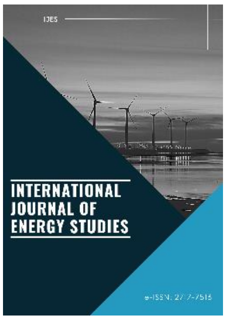
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2024; 9(2): 291-308

DOI: 10.58559/ijes.1437059

Received	:	14 Feb 2024
Revised	:	07 May 2024
Accepted	:	10 June 2024

Determining the most useful renewable energy alternative for Turkey by combining MAUT and TAOV methods

Burhan Aydın[a], Özlem Ege Oruç[b*]

[a]*DEU The Graduate School of Natural and Applied Sciences Department of Statistics, ORCID: 0000-0001-8983-3196*

[b*]DEU Faculty of Sciences Department of Statistics, *ORCID:* 0000-0003-0984-5459

*(*Corresponding Author: ozegeoruc@gmail.com)*

Highlights

- This study proposes a novel Multi-Criteria Decision Making (MCDM) method that integrates Total Area Based on Orthogonal Vectors (TAOV) and The Multi-Attribute Utility Theory (MAUT) to enhance decision-making for selecting the optimal renewable energy source in Turkey.
- Through a comprehensive literature review, the research identifies crucial decision criteria for renewable energy sources in Turkey, including efficiency, cost, government incentives, and environmental considerations.
- MAUT method is employed to determine criteria weights, improving the accuracy and reliability of decision-making in the context of renewable energy resources for Turkey.
- Applying the integrated MCDM approach, the study concludes that hydroelectric, wind, solar, biomass, and geothermal energy, in that order, are the most beneficial renewable energy resources for Turkey.

You can cite this article as: Aydın B, Oruç ÖE. Determining the most useful renewable energy alternative for Turkey by combining MAUT and TAOV methods. Int J Energy Studies 2024; 9(2): 291-308.

ABSTRACT

This study focuses on various Multi-Criteria Decision Making (MCDM) methods developed in the academic literature to facilitate the decision-making process. These methods are primarily aimed at establishing a ranking of alternatives based on specific criteria, with the ultimate goal of determining the most optimal alternative. In this work, we propose a novel integrated MCDM approach that combines the Total Area Based on Orthogonal Vectors (TAOV) method with the Multi-Attribute Utility Theory (MAUT) method. Within this framework, criteria weights are determined using the MAUT method, while the TAOV method is employed to ascertain the ranking of alternatives. The primary objective of this approach is to identify the most suitable renewable energy resource for the context of Turkey. Based on a comprehensive review of relevant literature regarding the evaluation of renewable energy sources in Turkey, a set of critical criteria influencing the decision-making process is delineated. These criteria encompass a range of factors including efficiency, construction duration, cost, government incentives, economic lifespan, external dependence, employment opportunities, social acceptance, spatial requirements, and environmental considerations such as greenhouse gas emissions. The outcomes of this study reveal that, according to the proposed approach, the most beneficial renewable energy resources for Turkey are ranked as follows: hydroelectric, wind, solar, biomass, and geothermal energy sources, respectively.

Keywords: Multi criteria decision making (MCDM), Multi attribute theory of utility (MAUT), Total area based on vertical vectors (TAOV), Renewable energy resources.

1. INTRODUCTION

Today, one of the most crucial necessities, playing a significant role in the economic and social advancement of both developed and developing nations, is energy. The escalating demands for energy cannot be met solely with limited resources due to the impacts of population growth, industrialization, and the rapid advancement of technologies. Consequently, a widening gap between power generation and consumption is emerging. Conversely, conventional "non-renewable" energy sources like oil, natural gas, coal, and nuclear power have increasingly posed threats to both the environment and human health. The emission of carbon dioxide (CO_2) resulting from the combustion of fossil fuels gradually intensifies, concomitant with deforestation, thus impeding the effective reflection of solar rays alongside other atmospheric gases. This, in turn, leads to the onset of the "greenhouse effect" and subsequent climate changes. Amidst these developments, the prospect of traditional energy resources depletion has prompted a shift towards the exploration of environmentally-friendly, clean, and relatively cost-effective energy alternatives. In light of this context, significant strides have been taken to harness the potential of "renewable energy resources," which exhibit sustainability over time and possess global applicability. A renewable energy resource is defined as an "energy source that can be reliably available on the following day through natural processes." The paramount attributes of renewable energy resources encompass environmental preservation through the mitigation of carbon dioxide emissions, reduction of external energy dependency, and the facilitation of increased employment opportunities, leveraging domestic resources. These initiatives garner substantial and enthusiastic public support. Today, energy is essential for the economic and social progress of both developed and developing countries. Growing energy demands can't be met with limited resources due to population growth, industrialization, and rapid technology advancement, resulting in a widening gap between power generation and consumption. Conversely, "non-renewable" energy sources like oil, natural gas, coal, and nuclear power increasingly threaten the environment and human health. Emissions from burning fossil fuels intensify with deforestation, causing the "greenhouse effect" and climate changes. In response, efforts are underway to explore clean, cost-effective, and sustainable "renewable energy resources." These sources can reliably provide energy through natural processes. They mitigate carbon emissions, reduce dependence on external energy, and boost job opportunities. Public support for these initiatives is substantial.

The essential characteristics of renewable energy resources encompass their role in safeguarding the environment by curbing carbon dioxide emissions, contributing to decreased reliance on external energy sources, and promoting domestic employment. These resources garner extensive and robust public support. Renewable energy has gained prominence, capturing growing attention within academia and the industrial sector. In recent years, multi-criteria decision analysis methods (MCDA) have emerged as potent and practical tools for assessing decisions pertaining to renewable energy, particularly sustainable energy solutions. Renewable energy sources encompass hydro, geothermal, solar, wind, plant residues, biomass, tidal, and wave energy. Turkey boasts a rich potential in terms of renewable energy resources, underscoring the impetus for this study. Within this context, a novel decision-making approach, the Total Area Based on Orthogonal Vectors and Multi-Attributed Utility Theory (TAOV-MAUT), was devised, Integrating two prominent multi-criteria decision-making methods. This innovative approach seeks to ascertain the most advantageous renewable energy source within Turkey, based on criteria delineated among alternatives such as hydroelectric, wind, solar, biomass, and geothermal sources. Through the proposed TAOV-MAUT approach in this study, the optimal renewable energy source for Turkey will be identified, aligning with established criteria among the aforementioned alternatives.

2. MATERIAL AND METHODS

In recent years, multi-criteria decision analysis methods (MCDA) are seen as an effective and applicable tool for decision making analysis for renewable energy and MCDA applications are widely used to make decisions about sustainable energy. Some of the studies in the literature on this subject are as follows; Heo, Kim, and Boo (2010) used the Fuzzy AHP method in their study where they analyzed the factors of the renewable energy distribution program. Frangopoulos and Keramioti (2010) used a multi-criteria approach to determine the sustainability index of energy systems. Amer and Daim (2011) examined AHP in terms of environmental, social, economic and technical criteria to evaluate renewable energy technologies and indicated biomass energy and wind energy as preferred alternatives. Troldborg et al. (2014) applied a national sustainability assessment and Multi-Criteria Analysis (MCA) method for Scotland to rank eleven renewable energy technologies and examine how uncertainties in the data affect the outcome. Ozcan, et al. (2017) used ANP and TOPSIS methods in their study to select the most suitable source among renewable energy sources in Turkey. Solangi, Tan, Mirjat, Valasai, Khan, and Ikram (2019) evaluated renewable energy sources in Pakistan using Integrated Delphi, AHP and Fuzzy TOPSIS. Renewable energy sources are considered as hydro, geothermal, solar, wind, plant residues, biomass, tide and wave. Turkey has a rich potential in terms of renewable energy resources. The main motivation for determining the subject of this study is thepromising potential of these resources in Turkey. In the study, a new decision-making method approach (MAUT- TAOV) was obtained by combining the Multi-Attributed Utility Theory (MAUT) and Total Area Based on Orthogonal Vectors (TAOV)methods, which are among the multi-criteria decision-making methods. Using this new approach, it has been tried to determine the renewable energy source that provides the most useful from renewable energy sources in Turkey. MAUT is an entropy-based decision making method, which is used to determine the most beneficial decision alternative. It was first introduced to the literature by Fishburn (1967) and Fishburn and Keeney (1974) and has become a method with a wide application area in recent years. Some of the studies conducted in the literature using the MAUT method are as follows; According to Sanayei et al. (2008) selected the supplier with the MAUT method and then presented an integrated approach to determine the optimum order quantity from the selected supplier with Linear Programming. In the study by Kim and Song (2009), column selection was made using AHP and MAUTmethods for the column decommissioning project at the Korea Research Reactor (KRR-1). Using similar techniques, Freitas, Veraszto, Marins, and Silva (2013) made a selection using the AHP and MAUT methods, using the price, quality and delivery time criteria determined to select the supplier of the service company. On the other hand, Ömürbek et al. (2017) determined the performances of fifty-three state universities with the MAUT method. The TAOV method, a new multi-criteria decision-making method based on orthogonal vectors, proposed by Razavi Hajiagha et al. in 2018, has been used in various researches. Using the BWM-TAOV approach in 2018, Mokhtarzadeh et al. examined the importance of project integration and budget for the most attractive technology options in a limited time frame. Vahid Jafari-Sadeghi et al. examined how Italian SMEs' decision to start a new business was affected in 2020 using the TAOV method. In this study, a new multi criteria decision making approach is proposed by combining TAOV and MAUT methods. In this approach, while the weights of the criteria are determined by the MAUT (Multi Attribute Utility Theory) method, TAOV (Total Area Based on Orthogonal Vectors) method is utilized to rate the alternatives. Steps of decision making method with TAOV-MAUT is as follows. The criteria weights are obtained by applying the first four steps of the MAUT method respectively. The entropy value is calculated to objectively obtain the weights of the criteria in the MAUT method.

Step 1: The decision matrix for a multi criteria decision making problem with m alternatives and n criteria is constructed.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \vdots & \vdots & \ldots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Where x_{ij} : is the success value of i^{th} alternative according to the $j^{\,th}$ criterion, i = 1,2,...,m and j = 1,2, ...,n.

Step 2: The normalized decision matrix ($R = [r_{ij}]_{mxn}$) is calculated by using equation (1).

$$r_{ij} = \frac{x_{ij}}{\sum_{p=1}^{m} x_{pj}}, \; i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n. \tag{1}$$

Step 3: The entropy value of each criterion is calculated by using equation (2).

$$e_j = \frac{1}{\ln m} \sum_{i=1}^{m} r_{ij} \ln r_{ij} \quad, j = 1,2, \ldots, n. \tag{2}$$

Step 4: The weighting value of each criterion is calculated by using equation (3)

$$W_j = \frac{1 - e_j}{\sum_{p=1}^{n} (1 - e_p)} \quad, j = 1,2, \ldots, n. \tag{3}$$

$\sum_{j=1}^{n} W_j = 1$.

Then, alternatives are rated by applying the steps of the TAOV method respectively.

Step 5: The utility values are determined according to utility criteria. Considering the monotonic increasing utility for the decision criteria, normalized values (r_{ij}) for the utility criteria set B are calculated by equation (4).

$$r_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \; j \epsilon B \tag{4}$$

Considering the cost for the decision criteria, the cost (i.e. the less the better) criteria set is calculated by normalized values (r_{ij}) for set C:

$$r_{ij} = \frac{\min_{i} x_{ij}}{x_{ij}}, \; j\epsilon C \qquad (5)$$

The normalized decision matrix R is obtained as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \dots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

Step 6: Construction of the Weighted Standard Decision Matrix (WN). Subsequently, each normalized element n_{ij} is multiplied by its corresponding criterion weight, w_j, i.e, to develop the weighted normalized matrix $WN = (\overline{r_{ij}})$.

$$\overline{n_{ij}} = w_j * n_{ij} \qquad (6)$$

Therefore, WN matrix is given below;

$$WN = \begin{bmatrix} \overline{r_{11}} & \overline{r_{12}} & \cdots & \overline{r_{1n}} \\ \overline{r_{21}} & \overline{r_{22}} & \dots & \overline{r_{2n}} \\ \vdots & \vdots & \dots & \vdots \\ \overline{r_{m1}} & \overline{r_{m2}} & \cdots & \overline{r_{mn}} \end{bmatrix}$$

Step 7: Checking that the columns of the WN matrix are not related to each other. To determine such an independence of the weighted normalized decision matrix, the orthogonal vector is subject to the TAOV method. This orthogonal vector is found when principal component analysis (PCA) is applied to matrix WN. Using PCA, linear combinations of vectors are found, and these are called as independent principal components. Every principal component, y_j is a linear combination of the vectors (r_1, r_2,…, r_n) (Orthogonalization) (Jolliffe 2013)

$$Y^T = AY^T = \begin{bmatrix} a_{11} & a_{12} \dots & a_{1n} \\ a_{21} & a_{22} \dots & a_{2n} \\ \vdots & \vdots & \vdots \\ a_{31} & a_{32} \dots & a_{nn} \end{bmatrix} \qquad (7)$$

Where, A contains the weights in PCA to convert the associated criteria to independent criteria. Now, consider that matrix WN is subject to PCA and the orthogonal decision matrix Y is calculated as follows:

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix}$$

Step 8: Finding the total area of each alternative. When the application of an alternative according to the criteria is ranked due to the criteria indices, the total area of alternative Ai is calculated by equation (8). As the columns of matrix Y are orthogonal, the distance between the different criteria can be calculated by the Euclidean distance. (According to the Pythagorean Theorem). Consider an alternative Ai , whose coordinate in two orthogonal components y_k and y_l are (0,0,…,0, y_{ik},0,…,0) and (0,0,…,0, y_{il},0,…,0) Then the distant between these two points is:

$$d_{k,l}^{i} = \sqrt{y_{ik}^2 + y_{il}^2} \tag{8}$$

$d_{k,l}^{i}$: the distance between these two orthogonal components

$$TA_i = \sum_{j=1}^{n-1} d_{j,j+1}^{i} \tag{9}$$

Step 9: The attractiveness of alternatives is computed using the normalized total area (NTA) by equation (9).

$$NTA_i = \frac{TA_i}{\sum_{k=1}^{m} TA_k} \tag{10}$$

3.CALCULATION

By applying the combined MAUT- TAOV approach, the energy source that provides the most useful from the renewable energy sources used in Turkey will be determined. Renewable energy sources alternatives used in Turkey for the application; hydropower, wind, solar, biomass and geothermal were selected. The decision criteria to be used in the evaluation of these alternatives were determined as: efficiency, construction time, cost, government incentives, economic life, foreign dependency, employment opportunities, social acceptance, area need and greenhouse gas emissions. The data for the selected criteria were obtained from the following sources; Alagoz et all (2021), Gullu, M. & Kartal, Z. (2021), Ozcan, E. C., Unlusoy, S. & Eren, T. (2017). “Ministry of Energy and Natural Resources 2019-2023 Strategy Plan”, (MENR, 2021), “BP Review of World Energy” (2019), “Renewable Energy Production Costs in 2018” (IRENA, 2019), "Electricity Market Sector Report" (EMRA, 2021) and "Energy Outlook" (ETKB, 2020), Turkey Electricity Generation Inc. April 2020 Electricity Transmission Statistics" (TEIAS, 2020) and "Energy Balance Sheets of the Ministry of Energy and Natural Resources of Turkey" (MENR, 2019). The application steps of the proposed TAOV-MAUT method to find the alternative that provides the most benefit from the renewable energy source alternatives used in Turkey are as follows:

Construction of the Decision Matrix :

The decision matrix, as shown in Table 1, has been constructed based on the data obtained in accordance with the renewable energy alternatives mentioned in the previous paragraph and the decision criteria to be used in their evaluation. The rows of the decision matrix consist of alternatives, and the columns consist of the criteria.

Table 1. Decision matrix

	Criteria									
Alternatives	**Efficiency (%)**	**Construction period (year)**	**Cost ($/kW)**	**Government incentive ($/kWh)**	**Economic life (year)**	**External dependency (Resource Potential kWh/year)**	**Employment opportunities (person/MW)**	**Social acceptance**	**Area requirement (km2/MW)**	**Greenhouse Gas Emission (g/kWh)**
Hydroelectric	90	4	3.500	9.6	30	140	0.36	0.1298	8.1	10
Wind	26	1	2.200	11	25	144	0.4	0.1737	0.05	10
Solar	21	1	2.479	22.5	25	380	1.28	0.1399	0.04	32
Biomass	40	2	3.575	18.9	20	93	3.06	0.1105	20	25
Geothermal	16	2	4.000	13.2	25	4.5	0.68	0.1405	0.007	38
Total	193	10	15.754	75.2	125	761.5	5.78	0.6944	28.197	115

Calculation of the Normalized Decision Matrix Values:

Each value in the decision matrix has been normalized using Equation (11). Following this process, the newly created normalized decision table has been obtained as presented in Table 2.

$$r_{ij} = \frac{x_{ij}}{\sum_1^j x_{ij}} \tag{11}$$

i: alternatives
j: criteria
r_{ij}:: normalized values

x_{ij}: ith alternative jth criterion for given utility values

Calculation of the Entropy Values The use of entropy to determine the importance weights of criteria in MCDM problems was first proposed by Zeleny in 1982. One of the reasons why the entropy weighting method is a suitable method that can be used in multi-criteria decision-making problems is that it allows the calculation of the importance weights of the criteria without resorting to the personal judgments and thoughts of the experts. The high entropy value indicates that the criterion is of high importance. The entropy value of each criterion is calculated by the equation (12). The entropy values are given in Table 3.

$$e_j = -k \sum_{i=1}^{m} r_{ij} \ln r_{ij} \quad (12)$$

where k: entropy coefficient, ej : entropy values, rij: normalized values

Table 2. Normalized decision matrix

Alternatives	Criteria									
	Efficiency (%)	**Construction period (year)**	**Cost ($/kW)**	**Government incentive ($/kWh)**	**Economic life (year)**	**External dependency (Resource**	**Employment opportunities (person/MW)**	**Social acceptance**	**Area requirement (km2/MW)**	**Greenhouse Gas Emission (g/kWh)**
Hydroelectric	0.4663	0.4000	0.2222	0.1277	0.2400	0.1838	0.0623	0.1869	0.2873	0.0870
Wind	0.1347	0.1000	0.1396	0.1463	0.2000	0.1891	0.0692	0.2501	0.0018	0.0870
Solar	0.1088	0.1000	0.1574	0.2992	0.2000	0.4990	0.2215	0.2015	0.0014	0.2783
Biomass	0.2073	0.2000	0.2269	0.2513	0.1600	0.1221	0.5294	0.1591	0.7093	0.2174
Geothermal	0.0829	0.2000	0.2539	0.1755	0.2000	0.0059	0.1176	0.2023	0.0002	0.3304
Entropy	1.3997	1.4708	1.5847	1.5574	1.6013	1.2603	1.2800	1.5986	0.6245	1.4783
1-Entropy	-0.3997	-0.4708	-0.5847	-0.5574	-0.6013	-0.2603	-0.2800	-0.5986	0.3754	-0.4783
Weight	0.1036	0.1220	0.1516	0.1445	0.1559	0.0675	0.0726	0.1552	-0.0973	0.1240

Table 3. Entropy values

Criteria	**Entropy values**
Efficiency (%)	1.3997
Construction period (year)	1.4708
Cost ($/kW)	1.5847
Government incentive ($/kWh)	1.5574
Economic life (year)	1.6013
External dependency (Resource Potential kWh/year)	1.2603
Employment opportunities (person/MW)	1.2800
Social acceptance	1.5986
Area requirement (km2/MW)	0.6245
Greenhouse Gas Emission (g/kWh)	1.4783

According to Table 3, the criterion with the highest entropy value has the Economic life (year) and the lowest entropy value is the External dependency (Resource Potential kWh/year). Weight value of each criterion is calculated by equation (13).The weights obtained from the entropy method should be the range 0 and 1, and the sum of the resulting weights should give the value 1. The obtained weight values are given in Table 4.

$$w_j = \frac{1-e_j}{\sum_{p=1}^{n}(1-e_p)}, \sum_{j=1}^{n} w_j = 1, j = 1,2, \ldots, n. \quad (13)$$

w_j: weight values
e_j: entropy values

Table 4. Weight values

Criteria	**Weight Values**
Efficiency (%)	0.1036
Construction period (year)	0.1220
Cost ($/kW)	0.1516
Government incentive ($/kWh)	0.1445
Economic life (year)	0.1559
External dependency (Resource Potential kWh/year)	0.0675
Employment opportunities (person/MW)	0.0726
Social acceptance	0.1552
Area requirement (km2/MW)	-0.0973
Greenhouse Gas Emission (g/kWh)	0.1240

The construction of the Decision Matrix, where the Maximum and Minimum Values are determined, involves marking the best and worst values of each criterion. In this matrix used within the application, the Maximum value is denoted in green, while the Minimum value is denoted in blue. These values are presented in Table 5.

Table 5. Decision matrix (maximum and minimum)

Alternatives	Criteria									
	Efficiency (%)	**Construction period (year)**	**Cost ($/kW)**	**Government incentive ($/kWh)**	**Economic life (year)**	**External dependency (Resource Potential**	**Employment opportunities**	**Social acceptance**	**Area requirement (km2/MW)**	**Greenhouse Gas Emission (g/kWh)**
Hydroelectric	90	4	3.500	9.6	30	140	0.36	0.1298	8.1	10
Wind	26	1	2.200	11	25	144	0.4	0.1737	0.05	10
Solar	21	1	2.479	22.5	25	380	1.28	0.1399	0.04	32
Biomass	40	2	3.575	18.9	20	93	3.06	0.1105	20	25
Geothermal	16	2	4.000	13.2	25	4.5	0.68	0.1405	0.007	38

Calculation of TAOV-MAUT Normalized Utility Values are determined according to the utility criteria and normalized values are calculated by using the equation (14). The calculated values are as shown in Table 6.

$$r_{ij} = \frac{x_{ij} - l_j^-}{u_j^+ - l_j^-} \tag{14}$$

Where $u_j^+ = \max_I x_{ij}$ and $l_j^- = \min_I x_{ij}$.

Table 6. TAOV-MAUT Normalized Utility Values

Alternatives	Criteria									
	Efficiency (%)	**Construction period (year)**	**Cost ($/kW)**	**Government incentive ($/kWh)**	**Economic life (year)**	**External dependency (Resource Potential kWh/year)**	**Employment opportunities**	**Social acceptance**	**Area requirement (km^2/ kWh)**	**Greenhouse Gas Emission (g/kWh)**
Hydroelectric	1.00	1.00	-0.28	0.00	1.00	-0.64	0.00	0.31	0.00	0.00
Wind	0.14	0.00	-1.00	0.11	0.50	-0.63	0.01	1.00	0.37	0.00
Solar	0.07	0.00	-0.85	1.00	0.50	0.00	0.34	0.47	1.00	0.79
Biomass	0.32	0.33	-0.24	0.72	0.00	-0.76	1.00	0.00	0.16	0.54
Geothermal	0.00	0.33	0.00	0.28	0.50	-1.00	0.12	0.47	0.13	1.00

The weight values calculated according to the entropy method and the normalized utility values are calculated using the equation (15).

$$WN = \sum_{j=1}^{n} w_j \, r_{ij} \tag{15}$$

WN: weighted normalized decision matrix

The calculation of some of the WN values given in Table 7 is shown below.

Table 7. Normalized Utility Values Multiplied With The Weight Values

	Criteria									
Alternatives	**Efficiency (%)**	**Construction period (year)**	**Cost (\$/kW)**	**Government incentive (\$/kWh)**	**Economic life (year)**	**External dependency (Resource Potential**	**Employment opportunities (person/MW)**	**Social acceptance**	**Area requirement (km^2/ kWh)**	**Greenhouse Gas Emission (g/kWh)**
Hydroelectric	0.0877	0.1033	-0.0356	0.0000	0.1320	-0.0365	0.0000	0.0401	0.0000	0.0000
Wind	0.0119	0.0000	-0.1283	0.0133	0.0660	-0.0359	0.0009	0.1314	0.0262	0.0000
Solar	0.0059	0.0000	-0.1084	0.1223	0.0660	0.0000	0.0209	0.0611	0.0715	0.0825
Biomass	0.0284	0.0344	-0.0303	0.0882	0.0000	-0.0437	0.0615	0.0000	0.0118	0.0562
Geothermal	0.0000	0.0344	0.0000	0.0341	0.0660	-0.0571	0.0073	0.0624	0.0090	0.1050

Transposing the Weighted Utility Matrix Getting the transpose of the matrix means that the rows and columns of the matrix with the same number are displaced. The matrix obtained as a result of this operation is the transpose of the initial matrix. At this stage, the transpose of a matrix i*j becomes a matrix j*i. The most important reason why we transpose at this stage is to reduce the number of columns. Thus, it directly makes a significant contribution to the PCA analysis to be carried out at the next stage. The variation of values to be found will be higher values. Calculation of Orthogonal Decision Matrix TAOV is a method applied on orthogonal vectors. Before obtaining the orthogonal matrix The first thing to note is that the columns of the weighted normalized decision matrix (WN) are independent of each other. To ensure independence between the columns of the WN matrix, the existing criteria vectors $Y_1, Y_2, \ldots, Y_n$ must be converted to the orthogonal vector.. To find this orthogonal vector, principal component analysis (PCA) is applied to the WN matrix. PCA finds a linear combination of vectors called principal components that are independent. Each principal component, y_j, is a linear combination of vectors ($r_1, r_2, \ldots, r_n$) (Jolliffe 2013)

$$Y^T = [Y_i]_{nx1} = AY^T = [A_{ij}]_{nxn} [\overline{r_i}]_{nx1} \tag{16}$$

Where, A includes the weights used in PCA to transform correlated criteria into independent ones. Performing PCA, the values of each alternative can be found easily in the corresponding components. In this step, principal component analysis was first performed on the values in Table 7. Principal component coefficients are shown in Table 8 by applying the SPSS package for each variable. Then the vertical decision matrix Y is obtained by multiplying the two matrices given in. The obtained orthogonal matrix is given in Table 9.

Table 8. Component Coefficient Matrix

Component	**1**	**2**	**3**	**4**	**5**
Hydroelectric	0.555	0.707	0.320	0.286	-0.092
Wind	0.819	0.320	-0.428	-0.009	0.210
Solar	0.852	-0.296	-0.364	0.048	-0.228
Biomass	0.650	-0.597	0.320	0.324	0.117
Geothermal	0.781	-0.018	0.352	-0.516	-0.003

Table 9. Orthogonal Decision Matrix

Criteria	**Alternatives**					
	Hydroelectric	**Wind**	**Solar**	**Biomass**	**Geothermal**	**Ideal**
Efficiency	0.0819	0.0471	0.0299	0.0345	-0.0036	0.0819
Construction Period	0.1066	0.0519	0.0562	0.0229	-0.0056	0.1066
Cost	-0.2369	-0.0161	0.0733	-0.0241	-0.0025	0.0733
Government Incentive	0.1991	-0.0852	-0.0100	0.0167	-0.0149	0.1991
Economic Life	0.2350	0.0937	0.0132	0.0063	-0.0135	0.2350
External Dependency	-0.1227	-0.0102	-0.0304	0.0052	-0.0091	0.0052
Employment Opportunities	0.0642	-0.0427	0.0142	0.0171	0.0026	0.0642
Social Acceptance	0.2306	0.0512	-0.0437	-0.0190	0.0098	0.2306
Area Requirement	0.0970	-0.0200	-0.0303	0.0024	-0.0094	0.0970
Greenhouse Gas Emission	0.1888	-0.0599	0.0249	-0.0320	-0.0125	0.1888

Subsequently, by applying equation (9), the TA measures are figured out. As a case in point, TA_1 is calculated as:

$$TA_1 = \Big[\sqrt{0.0819^2 + 0.1066^2} + \sqrt{0.1066^2 + (-0.2369)^2} + \sqrt{(-0.2369)^2 + (0.1991)^2} + \sqrt{(0.1991)^2 + (0.2350)^2} + \sqrt{(0.2350)^2 + (-0.1227)^2} + \sqrt{(-0.1227)^2 + (0.0642)^2} + \sqrt{(0.0642)^2 + (0.2306)^2} + \sqrt{(0.2306)^2 + (0.0970)^2} + \sqrt{(0.0970)^2 + (0.1888)^2}\Big] = 2.1172$$

Similarly, TA values are calculated for all alternatives, and the ranking of alternatives is obtained by a descending order of TA values. Table 10 shows the values of the TA measure along with the resulting ranking of the alternatives.

Table 10. Total area values

Alternatives	Criteria		
	TAi	**NTAi**	**Order**
Hydroelectric	2.1172	1.1860	1
Wind	0.6606	0.3701	2
Solar	0.4515	0.2529	3
Biomass	0.2246	0.1258	4
Geothermal	0.1131	0.0634	5
Ideal	1.7852	1	

4. CONCLUSION

Industrialization, population growth, rapid technological advancements, and expanding trade opportunities have significantly amplified the demand for energy. In response, nations have increasingly shifted their focus towards bolstering investments in renewable energy policies. Turkey, in particular, aims to address its doubled energy demand over the past decade through a combination of indigenous resources and well-developed renewable energy strategies. Given this context, the strategic allocation of investments becomes a matter of paramount importance. This study employs multi-criteria decision-making methodologies to facilitate a systematic and informed ranking of potential investments within Turkey's energy sector, with a specific emphasis on identifying the most viable renewable energy source. To this end, the study integrates the Multi-Attributed Utility Theory (MAUT) and the Total Area Based on Orthogonal Vectors (TAOV) methods. This innovative approach leverages normalized utility values and harnesses calculated entropy for criterion weight determination via the MAUT method. Subsequent stages encompass the application of principal component analysis (PCA), a critical element of the TAOV method, alongside other established methodological components. The overarching objective of this research is to harness the MAUT-TAOV approach to discern the optimal renewable energy resource for Turkey. To achieve this, an exhaustive literature review evaluates alternative renewable energy resources applicable within the Turkish context. This assessment highlights key criteria that wield significant influence over decision-making processes. These criteria encompass efficiency, construction timelines, cost considerations, government incentives, economic viability, external dependencies, employment potential, social acceptability, spatial requirements, and greenhouse gas emissions. By synthesizing the MAUT-TAOV methodology and rigorously evaluating these criteria, this study aspires to offer substantiated insights into the most advantageous renewable energy resource, thereby advancing Turkey's trajectory towards sustainable energy utilization.

The study identifies hydroelectric, wind, solar, biomass, and geothermal energy resources as the most beneficial options for Turkey. The MAUT-TAOV method determines hydroelectricity as the optimal choice, considering its economic viability, low emissions, and high efficiency, outweighing its longer construction duration. Although wind energy is cost-effective with lower emissions and shorter construction time, its efficiency and job creation potential fall short of hydroelectricity. Government incentives place solar energy third due to external resource dependency. The prioritization of these resources aligns with the Ministry of Energy and Natural Resources strategic goals. Biomass and geothermal resources, while local, rank lower due to limited potential, higher costs, emissions, and societal acceptance challenges. Renewable energy resources offer environmental benefits, reduced dependency, and increased employment opportunities. Turkey's significant potential necessitates strategic investments to shape energy policy and investment priorities.The study's insights aid future renewable energy resource allocation, highlighting the practical and theoretical value of the MAUT-TAOV method in multi-criteria decision-making.

NOMENCLATURE

Multi-Criteria Decision Making (MCDM)
Total Area Based on Orthogonal Vectors (TAOV)
The Multi-Attribute Utility Theory (MAUT)
multi-criteria decision analysis methods (MCDA)
principal component analysis (PCA)
Multi-Criteria Analysis (MCA)
Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
Analytical Hierarchy Process (AHP)

Analytic Network Process (ANP)

Best–Worst Method (BWM)

Weighted Normalized Decision Matrix (WN)

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Burhan Aydın: Obtained the data and analyzed the results.

Özlem Ege Oruç: Proposed the main idea of the work, wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1]Heo E, Kim J, Boo KJ. Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP. Renewable and Sustainable Energy Reviews 2010; 14(8), 2214–2220. https://doi.org/10.1016/j.rser.2010.01.020.

[2] Frangopoulos CA, Keramioti DE. Multi-criteria evaluation of energy systems with sustainability considerations. Entropy 2010; 12(5), 1006–1020. https://doi.org/10.3390/e12051006.

[3]Amer M, Daim TU. Selection of Renewable Energy Technologies for a Developing County: A Case of Pakistan. Energy for Sustainable Development 2011; 15, 420-435. http://dx.doi.org/10.1016/j.esd.2011.09.001.

[4]Troldborg M, Heslop S, Hough RL. Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties. Renewable and Sustainable Energy Reviews 2014 ; 39, 1173–1184. https://doi.org/10.1016/j.rser.2014.07.160.

[5] Özcan E, Ünlüsoy S, Eren T. Evaluation of renewable energy investment alternatives in Turkey using ANP AND TOPSIS methods. Selcuk University Journal of Engineering Science and Technology 2017 ; 5(2), 204–219. https://doi.org/10.15317/scitech.2017.82.

[6] Fishburn PC. Methods of estimating additive utilities. Management Science 1967 ; 13(7), 435–453. https://doi.org/10.1287/mnsc.13.7.435

[7] Fishburn PC, Keeney RL. Seven independence concepts and continuous multiattribute utility functions. Journal of Mathematical Psychology 1974; 11(3), 294–327. https://doi.org/10.1016/0022-2496(74)90024-8.

[8] Sanayei A, Farid Mousavi S, Abdi M, Mohaghar A. An integrated group decision-making process for supplier selection and order allocation using multi-attribute utility theory and linear programming. Journal of the Franklin Institute 2008; 345(7), 731–747. https://doi.org/10.1016/j.jfranklin.2008.03.005.

[9] Kim SK, Song O. A MAUT approach for selecting a dismantling scenario for the thermal column in KRR-1. Annals of Nuclear Energy 2009 ; 36(2), 145–150. https://doi.org/10.1016/j.anucene.2008.11.034.

[10]Freitas LV, Freitas APBR, Veraszto EV, Marins FAS, Silva MB. Decision-Making with Multiple Criteria Using AHP and MAUT:An Industrial Application. European International Journal of Science and Technology 2013 ; 2(9), 93-100.

[11] Ömürbek N, Karaatlı M, Balcı HF. Performance evaluation of automotive firms with entropy based MAUT and SAW methods. Dokuz Eylul University Journal of Economics and Administrative Sciences 2016 ; 31(1), 227–256. https://doi.org/10.24988/deuiibf.2016311446.

[12]Razavi SH, Amoozad H, Hashemi SS. Total area based on orthogonal vectors (TAOV) as a novel method of multi-criteria decision aid. Technological and Economic Development of Economy 2018; 24(4), 1679–1694. https://doi.org/10.3846/20294913.2016.1275877.

[13] Mokhtarzadeh N, Mahdiraji H, Beheshti M, Zavadskas E. A novel hybrid approach for technology selection in the information technology industry. Technologies 2018; 6(1), 34. https://doi.org/10.3390/technologies6010034.

[14] Jafari-Sadeghi V, Dutta DK, Ferraris A, Giudice M. Internationalization business processes in an under-supported policy contexts: evidence from Italian SMEs. Business Process Management Journal 2020; 26(5), 1055–1074. https://doi.org/10.1108/bpmj-03-2019-0141.

[15] Alagöz İ, Avşar Özcan N, Küçükyarar U. Özcan, E. Maintenance prioritization of the natural gas combined cycle power plants in terms of effective portfolio management. Journal of Polytechnic 2021; 24(3), 821–831. https://doi.org/10.2339/politeknik.716408.

[16] Güllü M, Kartal Z. Employment impact of renewable energy sources in Turkey. Sakarya Journal of Economics 2021; 10(1), 36–65. https://dergipark.org.tr/tr/pub/sid/issue/61134/849831.

[17]Ministry of Energy and Natural Resources. 2020; 2019-2023 Strategy Plan. https://sp.enerji.gov.tr/ETKB_2019_2023_Stratejik_Plani.pdf

[18]Ministry of Energy and Natural Resources. 2020; 2020 Activity Reports. https://enerji.gov.tr/Media/Dizin/SGB/tr/Faaliyet_Raporlari/2020/ETKB2020Y%C4%B1l%C4%B1%C4%B0dareFaaliyetRaporu.pdf

[19]Ministry of Energy and Natural Resources. 2020; 2019 Activity Reports.https://enerji.gov.tr/Media/Dizin/EIGM/tr/Raporlar/Ulusal_Enerji_Denge_Tablolari/2019.xlsx.

[20]British Petroleum Company. 2020; BP statistical review of world energy. London: British PetroleumCo.
https://www.bp.com/content/dam/bp/businesssites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020- full-report.pdf.

[21]Energy Market Regulatory Authority. 2020; Electricity market sector report. https://www.epdk.org.tr/Detay/Icerik/3-0-23-3/elektrikaylik-sektor-raporlar.

[22]Turkish Electricity Transmission Corporation. 2020; Turkish electricity transmission corporation activity report 2019. https://www.teias.gov.tr/faaliyet-raporlari.