DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DETERMINING THE MOST USEFUL RENEWABLE ENERGY ALTERNATIVE FOR TURKEY BY COMBINING MAUT AND TAOV METHODS

by
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IZMIR

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We have read the thesis entitled **"DETERMINING THE MOST USEFUL RENEWABLE ENERGY ALTERNATIVE FOR TURKEY BY COMBINING MAUT AND TAOV METHODS"** completed by **BURHAN AYDIN** under supervision of **PROF. DR. ÖZLEM EGE ORUÇ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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MAUT VE TAOV YÖNTEMLERİNİN BİRLEŞTİRİLMESİYLE TÜRKİYE İÇİN EN FAYDALI YENİLENEBİLİR ENERJİ ALTERNATİFİNİN BELİRLENMESİ

ÖZ

Dünyada enerji ihtiyacı, artan nüfus, küresel büyüme ve sanayileşme sonucunda son zamanlarda oldukça artmıştır. Artan enerji ihtiyacının, mevcut fosil kaynaklı rezervlerle tam olarak karşılanamaması, çevre bilincinin ve enerji arz güvenliğinin artması tüm dünyada olduğu gibi Türkiye'de de yenilenebilir enerji kaynaklarının kullanımın oldukça önemli olduğunu göstermektedir. Bu çalışmada, Çok Nitelikli Fayda Teorisi (MAUT) ve Dikey Vektörlere Dayalı Toplam Alan (TAOV) yöntemleri birleştirilerek çok kriterli yeni bir karar verme (TAOV-MAUT) yöntemi önerilmiştir. Önerilen bu yöntem kullanılarak Türkiye için en faydalı yenilenebilir enerji kaynağı belirlenmeye çalışılmıştır.

Türkiye'de yenilenebilir enerji kaynaklarının değerlendirilmesine ilişkin literatür taraması sonucunda kararı etkileyebilecek en önemli kriterler: verimlilik, inşaat süresi, maliyet, devlet teşvikleri, ekonomik ömür, dışa bağımlılık, istihdam, fırsatlar, sosyal kabul, alan gereksinimi ve sera gazı emisyonları olarak belirlenmiştir. Uygulama sonucunda Türkiye için en faydalı yenilenebilir enerji kaynakları sırasıyla hidroelektrik, rüzgar, güneş, biyokütle ve jeotermal enerji kaynakları olarak tespit edilmiştir.

Anahtar kelimeler: Çok kriterli karar verme (ÇKKV), Çok nitelikli fayda teorisi (MAUT), Dikey vektörlere dayalı toplam alan (TAOV), Yenilenebilir enerji kaynakları

DETERMINING THE MOST USEFUL RENEWABLE ENERGY ALTERNATIVE FOR TURKEY BY COMBINING MAUT AND TAOV METHODS

ABSTRACT

The need for energy in the world has recently increased as a result of the increasing population, global growth, and industrialization. The failure to meet the increasing energy with the existing fossil-resourced reserves, and the increase in environmental awareness and energy supply security shows that the use of renewable energy resources in Turkey is quite important as well as in the world. In the present study, a new combined MAUT and TAOV multi-criteria decision-making approach (TAOV-MAUT) method is submitted by combining the Multi Attribute Utility Theory (MAUT) and Total Area Based on Orthogonal Vectors (TAOV). It is tried to determine the most useful renewable energy resource for Turkey by using proposed method.

According to the literature review on the evaluation of renewable energy sources in Turkey, the most important criteria that can affect the decision were determined as follows: efficiency, construction time, cost, government incentives, economic life, foreign dependency, employment, opportunities, social acceptance, space requirement and greenhouse gas emissions. As a result of the study, the most useful renewable energy sources in Turkey were determined as 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

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LIST OF SYMBOLS

CO_2	: Carbon Dioxide
λ	: Lambda
m^2	: Square Meter
SO_2	: Sulphur Dioxide
NO_x	: Nitrogen Oxide
kW	: Kilowatt
kWh	: Kilowatt-hour
MW	: Megawatt
km^2	: Square Kilometers

ABBREVIATIONS

MAUT	: Multi Attribute Theory of Utility
TAOV	: Total Area Based on Vertical Vectors
MCDM	: Multi Criteria Decision Making
MCDA	: Multiple Criteria Decision Analysis
AHP	: Analytical Hierarchy Process
MCA	: Multiple Criteria Analysis
ANP	: Analytic Network Process
TOPSIS	: Technique for Order Preference by Similarity to Ideal Solution
KRR-1	: Korean Research Reactor
MODM	: Multi-Objective Decision Making
MADM	: Multi-Attribute Decision Making
CORPAS	: Complex Proportional Assessment
SAW	: Simple Additive Weighting
VIKOR	: Vise Kriterijumska Optimizacija I Kompromisno Resenje
ORESTE	: Organization Rangement Et Synthese De Donnes Relationnelles
ELECTREE	: Elimination Et Choix Traduisant la Realite
PROMETHEE	: Preference Ranking Organization Method for Enrichment Evaluation
ARAS	: Additive Ratio Assessment
CR	: Consistency Ratio
CI	: Confidence Indicator

RI	: Random Indicator
PCA	: Principal Component Analysis
ETKB	: Republic of Turkey Ministry of Energy and Natural Resources
IRENA	: International Renewable Energy Agency
EPDK	: Republic of Turkey Energy Market Regulatory Authority
TEIAS	: Turkish Electricity Transmission Corporation
TMMOB	: Union of Chambers of Turkish Engineers and Architects
EIA	: Energy Information Administration
SPSS	: Statistical Package for the Social Sciences

CHAPTER 1

INTRODUCTION

Today, one of the most essential needs, which has an important place in the economic and social progress of developed and developing countries, is energy. Energy needs cannot be met with limited resources via the effects of population growth, industrialization, and rapidly developing technologies in the world, and the gap between power generation and consumption is gradually increasing. On the other hand, “non-renewable” traditional energy resources such as oil, natural gas, coal, and nuclear energy have become an increasingly threatening situation for both environment and human health. The amount of carbon dioxide (CO_2) that emerges as a result of the burning of fossil fuels increases gradually with the decrease of forests, therefore, it prevents the reflection of the solar rays together with other gases in the atmosphere. Thus, “greenhouse effect” occurs and it causes climate changes. In addition to all these developments, with the prediction of the depletion of traditional energy resources, human beings have turned to search for nature-friendly, clean, and relatively cheap energy resources. Within this scope, steps have been taken to make more use of “renewable energy resources”, which are “sustainable” in terms of time and can exist throughout the world. Renewable energy resource is defined as “the energy resource that can be exactly available the next day in the self-evolution of nature”. The most important features of renewable energy resources are stated as helping to protect the environment by reducing carbon dioxide emissions, contributing to the reduction of external dependency in energy, and increasing employment as they are domestic resources, and they receive widespread and strong support from the public.

Renewable energy has become an important topic attracting increasing attention from academia and the industrial environment. 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 the promising potential of these resources in Turkey. In the study, a new decision-making method approach (TAOV-MAUT) 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 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 MAUT methods 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. Lopes and Almeida (2015) examined the decision-making situations of enterprises operating in the oil and gas sectors under risk and uncertainty with the MAUT method. 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, with the proposed TAOV-MAUT multi-criteria decision-making approach, the most useful renewable energy source for Turkey will be obtained according to the criteria determined among renewable energy source alternatives such as hydroelectric, wind, solar, biomass and geothermal. The study consists of introduction in the first chapter, multi-criteria decision making methods in the second chapter, application in the third chapter and the results obtained from the research in the last chapter.

CHAPTER 2

MULTI CRITERIA DECISION MAKING METHODS

2.1 Multi Criteria Decision Making

Nowadays, decision problems with multiple and conflicting criteria are very common. Thus, it becomes increasingly difficult to make a decision depending on a single criterion. In decision making problems with multiple and conflicting criteria, multi criteria decision making methods are used to make the best decision. In this chapter, multi criteria decision making process and methods will be introduced.

Multi Criteria Decision Making (MCDM) is expressed as the process of assigning values to alternatives by evaluating several criteria together. MCDM can be examined under two titles as multi-objective decision making and multi-attribute decision making. These titles can be summarized as given in Table 2.1.

Table 2.1 Multi criteria decision making

Multi Criteria Decision Making (MCDM)	
Multi-Objective Decision Making (MODM)	**Multi-Attribute Decision Making (MADM)**
Continuous Decision Space	Discrete Decision Space
The number of alternatives cannot be determined in advance, and the objective is to choose the best alternative.	It has a process of choosing according to previously determined alternatives.
It requires mathematical programming and optimization.	It may not require mathematical optimization.
The solution is made based solely on the choice.	The solution is based on classification and sorting. It aims to make the most appropriate decision by evaluating the set of alternatives based on certain criteria.

The main goal of multi criteria decision making problems is to identify the best alternative that provides the highest level of satisfaction in terms of all relevant criteria. MCDM consists of the start-up, problem formulation, modeling, analysis, and evaluation phases.

- Start-up phase: In this phase, the situation to which the optimum decision will be applied is determined. The purpose is interpreted by the decision maker.
- Problem Formulation phase: Determination of sub-criteria for the main goal includes the determination of the necessary elements, boundaries, and the environmental factors of the problem.
- Modeling: This is the phase determining the variables that will enable the analysis of the relevant parts of the modeling system and defining their logical correlations.
- Analysis and Evaluation: It is scored according to every alternative and the most suitable alternative is interpreted.

Some basic concepts should be known in order to solve multi criteria decision making problems. Basic concepts related to MCDM are defined below (Cebeci, 2013).

- Aim: Characteristics that are desired to be maximized or minimized according to the demands of the decision maker.
- Goal: Defined as the purpose specified with a desired level.
- Limitation: These are the limitations on the internal and environmental resources or variables with the aim or assumptions affecting the aims of the problems system.
- Alternatives: These are the various activity choices provided to the decision-maker.
- Criteria: All the aims, goals, and attributes that are evaluated in decision making problems. It is a measure of performance efficiency and forms the basis of being able to make an evaluation.
- Criteria weights: In order to solve a problem, information showing the relative importance of each criterion is required. Relative importance of the criteria is usually in the form of a normalized set of weights that add up to one. In case there are N criteria, the weights set is $W_t = (W_1, W_2, \ldots, W_n)$ ve $\sum_{j=1}^{N} W_j = 1$.

- Attribute: It is a measure used to evaluate the extent to which a specific decision can be realized, in which the needs of the decision maker are defined in a relatively independent way.
- Decision Matrix: It is the matrix that shows the alternatives and criteria together in decision making problems.

Multi criteria decision making problems have advantages and disadvantages. These can be sorted as follows:

2.1.1 Advantages of Multi Criteria Decision Making

- It is suitable to analyze complex and quite understated issues.
- It carries out the decision making processes in a systematic way.
- In the environments where there is more than one decision maker, it is suitable to create a common platform, facilitate communication, and enable the negotiations.
- It combines the alternatives with the expert opinions required in the evaluation of criteria and the subjective evaluations of the decision makers.
- It provides to make decisions by evaluating too large amount of or distributed data.

2.1.2 Disadvantages of Multi Criteria Decision Making

- Subjective assessment may provide different results at different times.
- It may not solve the problems in group decisions and negotiations on its own.

In the literature, there are many methods developed regarding the method to be used in MCDM problems. Some of the most frequently used MCDM methods can be sorted as Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), Complex Proportional Assessment (CORPAS), Simple Additive Weighting (SAW), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Organization

Rangement Et Synthese De Donnes Relationnelles (ORESTE), Elimination Et Choix Traduisant la Realite (ELECTREE), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Additive Ratio Assessment (ARAS), Multi Attribute Utility Theory (MAUT), and Total Area Based on Orthogonal Vectors (TAOV). These methods will be explained below in short. In addition, MAUT and TAOV methods, among the multi criteria decision making methods, will be combined (TAOV-MAUT) and be used as a new multi criteria decision making approach in the present study. The new combined approach will also be explained in this chapter.

2.2 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a powerful multi criteria decision making technique that is developed for solving complex and unstructured problems where interactions and correlations may exist between different objectives. The method was introduced to the literature by Myers and Alpert in 1968 and modeled by Saaty in 1977. Despite AHP is a decision making and estimation method, it is also used as a comparison method. In the comparison, the factors affecting the decision and the importance values of the decision points are compared by using a predetermined comparison table. As a result, the importance levels are shown as percentage on the decision points. Steps of decision making method via AHP is as follows.

Step 1: Decision making problem is defined.

While defining the problem, decision points are primarily determined. Then, the factors affecting the decision points are determined. The number of decision points is indicated by m, and the number of factors affecting the decision points by n. In order for the paired comparisons to be consistent, especially the number of factors that will affect the result, should be determined correctly.

Step 2: A comparison matrix is developed between the factors.

Step 3: The percentage importance distributions of the factors are determined.

Step 4: Consistency in the factor comparisons is measured.

Step 5: For each factor, the surface importance distributions at m decision points are found.

Step 6: Finding the result distribution at decision points.

K decision matrix with a size of m*n that is formed from the S column vector is created.

$$K = \begin{bmatrix} s_{11} & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ s_{m1} & \cdots & s_{mn} \end{bmatrix}$$

When the decision matrix is multiplied by the priority vector, the column vector L is obtained. This vector gives the percentage distribution of the decision points and the sum of these elements is 1. This distribution also shows the importance ranking of the decision points and a decision is made by considering this distribution.

2.3 Analytic Network Process (ANP)

ANP (Analytic Network Process), one of the MCDM (Multi Criteria Decision Making) methods, was introduced and developed by Thomas L. Saaty. ANP method considers the feedback between the between-groups and in-group dependencies and criteria. In this method, decision making problems are modeled as a network, and the external dependencies, feedbacks, and internal dependencies within the same criteria group are also calculated. By such a modeling process, complex problems that cannot be modeled by hierarchical structures can be modeled more easily, thus decision-making process are taken more effectively. Priority vectors that are calculated with paired comparison matrices in the ANP method are not calculated linearly. These vectors are placed in a matrix as columns in order to determine the effect of criteria in one cluster on criteria in another cluster (external dependency) or the effect (internal dependence) on other criteria in the same cluster. Since all the criteria in one cluster do not have to affect a criterion in another cluster, the contribution of these criteria that have no effect is zero. Steps of decision making method via ANP is as follows.

Step 1: Determination of the Goal and Forming a Model. In this step, criteria and alternatives are determined and the criteria related to each other are developed to be in the same cluster, and then the same procedures are applied for the alternatives. After this process, the interaction and dependency between the clusters are determined and the network structure is created.

Step 2: Calculating the Eigenvector by creating a paired comparison matrix.

Step 3: Calculation of the Weighted Supermatrix.

Step 4: Ordering the alternatives and selecting the best alternative. In this step, the final priorities of the criteria and alternatives are calculated. Final priorities are found by both normalizing each cluster and determining the priorities of both criteria and alternatives.

2.4 Complex Proportional Assessment (CORPAS)

COPRAS method was introduced in the literature by Zavadskas, Kaklauskas in 1996. The COPRAS method is used to rank and evaluate the alternatives by considering the benefit and cost characteristics of the criteria. The difference of this method from other MCDM methods is that the alternatives can be compared with each other and the percentage of their superiority over each other can be shown. The COPRAS method has advantages such as easy process steps and no need for any computer program for the calculations. COPRAS method also has fuzzy and gray versions. Steps of decision making method via CORPAS is as follows.

Step 1: Forming of a start decision matrix. The rows of the decision matrix consist of alternatives and the columns consist of the criteria.

Step 2: Normalizing the decision matrix.

Step 3: Weighting the normalized decision matrix.

Step 4: Calculation of S_i^+ and S_i^- values.

S_i^+: Total of the utility criteria in weighted normalized decision matrix

S_i^-: Total of the cost criteria in weighted normalized decision matrix

Step 5: Calculation of relative importance values(Qi).

Step 6: Calculation of the performance index values and determine the priority of alternatives. The greater weight Qi for alternative i shows, the higher is the priority (rank) of the alternative.

2.5 Simple Additive Weighting (SAW)

SAW (Simple Additive Weighting) method, also known as Weighted Sum Model, was introduced by Churchman and Ackoff in 1954. It is frequently used in multi criteria decision making methods because it is a simple method as an application. The method starts with the digitization of the criteria values for each determined alternative and continues with the formation of the decision matrix. The one with the highest score is selected according to the total score obtained for each alternative. Steps of decision making method via SAW is as follows.

Step 1: At first, criteria are determined and criteria are shown as maximum or minimum according to the benefit and cost principle.

$$r_{ij} = \begin{cases} \dfrac{x_{ij}}{\max x_{ij}} & i = 1,2,\dots,m \text{ ve } j = 1,2,\dots,n \\ \dfrac{\max x_{ij}}{x_{ij}} & i = 1,2,\dots,m \text{ ve } j = 1,2,\dots,p \end{cases} \tag{2.1}$$

Step 2: The preference value of each alternative is calculated by multiplying the weights of the criteria with the previously obtained values.

$$S_j = \sum_{j=1}^{m} w_{ij} r_{ij} \text{ i= 1,2,…,m and j= 1,2,…,n} \qquad (2.2)$$

w_{ij}: weight of the criteria

High S_j value shows that the alternative specified will be preferred more. If the values are calculated as %;

$$S_j^{\%} = \frac{S_j}{\sum_{j=1}^{n} S_j} \qquad (2.3)$$

2.6 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS Method, among the Multi Criteria Decision Making Methods, is developed by Hwang and Yoon (1981) and it is one of the methods widely used in the literature and developed as an alternative to the ELECTRE method. The basis of this technique is provided by the selection of the alternative having the shortest distance to the positive ideal solution and the farthest distance to the negative ideal solution. While the positive-ideal solution is the combination of the best available criteria, the negative-ideal solution is the combination of the worst available criteria (Feng & Wang, 2000, 138). The solution that maximizes the benefit criterion and minimizes the cost criterion is called as the positive ideal solution by the decision makers. TOPSIS method accepts the alternative that is closest to the positive ideal solution and the alternative that is farthest to the negative ideal solution as the best option (Pohekar and Ramachandran, 2004, 372). Steps of decision making method via TOPSIS is as follows.

Step 1: Construction of the Decision Matrix.

Step 2: Calculated of the Standard Decision Matrix.

Step 3: Calculated of the Weighted Standard Decision Matrix .

Step 4: Determination of Positive Ideal (A^*) and Negative Ideal (X^-) Solution Sets.

Step 5: Calculation of the distance measures between the alternatives.

Step 6: Calculation of relative proximity to the ideal solution.

Positive-ideal and negative-ideal discrimination measures are used to calculate the relative proximity of a decision point to the ideal solution (C_i^*). The criterion used is the share of the negative ideal discrimination measure in the total discrimination measure. C_i^* value is between $0 \leq C_i^* \leq 1$ and $C_i^* = 1$ shows the absolute proximity of the relevant decision point to the positive-ideal solution and $C_i^* = 0$ shows the absolute proximity to the negative-ideal solution. Accordingly, the alternative with the highest C_i^* value is evaluated as the most preferred alternative or the alternative showing the best performance.

2.7 Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

The foundations of the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method, that is developed for the optimization of multi criteria complex systems, were laid by Yu (1973) and Zeleny (1982) (Tzeng and Huang, 2011, 71). In 2004, it was introduced by Opricovic and Tzeng as a multi criteria decision making technique that can be used in the data groups obtained with different units of measurement. VIKOR method provides a common solution to a decision making problem with conflicting criteria and obtains the alternative solution that is nearest to the ideal (Ertuğrul, Özçil 2014).

In the VIKOR method, as the criteria weights are considered equal, the value weights obtained from different methods can also be included in the application steps. In other words, criterion weighting is not done by VIKOR method, the proximities of the alternatives to the ideal solution are calculated and the alternatives are ordered according to these values.

Decision via VIKOR method starts by the calculation of L_p criterion.

$$L_{pj}= \{ \sum_{i=1}^{n}[\frac{wi(fi^* - fij)}{fi^* - fi^-}]^p\}^{\frac{1}{p}} \quad 1 \leq p \leq \infty \quad j=1,2.....,n \tag{2.4}$$

The solution is obtained by the maximum group utility $\min_j S_j$ and the minimum individual attrition of the competitors $\min_j R_j$.

Steps of decision making method via VIKOR is as follows.

Step 1: Of all the criteria functions, i:1,2,……,n, the worst fi^- the best fi^* values are determined.

Step 2: S_j (group utility) and R_j (individual attrition of the competitor) values are calculated for every alternative.

Step 3: Q_j values are calculated for every alternative.

Step 4: Alternatives S, R, and Q values are ordered from the smallest to the largest.

Step 5: If the following two conditions are met, an alternative a' is suggested as an agreed solution, ordering by the best Q (minimum) values.

K1: "Admissible advantage":

$$Q(a'') - Q(a') \geq DQ$$

a'' Alternatives in the second order according to the Q value;

$$DQ = \frac{1}{J-1} \quad J : \text{number of alternatives} \tag{2.5}$$

K2: “Admissible stability in decision making”

Alternative a′ is the best alternative that is ordered according to the S and/or R values. This agreed solution is stable in the decision making process. Here, v is the weight of the decision making strategy.

If one of these conditions is not met, an agreed solutions set is offered. The content of this solutions set is:

- Only if the K2 condition is not met, a′ and a″ alternatives,
- If K1 condition is not met, a′ , a″,…,$a^{(M)}$ alternatives and $a^{(M)}$,
- For maximum M, $Q(a^{(M)})$ is determined by the $- Q(a') < DQ$ correlation.

The best alternative ordered according to the Q values is one of the alternatives with minimum Q value. The result of the main order is the agreed ordering list of the alternatives and the agreed solution with the “advantage ratio”.

2.8 Organization Rangement Et Synthese De Donnes Relationnelles (ORESTE)

ORESTE (Organisation, rangement et synthèse de données relationnelles) developed by M. Roubens (1979) is one of the ranking methods based on the relation of being senior / being important / being preferred. There are two steps in the solutions of multi criteria decision making problems with ORESTE (Organisation, rangement et synthese de donneesrelationnelles) (Eroğlu vd., 2015: 84). These are;

1. Establishing a global full preliminary order of alternatives based on the order of the alternatives depending on the criteria with the criterion order (ORESTE I)

2. After the contradiction and indifference analyzes are performed, the partial preliminary order on the alternatives is the (ORESTE II) steps.

Steps of decision making method via ORESTE is as follows.

Step 1: Determination of the decision problem.

Step 2: Determination of relative importance via preliminary order.

Step 3: Determination of Besson Rank values.

Step 4: Calculation of projection distances.

Step 5: Determination of global ranks. The step of calculating global ranks includes the assignment of Besson rank values to all the calculated projection distances. The projection distances calculated in the previous step are ordered from smallest to largest, and they take Besson rank values according to their current orders.

Step 6: Determination of average ranks. In the step of calculating the average ranks, the global ranks obtained in the previous step are gathered by summing them up for each alternative. Since the average ranks obtained are completely interpreted as ranking-directional, no external process is required. The average ranks obtained are ordered from the smallest to the largest, and the ranking of the alternatives according to the decision maker is obtained (Pastijn and Leysen, 1989, p:1261).

2.9 Elimination Et Choix Traduisant la Realite (ELECTRE)

ELECTRE I, II, III and IV methods take place in the literature under the name of ELECTRE method, which is one of the mathematical programming techniques for optimization purposes. Despite all the methods depend on the same basic concepts, their use differs according to the type of decision problem. This method is one of the Multi Criteria Decision Making methods that was first introduced by Beneyoun in 1966. The method is based on paired superiority comparisons between alternative decision points for each evaluation factor. By means of the technique in question, the decision maker can include a large number of quantitative and qualitative criteria in the decision making process, weight the criteria in line with their objectives, choose the sizes of the efficiency measures of criteria and determine the most appropriate alternative by adding their weights (Ersöz and Kabak, 2010, 111). The method consists of 7 steps. First two steps are similar to TOPSIS method. Steps of decision making method via ELECTRE is as follows.

Step 1: Construction of the Decision Matrix.

Step 2: Calculation of the Standard Decision Matrix.

Step 3: Calculation of the Weighted Standard Decision Matrix.

Step 4: Development of Concordance and Discordance Sets.

Step 5: Calculation of Concordance and Discordance İndices.

Step 6: Making a Superiority Comparison.

Step 7: Calculation of Net Concordance and Discordance İndices.

2.10 Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)

PROMETHEE method is one of the most recently developed methods among multi criteria decision making methods and it was introduced to the literature by Brans (1982) and developed by Brans and Vincke (1985). The main features of the PROMETHEE method are simplicity, clarity, and balance. The method uses the preference functions when creating an order. In order for the decision maker to make a decision easily, all the parameters should be clearly defined. With the PROMETHEE method, it is possible to perform both partial ordering (PROMETHEE I) and complete ordering (PROMETHEE II) on a finite number of alternatives (Brans et al. 1986:228). Steps of decision making method via PROMETHEE is as follows.

Step 1: The PROMETHEE method begins the decision making process by a paired comparison process of the criteria values of alternatives.

Step 2: Method, decision making uses one of the 6 preference functions defined by Brans (1982) during the paired comparison of the alternative on the basis of criteria.

Step 3: With the help of the preference functions, the preference indices of the alternatives on each other are determined.

Step 4: Via the preference indices obtained for each alternative, the positive and negative flows of the alternatives are obtained.

Step 5: The decision-making process, which obtains the PROMETHEE results with positive and negative flow values, ranks the alternatives with these results from best to worst.

2.11 Additive Ratio Assessment (ARAS)

ARAS (Additive Ratio Assessment Method), one of the multi criteria decision making (MCDM) methods, was developed by Zavadskas and Turskis in 2010. Unlike other MCDMs, the utility function values of the alternatives in ARAS method are compared with the utility function value of the optimal alternative. In ARAS method, it is the most suitable method for the purpose of ordering proportionally in MCDM problems. Steps of decision making method via ARAS is as follows.

Step 1: Construction of the Decision Matrix.

Step 2: Calculation of a Normalized Decision Matrix.

Step 3: Calculation of a Weighted Normalized Decision Matrix.

Step 4: Calculation of the optimal value:

$$S_i = \sum_{i=0}^{m} x_{ij} \text{ , } i = 0,1,\ldots,m \text{ and } j = 0,1,\ldots,n \tag{2.6}$$

Where S_i shows the optimal value of i^{th} alternative. S_i is the alternative with high value and is also the most effective alternative.

Step 5: Calculation of the utility grade and ordering: After determining the optimal values of the alternatives, the utility grade K_i of each alternative is calculated.

$$K_i = \frac{S_i}{S_0} \text{ , } i = 0,1,\ldots,m \tag{2.7}$$

In formula (2.7), S_0 is the optimal value of the best alternative. Values of the utility functions of the alternatives by using K_i values are obtained. Alternatives are evaluated by ordering these grades from the largest to smallest.

2.12 Multi Attribute Utility Theory (MAUT)

MAUT (Multi Attribute Utility Theory) method, which is a multi criteria decision making method and aims to select the criterion that provides maximum utility to the problems with more than one conflicting criterion, was first applied by Fisburn (1967) and Keeney (1974). Since MAUT is a method including the risk preferences and uncertainties into the decision making process, it offers more reliable results than other multi criteria decision making methods. Both qualitative and quantitative criteria are considered in the MAUT method. During the application of the method, while the decision matrix is being created, entropy values are calculated in order to calculate the objective weights. Thus, before explaining the steps of the method, the concept of entropy will be briefly mentioned.

2.12.1 Entropy

Entropy is the measure of the disorder of a system. There are at least three ways of describing entropy: thermodynamics, statistical physics theory, and information theory. In this study, since the definition of entropy within the scope of information theory is used, other definitions are not included.

As disorder increases in a system, entropy also increases. Thus, it moves in the same direction over time. The information required to know the possible states of a system exactly is equal to the entropy of the system. When a system changes from an ordered, organized, and planned structure to an irregular, distributed, and unplanned structure, the entropy of that system increases. In parallel, system information will also increase. Thus, information is defined as negative entropy. The question regarding the correlation of the concept of entropy, which is frequently mentioned in thermodynamics, with the information theory may come to mind. This correlation is not based on intuitive but purely mathematical proofs.

The entropy value of the random variable X(discrete and continuous) is calculated with the following formulas. (Cover, M., T. & Thomas, A., J., 1991);

$$H(x) = -\sum_{x \in X} p(x) \log_2 p(x) \tag{2.8}$$

$$H(x) = -\int_{-\infty}^{+\infty} f(x_i) \log_2 f(x_i) dx \tag{2.9}$$

As can be seen from the equations (2.8 and 2.9), entropy is independent from the range of the random variable. Namely, the measure of information is not related to its content. It is not the event itself that matters, but the probability of happening. Accordingly, entropy can be included in the non-parametric family in statistics since it does not require any assumptions.

2.12.2 The steps of the MAUT Methods

The entropy value is calculated to objectively obtain the weights of the criteria in the MAUT method. The steps of the MAUT method are as follows.

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

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

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 ($R = \left[r_{ij}\right]_{mxn}$) is calculated by using equation (2.10).

$$r_{ij} = \frac{x_{ij}}{\sum_{p=1}^{m} x_{pj}}, \ i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n. \tag{2.10}$$

Step 3: The entropy value of each criterion is calculated by using equation (2.11).

$$e_j = \frac{1}{\ln m} \sum_{i=1}^{m} r_{ij} \ \ln r_{ij} \quad, j = 1,2, \ldots, n. \tag{2.11}$$

Where e_j is the entropy value of the j^{th} criterion.

Step 4: The weighting value of each criterion is calculated by using equation (2.12).

$$W_j = \frac{1-e_j}{\sum_{p=1}^{n}(1-e_p)} \quad, j = 1,2, \ldots, n. \tag{2.12}$$

$$\sum_{J=1}^{n} W_j = 1$$

Step 5: Utility values are determined according to the utility criteria and normalized values (r_{ij}) are calculated by using the utility values:

$$r_{ij} = \frac{x_{ij}-l_j^-}{u_j^+-l_j^-} \tag{2.13}$$

where $u_j^+ = \max_i x_{ij}$ and $l_j^- = \min_i x_{ij}$.

Similarly, the utility value is determined according to the cost criterion and normalized values (r_{ij}) are calculated by using these values:

$$r_{ij} = \frac{u_j^+ - x_{ij}}{u_j^+ - l_j^-} \tag{2.14}$$

where $u_j^+ = \max_i x_{ij}$ and $l_j^- = \min_i x_{ij}$.

Step 6: Weighted r_{ij} values are calculated by multiplying the entropy weights (w_j), Total of these values gives the total utility value.

$$U_i = \sum_{j=1}^{n} w_j \, r_{ij} \tag{2.15}$$

Step 7: Preference order is done. The alternative with the highest total utility value is determined as the best alternative.

These steps are shortly shown in Figure 2.1.

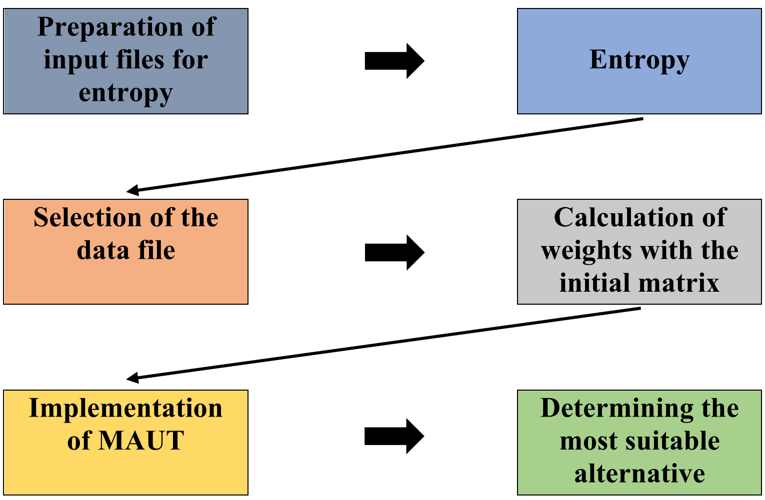

Figure 2.1 Stages of the MAUT method

2.13 Total Area Based on Orthogonal Vectors (TAOV)

The basis of the TAOV method is that its vectors basically act orthogonally to each other in order to apply the Pythagorean theorem for the calculation of the distance between two points. Therefore, an orthogonal decision matrix is obtained by converting the classic decision matrix via principal component analysis. The total area of each alternative is calculated as its overall performance relative to the other alternatives, and a decision is made.

Consider a multi-criteria decision-making problem consisting of the evaluation of m discrete alternatives A_1, A_2,..., A_m depending on n finite criteria of C_1, C_2,..., C_n. Below-mentioned decision matrix can be used to formulate the problem:

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

Steps of decision making method with TAOV is as follows.

Step 1: The utility values are determined according to utility criteria.

When the monotone increasing utility is used to evaluate the decision criteria, normalized values (r_{ij}) for the utility criteria set B are calculated by equation (2.16):

$$r_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \ j \epsilon B \tag{2.16}$$

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:

$$r_{ij} = \frac{\min_i x_{ij}}{x_{ij}}, \ j \epsilon C \tag{2.17}$$

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 2: 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 = $(\overline{r_{ij}})$.

$$\overline{n_{ij}} = w_j * n_{ij} \tag{2.18}$$

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 3: It should be verified 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).

$$Y^T = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ . \\ Y_n \end{bmatrix} = AY^T = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} \overline{r_1} \\ \overline{r_2} \\ \vdots \\ . \\ \overline{r_n} \end{bmatrix} \tag{2.19}$$

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 4: Using equation (2.21) to determine the total area for each alternative.

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 A_i, 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:

$$d_{k,l}^{i} = \sqrt{y_{ik}^{2} + y_{il}^{2}} \tag{2.20}$$

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

Step 5: When the performance of an alternative according to the criteria is ranked due to the criteria indices, the total area of alternative A_i is calculated as follows:

$$TA_i = \sum_{j=1}^{n-1} d_{j,j+1}^{i} \tag{2.21}$$

Step 6: The attractiveness of alternatives is computed using the normalized total area (NTA) as:

$$\mathrm{NTA_i} = \frac{\mathrm{TA_i}}{\sum_{k=1}^{m} \mathrm{TA_k}} \tag{2.22}$$

2.14 Combined MAUT and TAOV Method (TAOV-MAUT)

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 described in Section 2.12.2, respectively.

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

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

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 (2.10).

Step 3: The entropy value of each criterion is calculated by using equation (2.11).

Step 4: The weighting value of each criterion is calculated by using equation (2.12).

Then, alternatives are rated by applying the steps of the TAOV method described in Section 2.13, 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 (2.16).

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 are calculated by equation (2.17).

The normalized decision matrix R is obtained as follows:

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

Step 6: Construction of the Weighted Standard Decision Matrix (WN).

Step 7: Checking that the columns of the WN matrix are not related to each other.

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 A_i is calculated by equation (2.21).

Step 9: The attractiveness of alternatives is computed using the normalized total area (NTA) by equation (2.22).

CHAPTER 3

RENEWABLE ENERGY

Due to the effect of rapid increase in population and industrialization, the need for energy is increasing every passing day throughout the world. Increasing energy need, threatening of the nature by fossil fuels and their limited use show the importance of diversifying energy alternatives and using them more efficiently. Renewable energy resources, which is a concept that came into our lives in the 20th century, has recently been one of the most important agenda items among the future plans of both countries and large companies. Renewable energy, in other words sustainable energy, is a type of energy that can be used continuously without depending on a resource that that can be consumed as it is used. Besides, renewable energy resource is defined as the resources from which this type of energy is obtained, which can renew itself naturally and is inexhaustible. Renewable energy resources have some advantages and disadvantages: These can be specified as follows:

Advantages:

- The most important advantage of renewable energy alternatives is that they are inexhaustible because they are renewable.
- Clean and renewable energy resources do not cause global warming by producing less or no waste products, and within this scope, they are environmentally friendly and have a minimum impact on the environment.
- Renewable energy power plants require less maintenance than conventional generators. Operating costs are also generally low, as they are obtained from natural and ample resources.
- In renewable energy projects, it can also provide economic benefits to various regional areas, as most of the projects are located far from major urban centers and suburbs of capital cities. Such economic benefits may be caused by the increased use of tourism as well as local services.

Disadvantages:

The current use of renewable energy resources, which have advantages in terms of being environmentally friendly, is limited. The reasons of this can be ordered as follows:

- It's mainly disadvantage is that it is costly. Thus, it is accepted as economically expensive.
- Infrastructure investments are expensive to meet large amounts of energy demand and there are not enough credit and financing mechanisms to balance this.
- Weather conditions significantly affect the power generation phase. The same amount of energy may not always be produced, the energy demand may not be met, and the access to energy resources is not continuous.
- In order to use renewable energy alternatives effectively and to provide optimum benefit, consensus is not sufficient.
- Today, renewable energy resources have a small share in the power generation and consumption potential.
- Most of the renewable energy alternatives require storage for future use. However, this process is both costly and has difficulties.

Renewable energy alternatives and resources, which have a great role in sustainability and meeting the demands, are shown in Table 3.1.

Table 3.1 Renewable energy alternatives and resources

Biomass Energy	**Solar Energy**	**Hydroelectric Energy**	**Geothermal Energy**	**Wind Energy**
Biological waste	Solar	Rivers and streams	Groundwater	Wind

In this chapter, the renewable energy resources given in Table 3.1 explained in briefly.

3.1 Biomass Energy

Biomass is the general name for unfossilized biological resources obtained from living organisms. The resources of biomass consist of the forests, agricultural waste, plant and animal waste, organic waste, and many other resources. As it is possible to find biomass resources almost everywhere in nature, biomass agriculture is also present today. Biomass energy is the energy obtained from biomass, that is one of the alternative energy resources. Biomass energy is the conversion of biomass into chemical energy. The chemical energy contained in biomass is converted into utilizable energy by various methods. Biomass resources are converted into solid, liquid, and gaseous fuels by methods such as direct combustion, pyrolysis, and gasification (thermo-chemical cycle and bio-chemical cycle).

The main problem experienced in renewable energy resources such as wind and solar energy is the lack of uninterrupted generation due to the constant non-existence of the resource. However, as the biomass can be stored, uninterrupted generation can be provided that there is sufficient raw material. In this type of energy, emissions of harmful gases to the nature are lower in this type of energy when compared to production from fossil resources. In addition, the use of domestic resources in biomass energy contributes to reducing external dependency and supply security. Biomass is used not only in terms of energy but also with its by-products, thus contributes to the creation of additional business lines. Besides the advantages of biomass energy, it also has some disadvantages. When compared to the renewable energy power plants such as wind and solar energy, installation costs are high and installation time is longer. Moreover, agricultural production can be done for the biomass resource. If agricultural production becomes widespread in fertile areas where food production is made, it may cause a lack of food supply.

3.2 Solar Energy

Solar energy is the main resource of all the energy resources: The main resource of all renewable energy resources is the sun, as it is the resource of life on Earth and provides the formation of fossil fuels and climate events. Solar energy is the energy that is used by using an evolving array of technologies, such as heating with light and heat from the sun, photovoltaics, solar thermal energy, solar architecture, concentrated solar power plants, and artificial photosynthesis. Solar energy technologies are referred to as passive solar or active solar energy, depending on how they capture and distribute solar energy or convert it into solar energy. Active solar energy techniques are the use of photovoltaic systems, concentrated solar energy systems, and solar water heating to benefit from solar energy. Passive solar techniques are the technical methods that make the most use of solar energy in the living space, such as orienting a building towards the sun, choosing suitable thermal materials or the materials having diffusion properties, and designing the spaces that circulate the air naturally.

Solar energy is a 100% clean, renewable energy resource. It reduces the dependency on oil, coal, and natural gas for power generation. On the contrary to fossil fuels, solar energy does not create pollution. The power of the sun provides an unlimited energy resource that does not harm the environment. Solar energy is free and easily accessible. Solar energy technologies are rapidly developing, thus becomes cheaper and increases efficiency. Solar energy is used for heating and power generation purposes as follows:

- Power generation by Solar Energy: Electricity is produced from solar energy by means of solar panels or solar cells.
- Heating by Solar Energy: Solar energy is used as a tool for domestic heating and water heating.
- Cooking by Solar Energy: Solar energy is used in cooking by using the solar cookers.

Besides it advantages, solar energy also has some disadvantages. These can be sorted as the high initial installation cost and storage cost, the dependence on weather conditions, and the large space requirement for solar panels.

3.3 Hydroelectric Energy

Hydroelectric energy is also defined as renewable and clean energy due to the fact that water has a renewable feature with low carbon emission. The mechanism that is used to produce electrical energy from the power of water is called as hydroelectric power plant (HEPP). Hydroelectric power plants play an important role in the countries like our country, where energy resources are imported due to the insufficiency of energy resources, as they reduce external dependency.

Hydroelectric power plants have four main types.

- Storage (Dam) Hydroelectric power plants
- River-Type (without dam) Hydroelectric power plants
- Tide-type Hydroelectric power plants
- Depression-Type Hydroelectric power plants

As in the world, the most common types of HEPPs in our country are Storage and River-Type HEPPs. As a general working principle, electrical energy is produced as a result of transferring the water, which reaches to a certain height, towards the turbines located at a lower level, and the turbine impellers are rotated at a high speed and transmitted to the electricity generator. The electricity produced is sent to the mains in order to be used together with energy transmission lines.

In addition to its advantages, this type of energy also has disadvantages. In recent years, the impact of climate change, that has shown itself as drought, affects the production amounts of hydroelectric power plants. The fact that the carbon gas emission to the nature is minimal has also ensured that the Hydroelectric Power Plants are encouraged by the State, but whether the HEPPs are an environmentally friendly energy is a separate issue for the energy environments. Ecological areas can be destroyed during the installations of power plants that are constructed without complying with the standards. As a result, in order to increase the production of HEPPs instead of power generation with fossil energy resources based on imports, the world should struggle with the climate change. Despite rejecting that HEPP projects have a negative impact on the environment is to ignore the fact, the damage caused by hydroelectric power plants can be preferred instead of the damage caused by fossil energy resources to the environment.

3.4 Geothermal Energy

Geothermal energy is the thermal energy that is carried to the ground by means of underground fluids, water, water vapor, and gases. This thermal energy can be used directly or indirectly. Geothermal energy was used for heating and treatment purposes in ancient times of technology. However, with the development of the industry, electrical energy generation from geothermal energy has started. Geothermal power plants are used to generate electrical energy. In general, it has no difference from the power plants generating electricity from coal or natural gas. The difference of geothermal power plants is the energy resource. Geothermal energy resources are used in different areas according to the temperature of the resource. There are three types of geothermal power plants according to the temperature of the resource:

- Dry Steam Plants: It is the oldest method used to generate power from geothermal resources. Geothermal resources with very high temperature are used to generate power. In such power plants, dry steam obtained naturally from the geothermal resource is used.
- Flash-Cycle Steam Power Plants: This type of power plants is the most used plant type due to the lack of natural steam resources.
- Binary-Cycle Power Plants: Thanks to this plant type, the energy of geothermal resources at lower temperatures can be used. Maximum utilization of geothermal resources is provided.

3.5 Wind Energy

Wind energy is a type of renewable energy that generates electricity by converting the kinetic energy of the air into electricity via wind turbines. Wind energy is produced by converting the kinetic energy of the wind primarily into mechanical energy and then into electricity.

Wind energy provides numerous advantages as a renewable energy resource. These can be specified as follows:

- Wind energy has no raw material costs.
- Wind power plants do not emit harmful greenhouse gases to the nature.
- Wind power plants occupy less space than renewable energy resources such as solar energy. Thus, it prevents the occupation of agricultural land.
- Wind power generation is not affected by the variables such as seasons, daylight, and precipitation.[1]

Despite it is a renewable energy resource, wind energy also has some disadvantages.

- In order for a wind turbine to generate electricity, the wind must blow in the optimum speed range. When the wind blows at a velocity above or below this range, which varies according to the type of wind turbine, the turbine does not operate and the efficiency of the wind power plants decreases.
- The investment cost of the wind turbines is higher than solar power plants.
- The cyclic wind paths on which wind turbines are installed cause damage to migratory bird species as they are also migratory paths for some bird species.
- Wind power plants runs roughly. Thus, it is not suitable install them close to residential areas.

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[1] *What are the Advantages of Wind Energy?* (2022, Feb 11). encazip.com. Retrieved April 20, 2022, from https://www.encazip.com/ruzgar-enerjisi-nedir

CHAPTER 4

APPLICATION

In the literature, there are various Multi Criteria Decision Making (MCDM) methods that are developed to support the decision making process. The main purpose of these methods is to obtain the order of the alternatives according to criteria and to determine the best alternative. In this study, a new combined MCDM approach depending on Total Area Based on Orthogonal Vectors (TAOV) and Multi Attribute Utility Theory (MAUT) methods is suggested. In this approach, while the weights of the criteria are determined by the MAUT method, the TAOV method is used to obtain the order of the alternatives. By applying the proposed 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; Alagöz, İ., Avşar Özcan, N., Küçükyarar, U. & Özcan, E. (2021), Güllü, M. & Kartal, Z. (2021), Özcan, E. C., Ünlüsoy, 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), Türkiye Elektrik Üretim A.Ş. April 2020 Electricity Transmission Statistics” (TEİAŞ, 2020) and “Energy Balance Sheets of the Ministry of Energy and Natural Resources of Turkey” (MENR, 2019).

Brief explanations about the alternatives and criteria regarding the application are given below.

4.1 Alternatives

In application, hydroelectric, wind, solar, biomass and geothermal renewable energy sources used in Turkey were determined as alternatives in our decision model. Brief descriptions of these resources are given below.

4.1.1 Hydroelectric Energy:

Hydroelectric energy, which is one of the earliest energy resources, is the energy resource with the most advanced technology among renewable energy resources. Hydroelectric energy is obtained by converting the potential energy of water into kinetic energy. The main resource of hydroelectric energy is water, and thus, hydroelectric power plants have to be installed on a water resource for power generation. Of the world's processable hydroelectric energy potential, 1.5% belongs to Turkey (TMMOB, 2006). In addition, 42.7% of our power generation is met by the hydroelectric power plants (TEİAŞ, 2020b).

4.1.2 Wind Energy:

Wind energy is caused by the differential heating of ground surfaces by solar radiation. Varying rates of heating of the surfaces cause the temperature, humidity and pressure of the air to be different, and this pressure causes air motion. Wind turbines are used to generate electricity from wind energy, windmills to create mechanical energy, or wind pumps for well pumping, or sails are used to propel the ships. Wind energy is an important and reliable resource of energy for sustainable development. Also, the negative impact of wind energy on the environment is negligible. In Turkey, the region with the highest wind energy investments is the Aegean Region.

4.1.3 Solar Energy:

Solar energy technologies gather the sun rays directly and generate heat or electricity via these rays. The resource of this energy is the fusion reactions that is occurred by converting the hydrogen on the sun's surface into helium. The heating energy generated by the fusion process creates solar energy. The negative effects of solar energy generation on the environment are quite low. According to TEİAŞ data, there is an increase in the number of solar power plants in Turkey in recent years. In 2020, 7.2% of our power generation was obtained with solar energy. As can be understood from here, solar energy investments progress rapidly in our country.

4.1.4 Biomass Energy:

The utilization factor of biomass energy in our country is less than other energy resources. As a result of less number of investments, there has not been much progress in biomass energy. Of power generation, 2.6% is met from biomass resources.

4.1.5 Geothermal Energy:

Geothermal energy is the name given to the thermal energy accumulated on the crust of the earth. For heat or power generation, heat accumulated at various depths underground, hot water containing chemicals, steam and gases are used. When the heat level is high enough, geothermal energy can be used for power generation and high-grade water production for industry. Different from sun and wind, geothermal energy may provide continuous energy. The use of this energy dates back to ancient times. Ancient Romans and Chinese people used natural geothermal resources for bathing, heating, and cooking in 1500 BC. The great potential of this energy resource is now being rediscovered. Geothermal energy resource takes place a rich position among the countries of the world due to the geological and geographical location of Turkey. In our country, 5.3% of power generation is met by geothermal energy (TEİAŞ, 2020).

4.2 Criteria

While the criteria discussed in this study are being determined, MENR (Ministry of Energy and Natural Resources) 2019-2023 Strategy Plan, studies in the literature, and the facts, developments and trends in the world energy sector (EIA, IRENA 2019-2020) are considered. The ten evaluation criteria determined under four main titles are explained in detail below.

4.2.1 Technical Criteria

Technical criteria are related to the installation and process of the power plant of renewable energy resource alternatives.

4.2.1.1 Construction Period

This criterion is a prerequisite for the realization of other targets, as generation will begin after the completion of the power plant. In the decision matrix in the study, year is taken as the construction criterion.

4.2.1.2 Efficiency

Energy efficiency is the total of the measures used to prevent energy losses in gas, steam, heat, air and electricity, re-evaluate waste, and increase the efficiency of energy demand without reducing production with advanced technology.

4.2.2 Economic Criteria

Power production plants are investments that require large infrastructure, and a comprehensive feasibility study, which can be called a techno-economic analysis, is mandatory for them, as is the case with the establishment of any large generation facility. As technical parameters depend on the economic conditions in feasibility studies, this criterion is indispensable for the evaluation made in this study.

4.2.2.1 Cost

Cost is the leading criteria evaluated for every investment. In order for the investor not to make a loss, the sum of the initial investment cost and operating cost is expected to be less than the profit.

4.2.2.2 Government Incentive

In our country, especially in recent years, many incentives are given for the use of renewable energy resources. Value added tax, credit, purchase guarantee of the generated energy, etc. can be stated as the examples.

4.2.2.3 Economic Life

The economic life of the investment is an important criterion that determines the profitability due to the high installation and operational costs of the plant.

4.2.2.4 External Dependency (Resource potential)

Reducing external dependency is an important strategic goal that will be possible by increasing the total production of domestic and renewable energy resources. Thus, the size of the resource potential is a highly decisive criterion.

4.2.3 Social Criteria

Social benefit is an essential criterion that should be considered while making a power plant investment decision.

4.2.3.1 Employment Opportunities

Considering the power generation plants to be within the group of large infrastructure investments and the creation of employment areas is among the strategic duties of the states, when these situations are taken into consideration, the effect of employment opportunities is revealed on the power plant investment decision (Özcan and Erol, 2014).

4.2.3.2 Social Acceptance

Social acceptance, which is affected by many criteria such as employment opportunities, greenhouse gas emissions, visual pollution, use of area and water etc., showing the acceptability level of the power plants, is a goal that should be maximized (Özcan and Erol, 2014).

4.2.4 Environmental Criteria

It includes sub-criteria expressing the effect on human health and nature from the construction of the power plant to the time of production and consumption.

4.2.4.1 Area Requirement

The use of total area and the amount of energy per unit m^2 are important criteria for the power plant investment decision.

4.2.4.2 Greenhouse Gas Emission

It means the harmful molecules (CO_2, SO_2, NO_x) mixing with air from the flue gases of fossil-resourced power plants. It has negative effects on the quality of human and environmental health.

4.3 TAOV-MAUT Application

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.

4.3.1 Construction of the Decision Matrix

The rows of the decision matrix consist of alternatives and the columns consist of the criteria.

Table 4.1 Decision matrix

Alternatives	Criteria									
	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 (km^2/ kWh)**	**Greenhouse Gas Emission (g/kWh)**
Hydroelectric	90	4	3.500	9.6	30	140	0.36	0.1298	0.189	10
Wind	26	1	2.200	11	25	144	0.4	0.1737	0.814	10
Solar	21	1	2.479	22.5	25	380	1.28	0.1399	1.894	32
Biomass	40	2	3.575	18.9	20	93	3.06	0.1105	0.47	25
Geothermal	16	2	4.000	13.2	25	4.5	0.68	0.1405	0.404	38
Total	193	10	15.754	75.2	125	761.5	5.78	0.6944	3.771	115

4.3.2 Calculation of the Normalized Decision Matrix Values

The normalization process for each value in the decision matrix is calculated with equation (4.1).

$$\mathrm{r_{ij}} = \frac{\mathrm{x_{ij}}}{\sum_{1}^{j} \mathrm{x_{ij}}} \tag{4.1}$$

i: alternatives

j: criteria

$\mathrm{r_{ij}}$: normalized values

$\mathrm{x_{ij}}$: i^{th} alternative j^{th} criterion for given utility values

As a case in point, $\mathrm{r_{11}}$ and $\mathrm{r_{12}}$ is calculated as:

$$\mathrm{r_{11}} = \frac{90}{193} = 0.4663$$

$$r_{12} = \frac{4}{10} = 0.4000$$

Table 4.2 Normalized decision matrix

Alternatives	Criteria									
	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 (km^2/ kWh)**	**Greenhouse Gas Emission (g/kWh)**
Hydroelectric	0.4663	0.4000	0.2222	0.1277	0.2400	0.1838	0.0623	0.1869	0.0501	0.0870
Wind	0.1347	0.1000	0.1396	0.1463	0.2000	0.1891	0.0692	0.2501	0.2159	0.0870
Solar	0.1088	0.1000	0.1574	0.2992	0.2000	0.4990	0.2215	0.2015	0.5023	0.2783
Biomass	0.2073	0.2000	0.2269	0.2513	0.1600	0.1221	0.5294	0.1591	0.1246	0.2174
Geothermal	0.0829	0.2000	0.2539	0.1755	0.2000	0.0059	0.1176	0.2023	0.1071	0.3304
Entropy	1.3998	1.4708	1.5847	1.5575	1.6014	1.2603	1.2800	1.5987	1.3257	1.4784
1-Entropy	-0.3998	-0.4708	-0.5847	-0.5575	-0.6014	-0.2603	-0.2800	-0.5987	-0.3257	-0.4784
Weight	0.0877	0.1033	0.1283	0.1223	0.1320	0.0571	0.0615	0.1314	0.0715	0.1050

4.3.3 Calculation of the Entropy Values

Entropy concept, which was introduced by Shannon in 1948, was developed by using probability theory to measure uncertainty in information. 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 application steps of the method are summarized as follows.

The entropy value of each criterion is calculated by the formula (4.2). The logarithmic values of these values are added by multiplying the normalized values. This sum is multiplied by the last 'k' entropy coefficient and inserted into the table.

$$e_j = -k \sum_{i=1}^{m} r_{ij} \ln r_{ij} \tag{4.2}$$

k: entropy coefficient

e_j: entropy values

r_{ij}: normalized values

As a case in point, e_1 and e_2 is calculated as:

$$\begin{aligned} e_1 = -((\mathrm{LN}(2.7182818))^\wedge(-1) * ((0.4663 * (\mathrm{LN}(0.4663))) + (0.1347 \\ * (\mathrm{LN}(0.1347))) + (0.1088 * (\mathrm{LN}(0.1088))) + (0.2073 \\ * (\mathrm{LN}(0.2073))) + (0.0829 * (\mathrm{LN}(0.0829))))) = 1.3997 \end{aligned}$$

$$\begin{aligned} e_2 = -((\mathrm{LN}(2.7182818))^\wedge(-1) * ((0.4000 * (\mathrm{LN}(0.4000))) + (0.1000 \\ * (\mathrm{LN}(0.1000))) + (0.1000 * (\mathrm{LN}(0.1000))) + (0.2000 \\ * (\mathrm{LN}(0.2000))) + (0.2000 * (\mathrm{LN}(0.2000))))) = 1.4708 \end{aligned}$$

Table 4.3 Entropy values

Criteria	Entropy values
Efficiency (%)	1.3998
Construction period (year)	1.4708
Cost ($/kW)	1.5847
Government incentive ($/kWh)	1.5575
Economic life (year)	1.6014
External dependency (Resource Potential kWh/year)	1.2603
Employment opportunities (person/MW)	1.2800
Social acceptance	1.5987
Area requirement (km^2/ kWh)	1.3257
Greenhouse Gas Emission (g/kWh)	1.4784

According to Table 4.3, 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).

4.3.4 Calculation of Weight Values According to the Entropy Values

The criterion with a larger entropy weight is more important for decision making, as the entropy weight indicates the degree of useful information. Weight value of each criterion is calculated by equation (4.3). For the calculation of weight values, each of the calculated entropy values is subtracted from 1 and added up. Then, whichever criterion is desired, the entropy value of this value is subtracted from 1 and the weight value is divided by the first calculated sum. 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.

$$w_j = \frac{1-e_j}{\sum_{p=1}^{n}(1-e_p)}, \sum_{j=1}^{n} w_j = 1, j = 1,2, \dots, n. \tag{4.3}$$

w_j: weight values

e_j: entropy values

As an example of how the weight values given in Table 4.4 are calculated, the calculation of w_1 and w_2 is shown below.

$$w_1 = \frac{1-1.3997}{-3.8561} = 0.1036$$

$$w_2 = \frac{1-1.4708}{-3.8561} = 0.1220$$

Table 4.4 Weight values

Criteria	**Weight Values**
Efficiency (%)	0.0877
Construction period (year)	0.1033
Cost ($/kW)	0.1283
Government incentive ($/kWh)	0.1223
Economic life (year)	0.1320
External dependency (Resource Potential kWh/year)	0.0571
Employment opportunities (person/MW)	0.0615
Social acceptance	0.1314
Area requirement (km^2/ kWh)	0.0715
Greenhouse Gas Emission (g/kWh)	0.1050

4.3.5 Construction of the Decision Matrix in which the Maximum and Minimum Values are determined

The best and worst values of each criterion are marked on the decision matrix used in the application. (Maximum value: red, Minimum value: green).

Table 4.5 Decision matrix (maximum and minumum)

Alternatives	Criteria									
	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 (km^2/kWh)	Greenhouse Gas Emission (g/kWh)
Hydroelectric	90	4	3.500	9.6	30	140	0.36	0.1298	0.189	10
Wind	26	1	2.200	11	25	144	0.4	0.1737	0.814	10
Solar	21	1	2.479	22.5	25	380	1.28	0.1399	1.894	32
Biomass	40	2	3.575	18.9	20	93	3.06	0.1105	0.47	25
Geothermal	16	2	4.000	13.2	25	4.5	0.68	0.1405	0.404	38

4.3.6 Calculation of TAOV-MAUT Normalized Utility Values

When converting returns to benefit values, 0 can be assigned to the worst return and 1 to the best return. That is, it is the step by which the utility function is calculated from each criterion. With the normalization process, the best and worst values are determined and the highest satisfaction level is assigned to 1 and the worst level is assigned to 0. For values other than these values, the normalization formula is used. The normalization process belonging to the benefit and cost directional criteria is carried out.

Utility values are determined according to the utility criteria and normalized values are calculated by using the equation (4.4).

$$r_{ij} = \frac{x_{ij} - l_j^-}{u_j^+ - l_j^-} \tag{4.4}$$

Where $u_j^+ = \max_i x_{ij}$ and $l_j^- = \min_i x_{ij}$.

Similarly, the utility values are also determined according to the cost criteria and normalized values are calculated by using the equation (4.5).

$$r_{ij} = \frac{u_j^+ - x_{ij}}{u_j^+ - l_j^-} \tag{4.5}$$

Where $u_j^+ = \max_i x_{ij}$ and $l_j^- = \min_i x_{ij}$.

As an example of calculating the normalized utility values in Table 4.6, the calculation of r_{11} and r_{13} is given below.

$$r_{11} = \frac{90-16}{90-16} = 1.00$$

$$r_{13} = \frac{3.500-4.000}{4.000-2.200} = -0.28$$

Table 4.6 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 (person/MW)**	**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

4.3.7 Calculation of the Weighted Utility Values

The weight values calculated according to the entropy method and the normalized utility values are calculated using the equation (4.6).

$$WN = \sum_{j=1}^{n} w_j \, r_{ij} \tag{4.6}$$

WN: weighted normalized decision matrix

The calculation of some of the WN values given in Table 4.7 is shown below.

$$WN_{11} = 0.10367 * 1.00 = 0.1037$$

$$WN_{13} = 0.15164 * -0.28 = -0.0421$$

Table 4.7 Normalized utility values multiplied with the weight values

Alternatives	Criteria									
	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 (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

4.3.8 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. For example, let us have an R matrix. The transpose of this matrix R is denoted by R^T (R over T). It is shown as $R^T = R$.

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. The values obtained from the transposition are given in Table 4.8.

Table 4.8 Transposition of weighted utility matrix

	Alternatives				
Criteria	**Hydroelectric**	**Wind**	**Solar**	**Biomass**	**Geothermal**
Efficiency	0.0877	0.0119	0.0059	0.0284	0.0000
Construction Period	0.1033	0.0000	0.0000	0.0344	0.0344
Cost	-0.0356	-0.1283	-0.1084	-0.0303	0.0000
Government Incentive	0.0000	0.0133	0.1223	0.0882	0.0341
Economic Life	0.1320	0.0660	0.0660	0.0000	0.0660
External Dependency	-0.0365	-0.0359	0.0000	-0.0437	-0.0571
Employment Opportunities	0.0000	0.0009	0.0209	0.0615	0.0073
Social Acceptance	0.0401	0.1314	0.0611	0.0000	0.0624
Area Requirement	0.0000	0.0262	0.0715	0.0118	0.0090
Greenhouse Gas Emission	0.0000	0.0000	0.0825	0.0562	0.1050

4.3.9 Calculation of Component Coefficient Matrix

PCA recognition is a useful statistical technique used in the fields of classification, image compression. It is a technique whose main purpose is to keep the data set with the highest variance in high-dimensional data, but to achieve size reduction while doing so. It allows reducing the number of dimensions and compressing the data by finding the general properties of multidimensional data. It is certain that some features will be lost with a decrease in size; but the intention is that these lost features contain little information about the population. This method combines highly correlated variables to form a smaller set of artificial variables, called “principal components”, which make up the most variation in the data.

The values are calculated by performing PCA (principal components analysis) analysis with the SPSS program to the weighted utility matrix transposition. PCA finds a linear combination of vectors called, which are called as independent principal components. Each principal component, y_j, is a linear combination of vectors (r_1, r_2,…, r_n) (Jolliffe 2013). Where, A consists of the weights that are used in PCA for converting the correlated criteria into independent criteria. SPSS package can also be used to fix PCA. Via the application of PCA, the values of each alternative can be found easily in the corresponding components. The SPSS output values of these components are included in Appendix 1 in the Appendices section.

$$Y^T = [Y_i]_{nx1} = AY^T = [A_{ij}]_{nxn} [\overline{r_i}]_{nx1} \quad (4.7)$$

Table 4.9 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

4.3.10 Calculation of Orthogonal Decision Matrix

At this stage, the weighted normalized decision matrix(WN)columns should not be related to each other. To ensure this independence of the WN matrix, since the TAOV method acts on orthogonal vectors, the next step aims to convert the existing criterion vectors to an orthogonal vector. To find this orthogonal vector, WN principal component analysis (PCA) is applied to the matrix, which finds a linear combination of vectors called principal components that are independent.

The principal components matrix obtained as a result of the PCA analysis with the weighted utility matrix transposition is calculated with the formula (4.8). Via the application of PCA, corresponding components can be used to find the values of each alternative easily, i.e. in order to find an alternative A_i, its score in component y_j, illustrated as y_{ij} can be calculated as $y_{ij} = a_{j1}\ x_{i1} + a_{j2}\ x_{i2} + \ldots + a_{jn}\ x_{in}$ and here, $a_{j1} + a_{j2} + \ldots + a_{jn}$ show the coefficients of the variables in jth component. In order to find the orthogonal vector, principal component analysis (PCA) is applied on matrix WN.

$$y_{ij} = a_{j1}\ x_{i1} + a_{j2}\ x_{i2} + \ldots + a_{jn}\ x_{in} \tag{4.8}$$

$$Y = \left[y_{ij}\right]_{mxn}$$

Y: orthogonal decision matrix

Table 4.10 Orthogonal decision matrix

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

4.3.11 Transposing the Orthogonal Decision Matrix

In our decision matrix, transposition was applied at this step in order to reach the matrix size at the time of the beginning of the application. Orthogonal decision matrix is obtained. In addition, at this stage, the highest value for each criterion is determined as the ideal value.

Table 4.11 Transposition of the orthogonal decision matrix

Alternatives	Criteria									
	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 (km^2/kWh)**	**Greenhouse Gas Emission (g/kWh)**
Hydroelectric	0.0819	0.1066	-0.2369	0.1991	0.2350	-0.1227	0.0642	0.2306	0.0970	0.1888
Wind	0.0471	0.0519	-0.0161	-0.0852	0.0937	-0.0102	-0.0427	0.0512	-0.0200	-0.0599
Solar	0.0299	0.0562	0.0733	-0.0100	0.0132	-0.0304	0.0142	-0.0437	-0.0303	0.0249
Biomass	0.0345	0.0229	-0.0241	0.0167	0.0063	0.0052	0.0171	-0.0190	0.0024	-0.0320
Geothermal	-0.0036	-0.0056	-0.0025	-0.0149	-0.0135	-0.0091	0.0026	0.0098	-0.0094	-0.0125
Ideal	0.0819	0.1066	0.0733	0.1991	0.2350	0.0052	0.0642	0.2306	0.0970	0.1888

4.3.12 Calculation of the Total Area Values (Total area measure)

This method is based on the idea that in order to realize the Pythagorean Theorem in calculating the distance between two points, their vectors must essentially Dec perpendicular to each other. Therefore, using principal component analysis, the classical decision matrix is transformed into a vertical decision matrix.

Note that the columns of matrix Y are orthogonal; consequently, Euclidean distance can be used to calculate the distance between various criteria (according to Pythagorean Theorem). Then the distant between these two points is:

$$d^i_{k,l} = \sqrt{y^2_{ik} + y^2_{il}} \tag{4.9}$$

$d^i_{k,l}$: the distance between these two orthogonal components

For all the alternatives, TA_i and NTA_i total area values are calculated by using the formulas (4.10) and (4.11). Alternatives are ordered according to the results obtained. Table (4.12) gives the total area values and the order for the alternatives.

$$TA_i = \sum_{j=1}^{n-1} d^i_{j,j+1} \tag{4.10}$$

$$NTA_i = \frac{TA_i}{\sum_{k=1}^{m} TA_k} \tag{4.11}$$

Subsequently, by applying equation (4.10), the TA measures are figured out. As a case in point, TA_1 is calculated as:

$$TA_1 = \Big[\sqrt{0.1048^2 + 0.1364^2} + \sqrt{0.1364^2 + (-0.2809)^2} + \sqrt{(-0.2809)^2 + (0.2371)^2} + \sqrt{(0.2371)^2 + (0.2894)^2} + \sqrt{(0.2894)^2 + (-0.1490)^2} + \sqrt{(-0.1490)^2 + (0.0769)^2} + \sqrt{(0.0769)^2 + (0.2743)^2} + \sqrt{(0.2743)^2 + (-0.0896)^2} + \sqrt{(-0.0896)^2 + (0.2260)^2}\ \Big] = 2.5357$$

Table 4.12 Total area values

Alternatives	Criteria		
	TAi	**NTAi**	**Order**
Hydroelectric	2.1172	1.1859	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	

CHAPTER 5

CONCLUSIONS

Industrialization, population growth, ever-developing technology and the increase in trade opportunities have greatly increased the energy consumption rate. Thus, in recent years, the states have decided to increase their investments in renewable energy policies. Turkey aims to meet its energy demand, which has doubled in the last ten years, by its resources and the developed renewable energy policies. It is of great importance to determine the order of investments that Turkey will make in these potentials. With the multi-criteria decision-making methods used in this study, it is aimed to contribute to the priority ranking of the country's future investments by determining the renewable energy source that will be the most useful for Turkey.

In this study, MAUT and TAOV methods, which are used in solving multi-criteria decision making problems, are combined. While normalized utility values are found in the proposed new method (TAOV-MAUT); The MAUT method uses the calculated entropy to determine the criterion weights. In the next steps of the method, principal component analysis (PCA), which is an important step of the TAOV method, and other steps of the method were applied. The aim of our application is to determine the most beneficial renewable energy resource for Turkey by using the TAOV-MAUT method. As a result of the literature review regarding the evaluation of alternatives of renewable energy resources that can be used in Turkey, the most important criteria that can affect the decision are ordered as efficiency, construction time, cost, government incentives, economic life, external dependency, employment opportunities, social acceptance, space requirement, and greenhouse gas emissions. As a result of the study conducted, the most beneficial renewable energy resources of Turkey are found as hydroelectric, wind, sun, biomass, and geothermal energy resources, respectively.

According to the results of the TAOV-MAUT method proposed in this study, the most beneficial renewable energy source for Turkey has been determined as Hydroelectricity. Although hydroelectric energy covers a longer process than other sources in terms of construction time, it is the most accurate renewable energy source for Turkey with its economic life, low greenhouse gas emissions and 90% efficiency. On the other hand, despite wind energy is advantageous over other resources in terms of cost and construction time and low greenhouse gas emissions, it falls behind hydroelectric energy due to its 26% efficiency rate and low employment opportunities. Despite the government incentives, solar energy is in the third place as it is a renewable energy type that we are highly dependent on external resources. When the results are considered, the fact that the first three resources are in the priority utility group due to their high potential and other advantages in decision matrix is consistent with the strategy objectives of Ministry of Energy and Natural Resources. Another important point obtained as a result of the study is that although biomass and geothermal resources are local, they are in the last place. The main reason is the low potential of these resources. High cost rates, greenhouse gas emissions and low social acceptance rate by the public are also the factors that led to this result.

The most important advantages of renewable energy resources are that they help to protect the environment, and as they are domestic resources, they contribute to the reduction of external dependency in energy and to increase employment. As stated before, Turkey has a high potential in terms of renewable energy resources. Availability of these potentials can only be possible by making investments in these resources. Thus, determination of the itinerary to be followed by Turkey in terms of energy policies and the priority of investments to be made are of great importance. The results obtained in our study contain findings that will be useful in the resource determination processes of renewable energy investments to be made in the future. At the same time, it has been shown that the proposed method (TAOV-MAUT) is a multi-criteria decision-making method that can be accepted both practically and theoretically.

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APPENDICES

APPENDIX 1: Component Coefficient Matrix (SPSS)

Component Matrix[a]

	Component				
	1	2	3	4	5
Hydroelectric	,555	,707	,320	,286	-,092
Wind	,819	,320	-,428	-,009	,210
Solar	,852	-,296	-,364	,048	-,228
Biomass	,650	-,597	,320	,324	,117
Geothermal	,781	-,018	,352	-,516	-,003

Extraction Method: Principal Component Analysis.

a. 5 components extracted.