literature. The selected criteria and their explanations are given in Table 1.

Table 1: Criteria and sub-criteria

Main criteria	Sub criteria	Explanations	References
Economy	Investment Cost (C1)	Facility installation cost	Cavallaro & Ciraolo (2005); Wang et al. (2009); Lee & Chang (2018)
	Maintenance Cost (C2)	Facility maintance/ Operation cost	Cavallaro & Ciraolo (2005); Stein (2013); Wang et al. (2009); Büyüközkan & Güleryüz (2016b); Tolga & Turgut (2018)
Environmental	Land Requirement (C3)	Area where the facility will be established	Alkan (2020); Diakoulaki & Karangelis (2007); Beccali et al. (2003); Amer & Daim (2011); Kahraman & Kaya (2010); Wang et al. (2009); Büyüközkan & Güleryüz (2016b); Troldborg et al. (2014); Lee & Chang (2018); Katal & Fazelpour (2018)
	Co2 emission (C4)	Reduction in CO2 emissions	Vishnupriyan & Manoharan (2018); Ahmat & Tahar (2014); Wang et al. (2009); Büyüközkan & Güleryüz(2016b); Troldborg et.al. (2014); Lee & Chang (2018); Özkale et al. (2018); Katal & Fazelpour (2018)
	Impact Ecosystem (C5)	Ecosystem problems	Shao et al., (2020); Ahmat & Tahar (2014); Büyüközkan & Güleryüz (2016b); Tolga & Turgut (2018)

Table 1 continue

Technical	Production Capacity (C6)	Electrical energy production capacity	Vishnupriyan & Manoharan (2018); Stein (2013); Büyüközkan & Güleryüz (2016b)
Social	Work Employment (C7)	Social impacts and social benefits	Begic & Afgan (2007); Beccali et.al. (2003); Amer & Daim (2011); Ahmat & Tahar (2014); Stein (2013; Kahraman & Kaya (2010); Wang et al., (2009); Lee & Chang (2018); Özkale et.al., (2018); Tolga & Turgut (2018)
	Government Support (C8)	Government incentives	Shao et al., (2020); Kahraman & Kaya (2010); Büyüközkan & Güleryüz (2016b); Streimikiene et al., (2016); Tolga & Turgut (2018)

As a first step in the IF-WASPAS technique, the decision-making group should be determined after the alternatives and criteria are determined. An expert group consisting of 3 associate professors and 1 assistant professor who have worked in the field of renewable energy for many years and have published in this field was formed. Language expressions such as A1: "very important", A2: "very important", A3: "important" and A4: " medium " are used, and each academic is weighted according to the intensity of his/her work on this subject. Language qualifiers like "very important," "very important," "important," and " medium " are employed, and each scholar is given a weight based on how hard they worked on the issue. In Table 2, these linguistic expressions were converted into IF numbers, and weight values were calculated using Equation 10.

Table 2: Linguistic terms and IFN

LT	IFN
VI (very important)	0.80-0.10
I(important)	0.50-0.30
M (medium)	0.50-0.50
U (unimportant)	0.30-0.50
VU (very unimportant)	0.20-0.70

Table 3: Expert's weight value

EG	Importance ratings	λ
E1	VI	0,300
E2	VI	0,300
E3	I	0,232
E4	M	0,168

Using the linguistic phrases in Table 4, each decision maker is asked to assess the alternatives in accordance with the criteria. Table 5-6-7-8 lists the linguistic assessments of each decision-maker.

Table 4: Linguistic terms

Linguistic Terms	Abbreviation	Linguistic Terms	Abbreviation	IFN
Absolutely Important	AI	Absolutely Good	AG	0.90-0.10
Very Important	VI	Very Good	VG	0.80-0.05
Important	I	Good	G	0.65-0.25
Medium	M	Medium	M	0.50-0.50
Unimportant	U	Bad	B	0.35-0.55
Very Unimportant	VU	Very Bad	VB	0.20-0.05
Absolutely Unimportant	AU	Absolutely Bad	AB	0.10-0.90

Table 5: Evaluation of A1

Criteria	SE	WE	LE	JE
C1	M	AG	B	B
C2	AG	G	M	B
C3	M	AG	M	AG
C4	AG	G	G	AG
C5	AG	B	G	AG
C6	M	M	M	G
C7	G	AG	B	M
C8	AG	AG	G	G

Table 6: Evaluation of A2

Criteria	SE	WE	LE	JE
C1	M	AG	B	B
C2	AG	AG	G	M
C3	G	VG	M	AG
C4	AG	G	G	AG
C5	AG	M	G	AG
C6	M	AG	M	G
C7	M	G	G	M
C8	AG	AG	M	G

Table 7: Evaluation of A3

Criteria	SE	WE	LE	JE
C1	G	M	B	VB
C2	AG	M	VG	G
C3	AB	AB	VG	AB
C4	AG	AG	VB	G
C5	VB	VG	B	M
C6	VB	AB	B	M
C7	AG	VG	G	M
C8	G	M	AG	VG

Table 8: Evaluation of A4

Criteria	SE	WE	LE	JE
C1	M	M	M	M
C2	G	G	G	G
C3	AG	G	G	AG
C4	G	B	G	G
C5	G	G	AG	B
C6	G	G	G	B
C7	G	B	B	G
C8	AG	B	B	G

Each academician is asked to rate each criterion using the linguistic phrases listed in Table 4. Table 9 displays the evaluation results.

Table 9: Expert results

Criteria	A1	A2	A3	A4
C1	AI	AI	AI	AI
C2	I	I	VI	VI
C3	M	I	AI	I
C4	M	VI	I	AI
C5	M	I	VI	AI
C6	AI	AI	VI	I
C7	I	I	I	M
C8	I	VI	VI	I

Table 10 displays the combined results with $IFWA_\lambda$, taking into account the expert team's linguistic evaluations as well as their significant weights. Clarification and Normalization procedures are performed on the derived weight values using Equation 12-13, and the results are shown in Table 10.

Table 10: Weight, clarification and normalization values

Criteria		W		Si	Ni
C1	0.900	0.100	0.000	0.900	0.162
C2	0.720	0.131	0.149	0.827	0.149
C3	0.709	0.249	0.042	0.739	0.133
C4	0.733	0.163	0.164	0.809	0.145
C5	0.732	0.182	0.099	0.795	0.143
C6	0.855	0.099	0.046	0.894	0.161
C7	0.628	0.281	0.091	0.685	0.123
C8	0.740	0.106	0.157	0.854	0.153

Each academician evaluates the alternatives according to predetermined criteria, and with the help of the IFWA operator, they are combined to form a combined decision matrix. Each criterion is evaluated as a utility criterion. Table 11 shows the combined decision matrix obtained.

Table 11: Combined decision matrix

	C1			C2			C3			C4	
(0.540	0.425	0.035)	(0.877	0.116	0.007)	(0.607	0.355	0.038)	(0.877	0.116	0.007)
(0.810	0.190	0.000)	(0.739	0.223	0.038)	(0.747	0.158	0.095)	(0.710	0.231	0.059)
(0.378	0.541	0.081)	(0.658	0.212	0.130)	(0.647	0.216	0.140)	(0.576	0.163	0.261)
(0.353	0.310	0.337)	(0.531	0.390	0.019)	(0.834	0.166	0.000)	(0.793	0.184	0.023)
	C5			**C6**			**C7**			**C8**	
(0.800	0.099	0.101)	(0.696	0.261	0.043)	(0.709	0.249	0.042)	(0.866	0.124	0.010)
(0.588	0.268	0.144)	(0.667	0.314	0.019)	(0.766	0.149	0.085)	(0.801	0.193	0.006)
(0.673	0.257	0.070)	(0.500	0.454	0.046)	(0.532	0.362	0.106)	(0.677	0.284	0.039)
(0.801	0.193	0.006)	(0.578	0.335	0.087)	(0.530	0.444	0.026)	(0.693	0.172	0.135)

The relative important values of the alternatives calculated using the weighted total model $\bar{Q}_i^{(1)}$ and the relative importance values of the alternatives calculated using the weighted product model $\bar{Q}_i^{(2)}$ are shown in the Table 12.

Table 12: $\bar{Q}_i^{(1)}$, $\bar{Q}_i^{(2)}$ values

$\bar{Q}_i^{(1)}$			$\bar{Q}_i^{(2)}$		
0.83	0.14	0.03	0.70	0.26	0.04
0.79	0.16	0.05	0.69	0.25	0.06
0.65	0.24	0.12	0.52	0.37	0.11
0.73	0.20	0.07	0.56	0.32	0.12

The Q_i value for each option is calculated using equation 9 and clarified using the score function, with the results shown in Table 13.

Table 13: Rank

lternative	Q_i	Rank
SE	0.798	1
WE	0.783	2
LE	0.654	4
GE	0.714	3

According to the rankings in Table 13, the solar power plant came in first, the wind power plant came in second, the geothermal power plant came in third, and the landfill gas power plant came in last. The solar power plant is the best suited terrestrial renewable energy power plant for Turkey, according to the results of this ranking.

5. Comparative Analysis and Sensitivity Analysis

5.1. Comparative Analysis

The proposed method for the selection of the terrestrial renewable energy power plant is subjected to a comparative study. The decision problem is solved again with the IF-TOPSIS method, and the ranking results are shown in Table 14. The algorithms used by the IF-TOPSIS and IF-WASPAS approaches are different. As a result, different techniques handle the same data in different ways. In the TOPSIS approach, the best alternative is determined by the closest distance to the positive ideal and the farthest distance to the negative ideal. As shown in Table 14, there is no significant difference between the proposed approach and the compared method in terms of the best alternative. The ranking has not changed in either method. A solar power plant is the best terrestrial renewable energy power plant.

Table 14: **Comparative analysis**

Method	Rank
IF-WASPAS	SE>WE>GE>LE
IF-TOPSIS	SE>WE>GE>LE

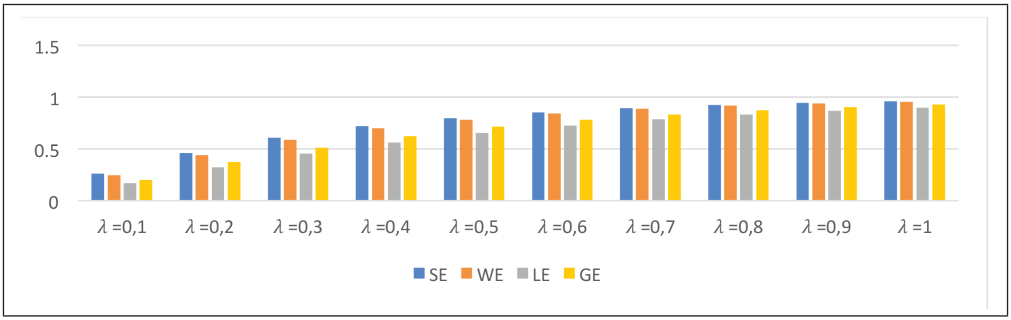
5.2. Sensitivity Analysis

A sensitivity analysis is performed by assigning different values to the coefficient in order to assess the rankings of the alternatives. Table 15 and Figure 1 show the findings of the sensitivity analysis.

Table 15: Sensitivity analysis results

	λ =0.1	λ =0.2	λ =0.3	λ =0.4	λ =0.5	λ =0.6	λ =0.7	λ =0.8	λ =0.9	λ =1
SE	0.262	0.461	0.610	0.719	0.798	0.855	0.896	0.926	0.947	0.962
WE	0.247	0.442	0.590	0.701	0.783	0.843	0.887	0.918	0.941	0.957
LE	0.170	0.323	0.454	0.564	0.654	0.727	0.785	0.832	0.868	0.897
GE	0.200	0.372	0.513	0.625	0.714	0.782	0.835	0.875	0.905	0.929

Figure 1: Sensitivity analysis by changing λ



As can be seen in Table 15 and Figure 1, as the value of **λ** increases, the performance of the alternatives also increases. Although the performance values increase in response to the change in the value of **λ**, there is no change in the ranking. The sensitivity analysis shows the consistency of the proposed method since the changes in **λ** value do not affect the ranking of the terrestrial renewable energy power plant selection decision.

6. Discussion and Conclusions

One of the most urgent issues today is to meet the increasing energy demand caused by population growth, industrialization, and technological development. However, since fossil fuels are limited by their nature, they are insufficient to meet this increasing energy demand. Therefore, the search for alternative energy sources has accelerated recently, and this situation has led countries to renewable energy alternatives. Considering concerns such as energy production and meeting current or future demands, depletion of fossil resources, and building a sustainable world, the problem of selecting renewable energy sources arises. This situation emphasises the importance of selecting the best renewable energy plant. Selecting the best renewable energy power plants is a complex and important decision-making process. For the selection of an effective renewable energy power plant, it is necessary to determine the appropriate criteria and to select the best power plant according to the determined criteria. The

IF- WASPAS method is a decision-making method that combines weighted sum and product methods to improve the accuracy of the ranking obtained to determine the best alternative based on the criteria determined in selection and ranking problems. The IF-WASPAS method was chosen for this study because it allows for the selection of the most accurate alternative by evaluating the alternatives as a whole.

In this study, a systematic approach is presented for governments, investors, decision makers, and anyone interested in investing in renewable energy. A feasible model is proposed for the selection of terrestrial renewable energy power plants among renewable energy plants. With the proposed model, four main criteria and eight sub-criteria are used to select the most suitable power plant for Turkey among four terrestrial renewable energy power plants. In the evaluation process, each criterion is evaluated linguistically by the decision makers, and the linguistic terms are transformed into IF numbers. The evaluations of each decision maker are combined using the IFWA operator. According to the calculated criterion weight values, investment cost, generation capacity, and government support are found to be the most important criteria in the selection of a terrestrial renewable energy power plant. The work employment criterion is determined as the least important criterion. Solar energy ranked first in the ranking of terrestrial renewable energy plants in Turkey. The results obtained are similar to the results of Ertay et al., (2013); Tolga & Turgut (2018); Karakul (2020); Bilgili et al. (2022), which shows the consistency of the study. The investment advantages of solar power plants are that solar power plants require less investment compared to other renewable energy alternatives; the installation period is short and can be put into production immediately; government incentives are greater than other alternatives; the technical potential is very high; it can be easily installed and used in homes and vehicles; and social acceptance is high. These advantages of solar power plants show that the result obtained is suitable for Turkey.

Consequently, in this study, the IF-WASPAS method is used to evaluate the problem of the selection of terrestrial renewable energy plants. IFnumbers have been used to eliminate uncertainties in the decision-making process, such as uncertainty and lack of information. The proposed method was chosen for this study because it has few analytical steps and produces simple mathematical operations. In addition, the decision model was solved again with the IF-TOPSIS method to evaluate the proposed model. In the solution with the IF-TOPSIS method, the ranking did not change, and the solar power plant ranked the highest among the terrestrial renewable energy plants. The obtained result reveals that a solar power plant is the most suitable terrestrial renewable energy power plant for Turkey. A biomass power plant is seen as the least important terrestrial renewable energy power plant for electricity generation. According to the results of the sensitivity analysis, it is seen that the results obtained are reliable and robust, and there is no significant change in the results. The results of the study are a guide for investors who want to invest in this sector. It is also believed to enrich the literature and help researchers develop a theoretical understanding of terrestrial renewable energy power plants.

In future studies, the analysis can be extended by using different criteria for terrestrial renewable energy power plant selection and by adding more criteria. The study can be solved with different IF-MCDM techniques and compared with the findings of the current study. The correlation levels between the ranking results can be investigated, and combined ranking results can be generated. In addition, the study can be integrated with different fuzzy sets (such as bipolar fuzzy and spherical fuzzy) and the results can be compared.

Conflict of Interest

The authors declare that they have no conflict of interest.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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