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Highlights

- ❖ *Each renewable energy sources should be evaluated with data envelopment analysis, and the obtained solution proposals for each province are the research subjects.*
- ❖ *Suggestions have been made that overlapping alternative solutions should be transformed into the hybrid structures in Turkey.*
- ❖ *A similar study was conducted using TOPSIS method, and an answer was sought to the question of what hybrid structures should be in terms of economics.*

Graphical Abstract

Analysis results have been mapped for on-site solutions with renewable energy sources in the solution of district heating/cooling problems within the framework of increasing energy prices.
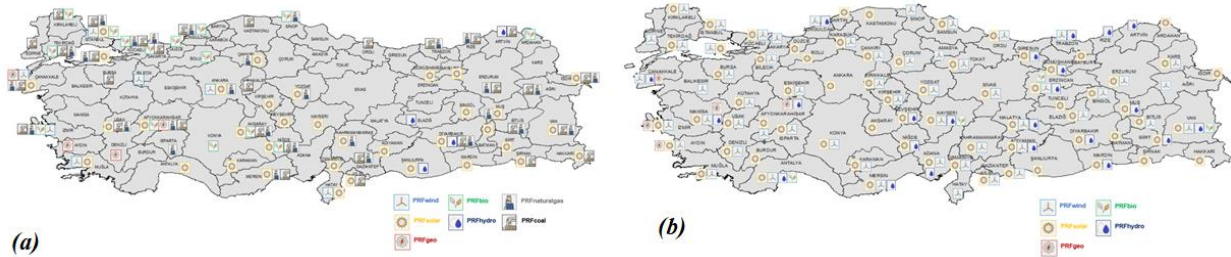
Figure. (a) CRSM results, and (b) bybrid solutions of TOPSIS

Aim

In this study, each renewable energy sources should be evaluated with data envelopment analysis, and the obtained solution proposals for each province are the research subjects.

Design & Methodology

The PRF values of fossil fuels were determined for heating resources (natural gas, solid fuels (wood and coal) and electricity), and for cooling resource (electricity) as primary energy sources in Turkey.

Originality

The values of QE were obtained from the summation of natural gas, coal, and electrical energy that are used for heating and cooling in each city. Moreover, the values of QP were determined from the amount of natural gas, coal, and electricity that were supplied to each city from such establishments as BOTAŞ, TKI and EMRA.

Findings

According to the importance levels of the criteria, the weight vector was determined as [0.4 0.25 0.25 0.1].

Conclusion

It would be a more correct approach to use TOPSIS results in the selection of economical solution proposals.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Alternative Hybrid Solution Suggestions for Heating/Cooling in Turkey Using Data Envelopment Analysis and TOPSIS

Araştırma Makalesi / Research Article

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ABSTRACT

Developing alternative and hybrid solution proposals for increasing Primary Resource Factor (PRF) values of the provinces in Turkey will lead to an increase in the use of renewable energy resources. In this study, each renewable energy sources should be evaluated with data envelopment analysis, and the obtained solution proposals for each province are the research subjects. Suggestions have been made that overlapping alternative solutions should be transformed into the hybrid structures in Turkey. In addition, a similar study was conducted using TOPSIS method, and an answer was sought to the question of what hybrid structures should be in terms of economics. Analysis results have been mapped for on-site solutions with renewable energy sources in the solution of district heating/cooling problems within the framework of increasing energy prices. Prominent alternative solutions are listed as solar, wind and hydraulic.

Keywords: Heating/cooling, Data Envelopment Analysis, TOPSIS.

1. GİRİŞ (INTRODUCTION)

The energy demand of the countries is increasing day by day in parallel to intensifying population, even in rural areas. Considering that fossil-based energy resources will be terminated in the near future, the utilization of renewables more is an unavoidable requirement. However, such parameters as region, climate, etc. are greatly determined the availability of renewables, i.e. these are main restrictions of them, which sometimes provides no continuous energy generation. On the other hand, as far as hybrid utilization of two or more renewables is considered, a continues energy generation and use can make possible, specifically in district heating and cooling implementations.

District heating/cooling corresponds to utilization of regional fuel or any heat resources which would or else be wasted to satisfy the demand of local customer for heating/cooling, by employing a heat distribution pipe network as a local market place. The most remarkable benefit of district heating/cooling is lower heating/cooling expenditures, especially when international fuel prices are high and when lower environmental or climate influences are estimated by internalization of external harm expenditures into any kind of fees like national taxes. In intense urban areas with intensified heat demands, the costs of heat distribution are generally low. The deficiencies are as follows: High distribution expenditures in sub-urban and rural regions with less intensified heat demands, and lower competition capacity at low international fuel prices. In some countries which are of strong driving forces, district heating systems supply heat to approximately one-half of the national building stocks. Nonetheless, in other countries, very few systems come out due to low awareness or competition capacity for district heating.

District heating/cooling applications are available in many countries ranging from Germany to United States [1-7]. The utilization of renewables is also available [8, 9]. Besides, Persson and Werner evaluated the current excess heat usage amounts via district heat distribution, and reported by such concepts as recovery efficiency, heat utilization rate, and heat recovery rate. Besides, they compared the two selected excess heat activities for current average EU27 heat recovery levels to currently best Member State practices, and then evaluated the future potentials of European excess heat recovery and utilization rates. Their fundamental conclusion was that a future four-fold increment of current EU27 excess heat utilization with district heat distribution to residential and service sectors was designated as reasonable on condition that applying best Member State practice [10]. Westin and Lagergren discussed the differences in idea go beyond the real duties assigned to the authorities, namely The Swedish Competition Authority and the National Energy Administration (STEM), but rather based upon perspectives: economics and consumer perspective versus an engineering, environmental and production perspective. They also wanted to encourage a broad discussion regarding the state of district heating and its regulatory condition and that neither economical models nor energy models were taken for granted [11].

In this study, the PRF values of fossil fuels were determined for heating resources (natural gas, solid fuels (wood and coal) and electricity), and for cooling resource

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(electricity) as primary energy sources in Turkey. Initially, the PRFs were calculated for natural gas, solid fuels and electricity. The values of Q_E were obtained from the summation of natural gas, coal, and electrical energy that are used for heating and cooling in each city. Moreover, the values of Q_P were determined from the amount of natural gas, coal, and electricity that were supplied to each city from such establishments as BOTAŞ, TKI and EMRA.

2. METHODOLOGY

2.1. Primary Energy

Primary energy refers to the energy that has not been subjected to any conversion or transformation process. Primary energy may be resource energy or renewable energy or a combination of both of them. Resource refers to a source depleted by extraction (e.g. fossil fuels) and renewable energy to a source that is not depleted by extraction (e.g. wind, biomass, solar). The use of the primary resource factor (PRF) enables to measure the savings and losses occurring from energy generation to the delivery to the building. The primary resource factor represents the energy delivery but excludes the renewable energy component of primary energy. The primary resource factor expresses the ratio of the non-regenerative resource energy (Q_P) required for the building to the final energy supplied to the building (Q_E).

$$PRF = Q_P/Q_E$$

The advantages of district heating and cooling become visible in the frame of such a broad analysis based on the use of fuel input. The PRF can shed light on the benefits of using fuel and energy (in the form of waste, renewable heat) that would be emitted into the atmosphere as unused. Such fuels and energy streams include biomass, biogas, solar and geothermal heat. In other words, PRF is an indicator of how effectively a fuel is used.

2.1. Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a linear programming-based technique that analyses the technical efficiency of decision-making units (DMUs). A DMU is defined as the tangible or intangible asset responsible for transforming a set of inputs into outputs, whose performance is supposed to be evaluated.

DEA is a technique that is used to estimate the relevant technology over the production possibilities frontier based on what is observed. The production possibilities frontier is defined as the set of input-output combinations. The boundary of this set, reflecting the greatest amount of output that can be produced from a given amount of input, defines the relevant technology or production function. Based on this, it is then possible to compute the efficiency score of a given decision-making unit (provinces is DMU in this study), a measure of its relative distance to the frontier surface. In DEA, one uses a series of linear programming problems to determine this production frontier surface. The efficiency of each DMU is evaluated against this frontier surface. Hence the efficiency of each DMU is evaluated relative to the performance of other DMUs. DEA assigns specific weights to the input/s and output/s of a DMU that give it the maximum possible efficiency score.

In this study, an output-oriented production efficiency model (Model 1) was used. Using output-oriented models, the efficiency score is determined by holding the set of inputs input constant and assessing to what extent the level of output would have to be improved (increased) for the DMU to be considered efficient. The dual form of Constant Returns to Scale Model (CRSM) output-oriented are as follows:

$$\max h_0 = \emptyset + \varepsilon \sum_{r=1}^{s} S_r^+ \varepsilon \sum_{i=1}^{m} S_i^-$$

Subject to

$$\emptyset. y_{r0} - \sum_{j=1}^{n} \lambda_j y_{rj} + S_r^+ = 0$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} + S_i^- = x_{i0}$$

$$\lambda_j, S_i^-, S_r^+ \geq 0$$

$$j = 1, \dots, n; i = 1, \dots, m; r = 1, \dots, s$$

Where the subscript o represents the DMU being assessed and ho denotes the efficiency score of DMU_o. x_{ij}, y_{rj} denotes the input "i" and output "r" of DMU_j, respectively. ε is an arbitrary small "non-Archimedean" number. S_i ; S_r are the slacks in the ith input and the rth output and n, m and s are the number of DMUs, inputs, and outputs, respectively.

From the CRSM, output augmentation is accomplished through the efficiency indicator variable ϕ. If ϕ is greater than 1.0 (or 100) and/or the slacks are not zero, then the DMU under investigation is inefficient. To improve and shift the DMU towards the efficient frontier, a proportional increase in ϕ for all outputs is required, followed potentially, by an adjustment of individual slacks.

DEA output-oriented model is illustrated graphically in Fig. 1. There are two outputs (Y1, Y2) proportioned to one input (X) and eight DMUs from A to H. The efficient frontier is a convex line EFGH. E, F, G, and H are efficient DMUs because they are on the efficient frontier and have an efficiency score of 1 or 100. The rest of DMUs (A, B, C, D) are technically inefficient because they are below the efficient frontier. The inefficient DMUs will have greater than 1 or 100. For example, in the case of the output orientation model, the technical efficiency of DMU C would be given provided by OC/OC' which is greater than unity. This value is the expansion coefficient for output/outputs of this inefficient DMU. The outputs were to be accessed at this

rate then inefficient DMU rises to the efficient position. In addition, DMU C should be referenced/benchmarked F and G DMUs with the rates of FC' and C'G respectively.
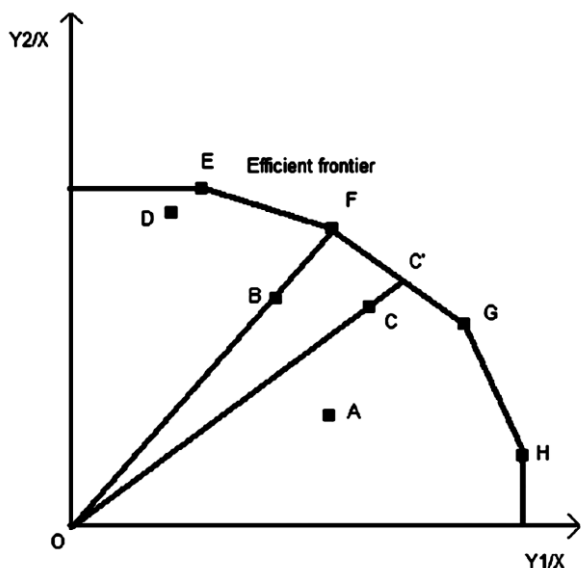

Figure 1. Efficiency frontier of an output-oriented model and measurements.

2.3. TOPSIS Method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was developed by Yoon and Hwang in 1980 and uses the basic approaches of the ELECTRE method. The proximity of decision points to the ideal solution is based on the main principle. The TOPSIS method includes a solution process consisting of 6 steps. The first two steps of the method are common with the ELECTRE method. The steps of the TOPSIS method are described below:

Step 1: Construct the Decision Matrix (A)

The rows of the decision matrix contain the decision points whose advantages are to be listed, and the columns contain the evaluation factors to be used in decision making. Matrix A is the initial matrix created by the decision-maker. The decision matrix is shown as follows:

$$A_{ij=} \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix}$$

Returns the number of decision points m in the matrix A_{ij}, and n is the number of evaluation factors.

Step 2: Obtain the normalized Decision Matrix (R)

The Normalized decision matrix is calculated using the elements of matrix A and using the formula below.

$$r_{ij=} \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}}$$

The R matrix is obtained as follows:

$$R_{ij=} \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}$$

Step 3: Obtain the Weighted Normalized Decision Matrix (V)

First, the weight values (W_i) for the evaluation factors are determined ($\sum_{i=1}^{n} w_i = 1$).

Then, the elements in each column of the R matrix are multiplied by their respective values and the V matrix is formed. The v matrix is shown below:

$$V_{ij=} \begin{bmatrix} w_1 r_{11} & \cdots & w_n r_{1n} \\ \vdots & \ddots & \vdots \\ w_1 r_{m1} & \cdots & w_n r_{mn} \end{bmatrix}$$

Step 4: Determine Ideal (A^*) and Negative Ideal (A^-) Solutions

The TOPSIS method assumes that each assessment factor has a monotonously increasing or decreasing trend.

To create the ideal solution set, the largest of the weighted evaluation factors, namely the column values, in the V matrix (the smallest if the relevant evaluation factor is minimized) is selected. Finding the ideal solution set is shown in the formula below.

$$A^* = \{(max_i v_{ij} | j \in J), (min_i v_{ij} | j \in J')\}$$

Eq. (2) can be represented as $A^* = \{v_1^*, v_2^*, ..., v_n^*\}$ a set to be calculated.

e negative ideal solution set is created by selecting the smallest of the weighted evaluation factors, namely the column values, in the V matrix (the largest if the relevant evaluation factor is maximized). Finding the negative ideal solution set is shown in the formula below.

$$A^- = \{(min_i v_{ij} | j \in J), (max_i v_{ij} | j \in J')\}$$

Eq. (3) can be represented as $A^- = \{v_1^-, v_2^-, ..., v_n^-\}$ a set to be calculated from the formula.

In both formulas, J shows the benefit (maximization) and J' shows the loss (minimization) value. Both ideal and negative ideal solution set consists of the number of evaluation factors, namely m elements.

Step 5: Calculation of Separation Measures

In the TOPSIS method, Euclidian Distance Approach is used to find the deviations of the evaluation factor value for each decision point from Ideal and negative ideal solution sets. Deviation values related to decision points obtained here are called Ideal Discrimination (S_i^*) and Negative Ideal Discrimination (S_i^-) Measure. Calculation of ideal separation (S_i^*) measure is shown in

Eq. (4) formula, and calculation of negative ideal separation (S_i^-) measure is shown in Eq. (5) formula.

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}$$

The S_i^* and S_i^- number to be calculated here will naturally be as much as the number of decision points.

Step 6: Computing Relative Closeness Coefficient to Ideal Solution

Ideal and negative ideal separation measures are used to calculate the relative proximity (CC_i^*) of each decision point to the ideal solution. The criterion used here is the share of the negative ideal measure of discrimination in the total measure of discrimination. The calculation of the relative proximity to the ideal solution is shown in the formula below.

$$CC_i^* = \frac{s_i}{s_i^- + s_i^*}$$

Here, CC_i^* value takes value in the range of $0 \le CC_i^* \le 1$ and $CC_i^* = 1$ indicates the absolute proximity of the relevant decision point to the ideal solution, and $CC_i^* = 0$ the negative ideal solution of the relevant decision point.

3. APPLICATIONS

3.1. Application of DEA

DEA has been used in this study to determine in which energy resources the provinces are leading. The population of each province, the amount of energy produced in that province, the primary energy resource capacity of that province (such as solar, wind, bio, coal, natural gas) were taken into account as inputs of the study. As the output of the analysis, the PRF values of each energy source belonging to 0 were taken into account. The analysis was repeated for the PRF value outputted for each energy source. According to the efficiency scores obtained in the analysis results, it was determined that for which PRF energy source was obtained for the province with a score of 100%, the province was effective in this energy source, therefore this energy source means that that province is the leading energy source. The 2.1 version of DEAP software developed by Queensland University was used in the study [12].

3.2. Application of TOPSIS

In the implementation, six different alternatives for 81 provinces, "Wind Energy", "Bio Energy", "Solar Energy," Hydro Energy "Geothermal Energy "and" Waste Heat ", four criteria "PRF value", "Installation Cost" it has been evaluated by taking into account the

operating cost" and "CO_2 emission". According to the importance levels of the criteria, the weight vector was determined as [0.4 0.25 0.25 0.1]. The "PRF value" criterion was considered as the most important criterion and the weight value was taken as 0.4. "Installation Cost" and "operating cost" criteria are of equal importance and the weight values are taken as 0.25. Finally, the criterion weight for "CO2 emission" was determined as 0.1. In the evaluation phase, if the "PRF value" of the relevant alternative is equal to zero, the relative proximity value (CC_i^*) of the alternative to the ideal solution is considered to be equal to zero without any calculation and the ranking is not taken into account. In practice, using the TOPSIS method for each province, 6 alternatives 4 criteria have been evaluated, the relative proximity value of each alternative to the ideal solution has been calculated.

4. RESULTS & DISCUSSION

The values of the calculated PRFs were given in Figs.2-6. The high values of PRF indicate that the fuel is not used effectively. A high PRF value means that energy source can be a solution for heating and cooling. For hydraulic energy provinces such as Elazığ, Bingöl, Gümüşhane and Artvin are interesting (Fig.2). For solar energy, provinces such as Konya, Nevşehir and Niğde in central Anatolia are the forefront, and Şanlıurfa and Adıyaman provinces in southeast Anatolia (Fig.3).

Figure 2. PRF values of Hydro

Figure 3. PRFvalues of Solar

Figure 4. PRF values of Bio

Figure 5. PRF values of geothermal

Figure 6. PRF values of wind

In bio energy, the central Black sea and Central Anatolia regions are attractive (Fig.4). Aydın, Manisa, Denizli and Çanakkale provinces are important for geothermal energy (Fig. 5). It is seen that Çanakkale, Edirne and Balıkesir provinces stand out for wind energy (Fig. 6). In addition, the Aegean region can evaluate its wind energy resource in general terms compared to other regions.

4.1. Results of DEA

With the model we developed for DEA analysis, we have determined in which energy source the provinces are one step ahead of the others, in other words, they are pioneers compared to other provinces, depending on the energy source infrastructure of that province. With the Models developed, which provinces should use which renewable energy source will be determined, and the overlapping provinces for different renewable energy sources will be an indicator that energy can be used as a hybrid. the solutions featured in the renewable energy model for Turkey can be summarized as follows:

1. Solar
2. Wind
3. Geothermal
4. Biomass
5. Hydro

According to the developed CRSM results, it was revealed which alternative solutions should be evaluated together for each province. PRF types with scores of 100% are the absolute available energy source for a city. Therefore, for provinces with 100% for more than one resource, it seems possible to combine these resources as hybrid or triple. Scores smaller or greater than 100% mean that there are deficiencies or excesses in the determined renewable energy source and it can be evaluated that meaningful results have not emerged for this study. Since our priority is to evaluate alternative and hybrid solutions for cities, we only need to know that the scores of 100% have meanings.

If we examine the Fig. 7, no alternative solution other than solar energy has been found for Adıyaman. However, for Istanbul, biomass and solar energy are considered hybrid energy sources. When evaluated in general, the result is that renewable energy sources are used together with coal or electricity instead of hybridizing with each other. For example, İzmir, Iğdır.

Figure 7. CRSM results

4.2. Results of TOPSIS

In the implementation, six different alternatives for 81 provinces, "Wind Energy", "Bio Energy", "Solar Energy," Hydro Energy "" Geothermal Energy "and" Waste Heat ", four criteria" PRF value "," Installation Cost "" it has been evaluated by taking into account the operating cost "and" CO_2 emission ".

According to the importance levels of the criteria, the weight vector was determined as [0.4 0.25 0.25 0.1]. The "PRF value" criterion was considered as the most important criterion and the weight value was taken as 0.4. "Installation Cost" and "operating cost" criteria are of equal importance and the weight values are taken as 0.25. Finally, the criterion weight for "CO2 emission" was determined as 0.1. In the evaluation phase, if the "PRF value" of the relevant alternative is equal to zero, the relative proximity value (CC_i^*) of the alternative to the ideal solution is considered to be equal to zero without any calculation and the ranking is not taken into account.

In practice, using the TOPSIS method for each province, 6 alternative 4 criteria have been evaluated, the relative proximity value of each alternative to the ideal solution has been calculated and the results are given in Fig. 8. In the light of this information, the relative proximity value to the ideal solution was ranked from high value to low value and the alternative with the highest value was evaluated as the best alternative.

Figure 8. Hybrid solutions of TOPSIS

5. CONCLUSION

Considering the hybrid solutions obtained by both methods, we can see that the same hybrid solutions come side by side for some provinces. Although the parameters used for evaluation in both methods are different, it can be concluded that the energy source to be used is the definitive solution for that city, since the solutions are common. In addition, it would be a more correct approach to use TOPSIS results in the selection of economical solution proposals. Although there has been a great development in the use of renewable energy resources in Turkey in recent years, it is still in the initial stage of using it for heating/cooling purposes. This study will be a guide on which resources should be evaluated in which province at the initial stage.

ACKNOWLEDGMENT

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Adnan SÖZEN: Calculated the therorical values and analyse the results.

Tayfun MENLİK: Calculated the therorical values and analyse the results.

Erdem ÇİFTÇİ: Calculated the therorical values and analyse the results.

Amjad ANVARİ-MOGHADDAM: Calculated the therorical values and analyse the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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