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Research Article

Optimal Site Selection for a Solar Power Plant in the Central Anatolian Region of Turkey

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Primary energy sources are running out due to the increase in electrical energy consumption. Environmental problems caused by primary energy sources are also increasing. Using more renewable energy resources (RES) can be considered as one of the most powerful solutions to address these problems. Today, required photovoltaic power systems (PVPS) and wind energy systems (WES) are widely used as RES for addressing these problems. Because of their high costs, feasibility studies are required for locating large systems associated with these resources. In this study, various suggestions are determined about location selection, which is an important stage in the PVPS's establishment. Hence, the criteria for selecting the appropriate location are analyzed by the multicriteria decision making (MCDM) methods and the results are evaluated for 5 cities in the Central Anatolian Region of Turkey. In conclusion, it is determined which city is the most suitable place for installation of solar power plants.

1. Introduction

Solar energy is one of the most important RES, and it is becoming more popular day by day for many reasons such as the purification of raw materials and the reduction of dependence on foreign oil and gas. Moreover, solar energy is an inexhaustible reliable source and it is harmless to the ecological environment. The choice of the appropriate solar energy location, which is important in their setup, depends on many factors. These factors should be optimized to get more energy as well as to reduce initial investment and operation costs. These operations should be considered during the first phase of solar energy installation to locate the plant accurately. Hence, many studies are performed in the literature locating the power plants in to the most appropriate places [1–4]. Multicriteria decision making (MCDM) methods are used in the optimization of systems with multiple parameters taken into consideration at the same time [5]. For this purpose, various submethods have been used to meet the requirements.

MCDM is a subbranch of a decision process. The decision process consists of the determination of different criteria for modelling goals, evaluation of alternatives, and getting results. To evaluate the alternatives based on criteria, different methods are used, such as analytic hierarchy process (AHP), analytic network process (ANP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Translating Reality English (ELECTRE), The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), and Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [6].

There are many studies that use the MCDM methods to solve location problems in the literature. Kengpol et al. developed a decision support system for solar power plant site selection in Thailand. They applied fuzzy analytic hierarchy process (Fuzzy AHP) model for the problem [7]. Uyan worked for suitable site selection in solar farms using geographical information system (GIS) and AHP. Karapinar Region in Konya/Turkey was chosen as the study area [8]. Asakereh et al. used a Fuzzy AHP and GIS to locate the most appropriate sites for solar energy farms in Shodirvan region in Iran [9]. ElQuoliti used AHP to determine the suitable site for solar power generation in the Western Region of Saudi Arabia. Fourteen site selection criteria are determined in the study [10]. Sozen et al. presented an approach for the location of solar plants by data envelopment analysis (DEA) and using the TOPSIS method. They applied it to 30 different cities in different regions of Turkey [11]. Lee et al. proposed a multiple-criteria decision-making model that incorporates the interpretive structural modeling (ISM), fuzzy ANP, and VIKOR to select the most suitable photovoltaic solar plant location and applied it in a case study in evaluating photovoltaic solar plant locations in Taiwan [12]. Sindhu et al. used hybrid combination of AHP and fuzzy TOPSIS to select an appropriate site in India [13].

In this study, four different MCDM methods are used to select the most suitable city among 5 cities in the Central Anatolian Region of Turkey for the establishment of solar power plant in order to get maximum power output and have minimum cost. Aksaray, Konya, Karaman, Nevşehir, and Niğde, which have the highest solar radiation, are selected for comparison. Three main criteria are defined for solar power plant location selection. These criteria rely on solar energy potential, feeder capacity, and surface slope. This study differs from other studies in terms of comparative use of all the MCDM methods. This situation has not been studied previously in the literature, especially when choosing suitable locations for PVPS. In addition, associating such a study with cities that have not been selected before is another contribution of this study. In conclusion of the study, it is observed that Karaman is determined as the most suitable city for the establishment of the solar plant station.

2. Problem Definition

It has become important to determine the installation location of solar energy systems that are in the foreground among the RES. Since the lifetime of such systems is a long time in 25 years, the location of a solar power plant that can obtain maximum energy is significant. Moreover, it is not possible to change the place of the system after installation because of the construction costs.

There are different criteria that can be used to determine the solar power plant location. Solar energy potential, feeder capacity of the distribution center, and surface slope are the main criteria that have been used for the selection of the solar power plant location. These main criteria have subcriteria to examine the problem in detail. Subcriteria of energy potential criterion are photovoltaic (PV) solar radiation, sunshine duration, and the total amount of energy/PV area. The feeder capacity of the distribution center has subcriteria of total capacity and available quota. Subcriteria of the power plant surface are the surface slope, ice load, and wind potential. Each subcriterion has its own weight factor for the related main criterion. In the following, the above-mentioned main criteria for the related cities will be, respectively, explained.

2.1. Solar Energy Potential. The location where the solar power plant will be installed is highly related with the solar energy potential of the location. The information about the solar energy potential of a location can be determined from the global radiation values (kWh/m^2-day), sunshine duration (hours), and PV-type area energy generation (kWh/year). In this study, these values of the cities are obtained from solar energy potential atlas (GEPA) of Directorate General of Renewable Energy in Turkey [14]. In Figures 1–5, each city's global radiation values, sunshine duration, and total amount of energy/PV area are shown.

The data in the figures are used as inputs to the proposed methods. Since the cities are in the same region and are close to each other, the suitable location of the installation cannot be estimated from the figures easily. However, they are very useful while using together with other methods. For this reason, they have been thoroughly examined.

2.2. Feeder Capacity of the Distribution Center. When an electric energy production facility is installed in a region, the infrastructure of the region should be examined. Therefore, the transformer capacities, the number of lines, cable sections, and so forth are considered as the parameters. In this context, the allocated capacity should also be considered. The allocated capacity of the transformer center for solar and wind energy power plants within unlicensed electricity generation is obtained with the notification of Directorate General of Turkish Electricity Transmission Corporation (TEİAŞ) [15]. The cities of Aksaray, Konya, Karaman, Nevşehir, and Niğde have a number of 10, 38, 5, 2, and 1 allocated capacities of the feeders, respectively.

2.3. Surface Slope. Another main criterion is surface slope. The slope of the surface where a solar power plant will be installed is usually kept below 5% [16]. The data in the study [17] is considered for the average slope data of the cities. Aksaray has 2%, Konya has 1%, Karaman has 3%, Nevşehir has 7%, and Niğde has 5% of surface slope coefficient. This suggests that the cities of Nevşehir and Niğde are problematic in terms of installation. However, these cities, which are good in terms of the amount of sunlight, have not been extracted from the analysis.

3. Methods

In this study, the AHP, ELECTRE, TOPSIS, and VIKOR, submethods of the MCDM, are used to decide which of the above-mentioned cities is suitable for the PVPS installation. These methods are described next for a better understanding of the simulations.

3.1. Analytic Hierarchy Process (AHP). AHP can be explained as the decision and the estimation method that is used for the identification of the decision hierarchy, and it gives percentage distribution of the decision points in terms of factors which affect the decision [18]. Its solution consists of 5 steps. Firstly, the decision-making problem is defined. The decision points and affecting factors are determined to define the decision-making problem. The number of decision points is denoted by m, and the

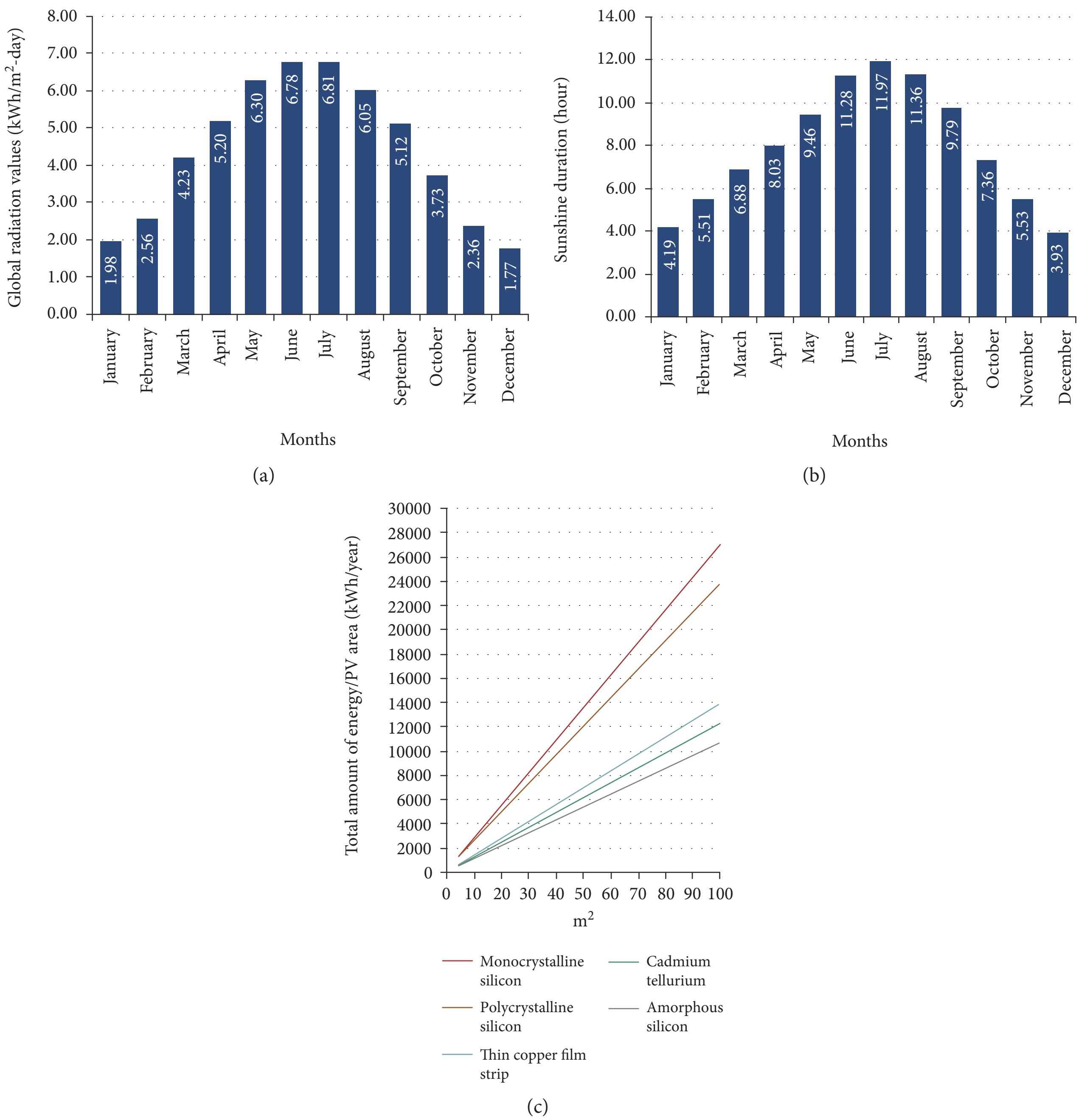

Figure 1: Konya province (a) global radiation values, (b) sunshine duration, and (c) total amount of energy/PV area.

number of factors affecting them is denoted by n. In the second step, comparison matrix among factors is formed. It is a square matrix of size nxn. The components on the diagonal of the matrix take the value of "1." The resulting comparison matrix is shown in

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}, \quad (1)$$

where a_{mn} is the element of mth row, nth column of matrix A, and shows the intensity of importance of mth factor over nth factor. The relative importance of pairwise comparisons is measured according to a numerical scale from 1 to 9 as shown in Table 1 [19]. When factor m compared to n is assigned with the number shown in Table 1, the factor n compared to m becomes its reciprocal.

In the third step, percentage importance distribution of the factors is determined. Comparison matrix shows the importance level with respect to each factor. The column vector B that has k components is formed to determine weights or the percentage importance distribution of all factors by using column vectors that form the comparison matrix. The column vector B is shown in

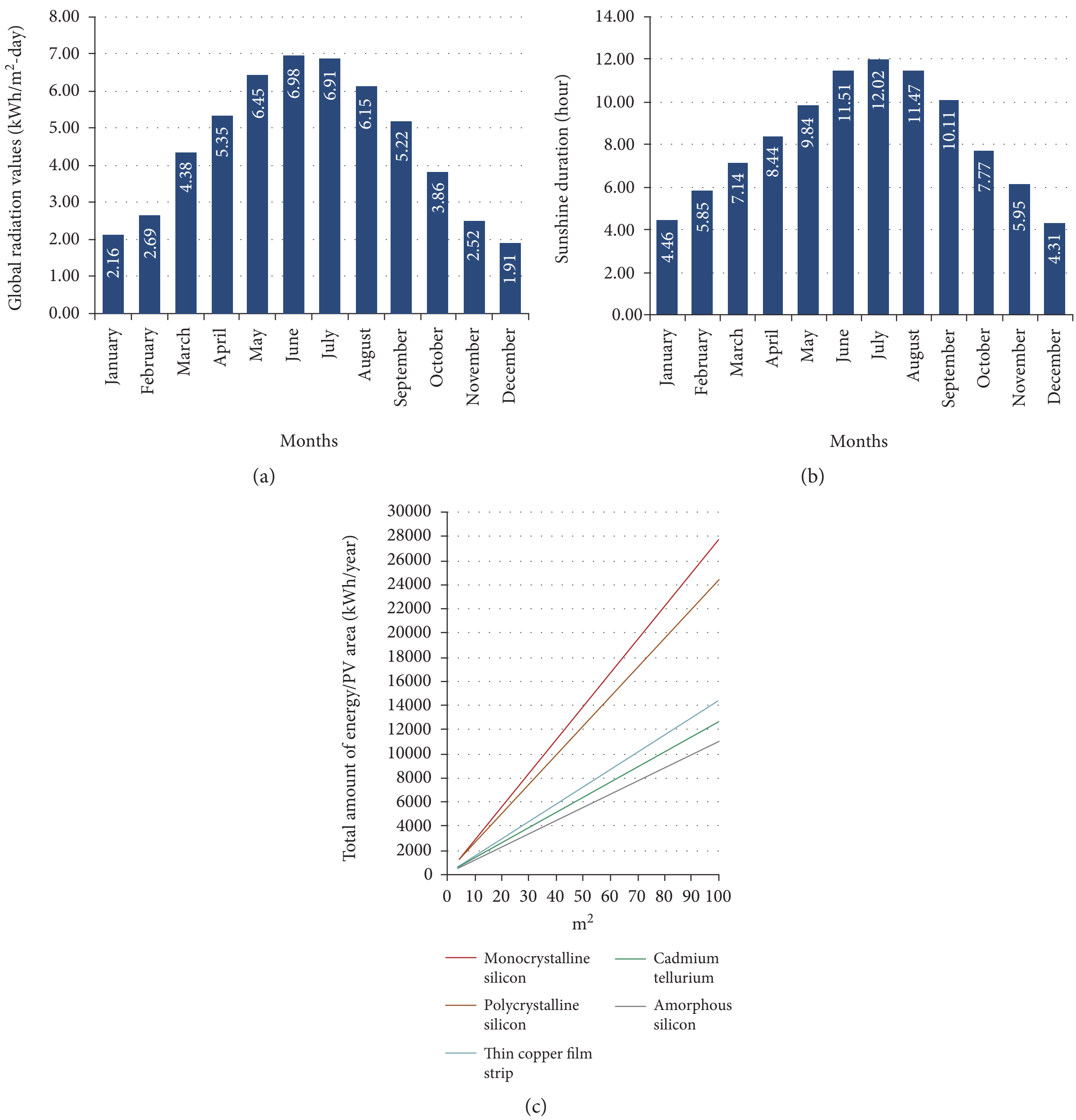

FIGURE 2: Karaman province (a) global radiation values, (b) sunshine duration, and (c) total amount of energy/PV area.

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ \vdots \\ b_{n1} \end{bmatrix}. \quad (2)$$

The components of the column vector B are calculated as shown in

$$b_{mn} = \frac{a_{mn}}{\sum_{m=1}^{k} a_{mn}}. \quad (3)$$

The matrix C is formed by combining the column vector B as shown in

$$C = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ c_{m1} & c_{m2} & \dots & c_{mn} \end{bmatrix}, \quad (4)$$

where c_{mn} is the element of mth row, nth column of matrix C.

The percentage importance distribution that shows the relative importance of each factor can be obtained with the help of matrix C. The column vector W called weighting

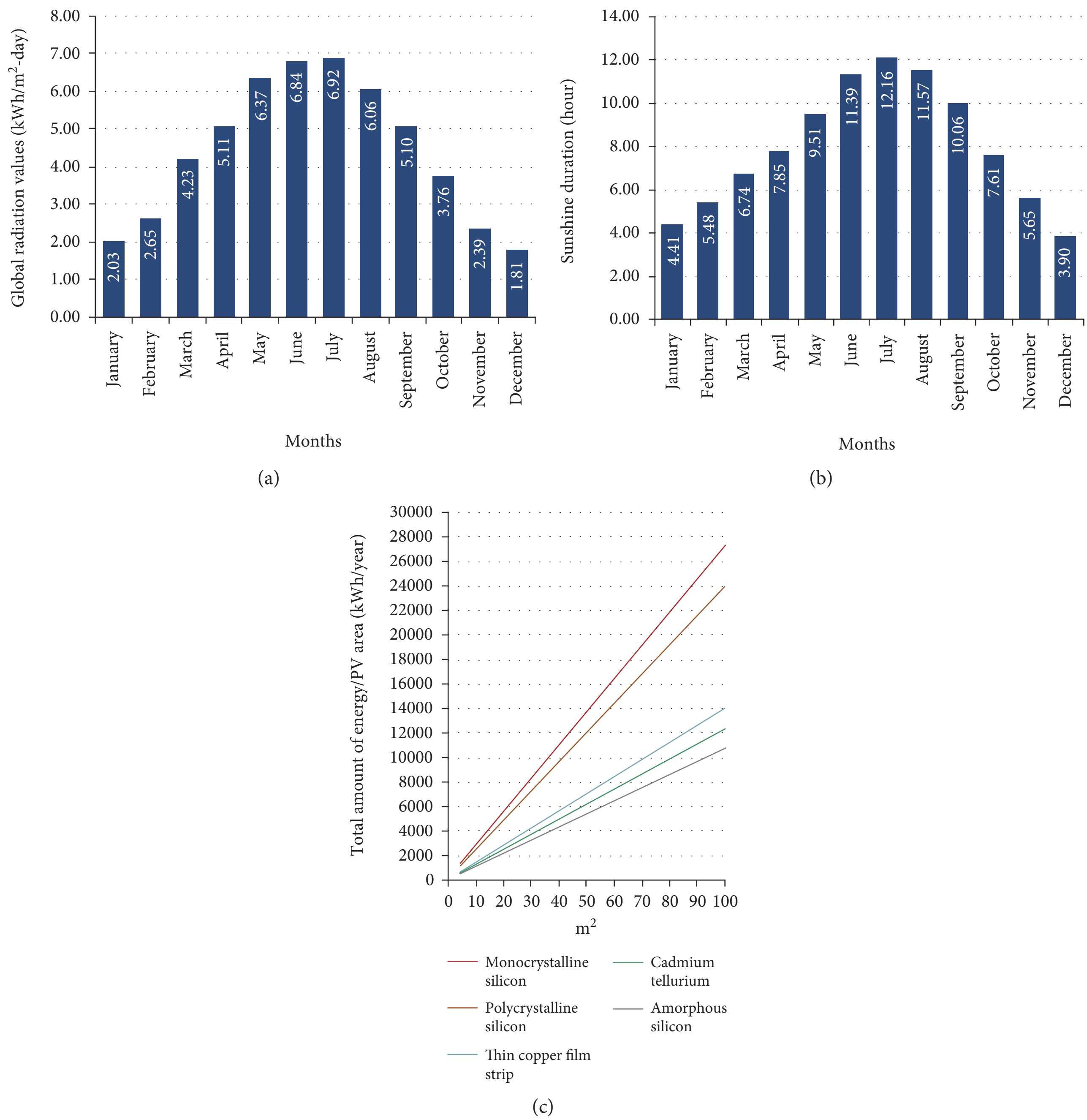

Figure 3: Niğde province (a) global radiation values, (b) sunshine duration, and (c) total amount of energy/PV area.

vector is obtained by taking the mean of row components of matrix C. W is shown in (5). The calculation of components of vector W is shown in (6).

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}, \quad (5)$$

$$w_m = \frac{\sum_{n=1}^{k} c_{mn}}{k}. \quad (6)$$

In the fourth step, consistency of factor comparison is measured. Consistency ratio (CR) determines whether the comparisons that are made by AHP method are true or not. Firstly, column vector D is obtained by multiplying comparison matrix A with weighting vector W as shown in

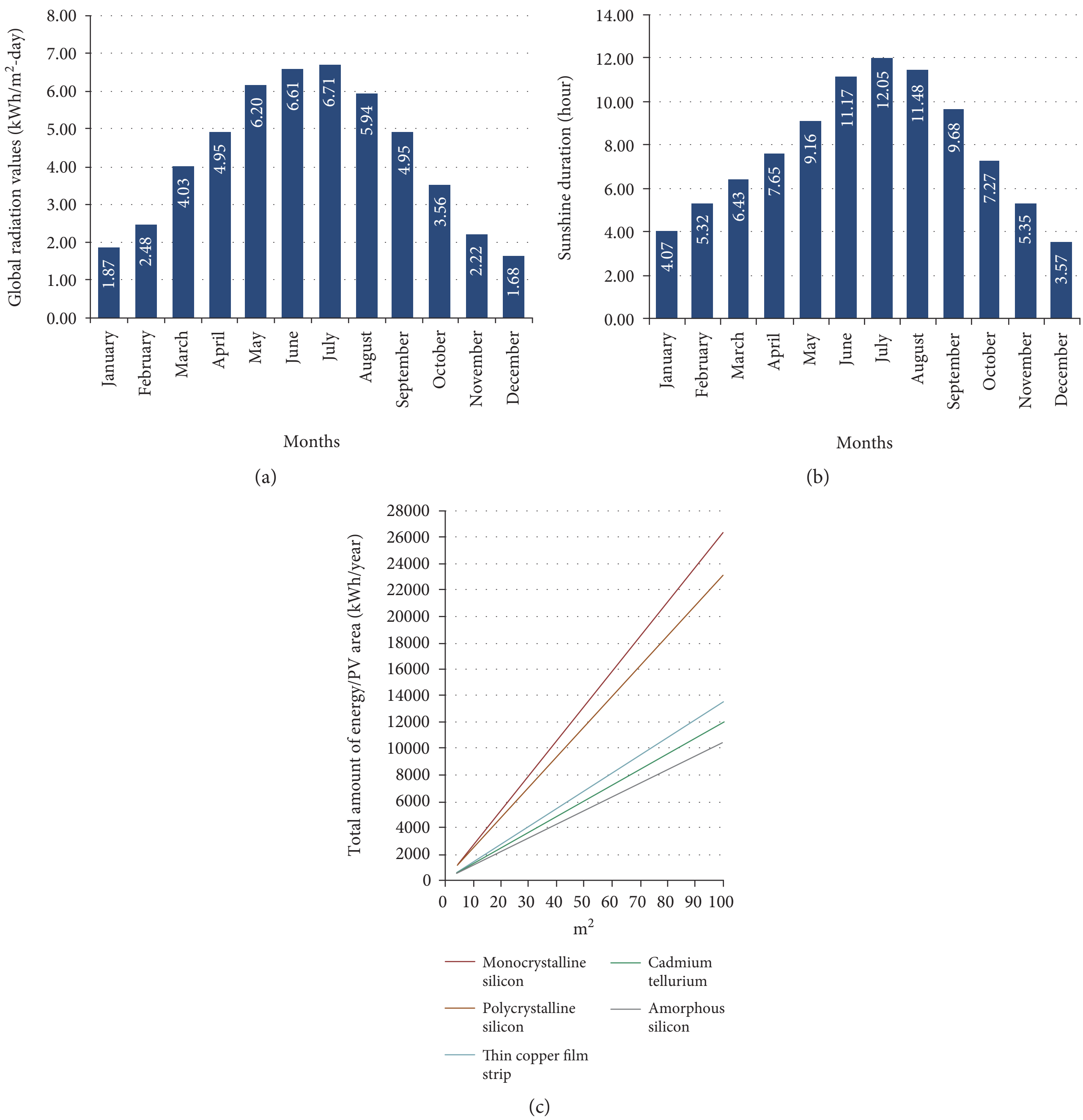

Figure 4: Nevşehir province (a) global radiation values, (b) sunshine duration, and (c) total amount of energy/PV area.

$$D = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}. \quad (7)$$

Main value related to each evaluation factor (EF) is obtained by dividing column vector D to the corresponding elements of column vector W as shown in

$$\mathrm{EF}_m = \frac{d_m}{w_m} \quad (m = 1, 2, \dots, k). \quad (8)$$

Mean value related to the comparison (λ) is obtained by taking the mean of EF elements as shown in

$$\lambda = \frac{\sum_{i=m}^{k} \mathrm{EF}_m}{k}. \quad (9)$$

Then, consistency index (CI) and the (CR) are calculated as shown in (10) and (11).

The value of CR must be smaller than 0.10 to be consistent with comparison matrix [20].

Random index (RI) in (11) takes different values by the number of criteria. The values of RI according to n, which is the number of criteria, are shown in Table 2.

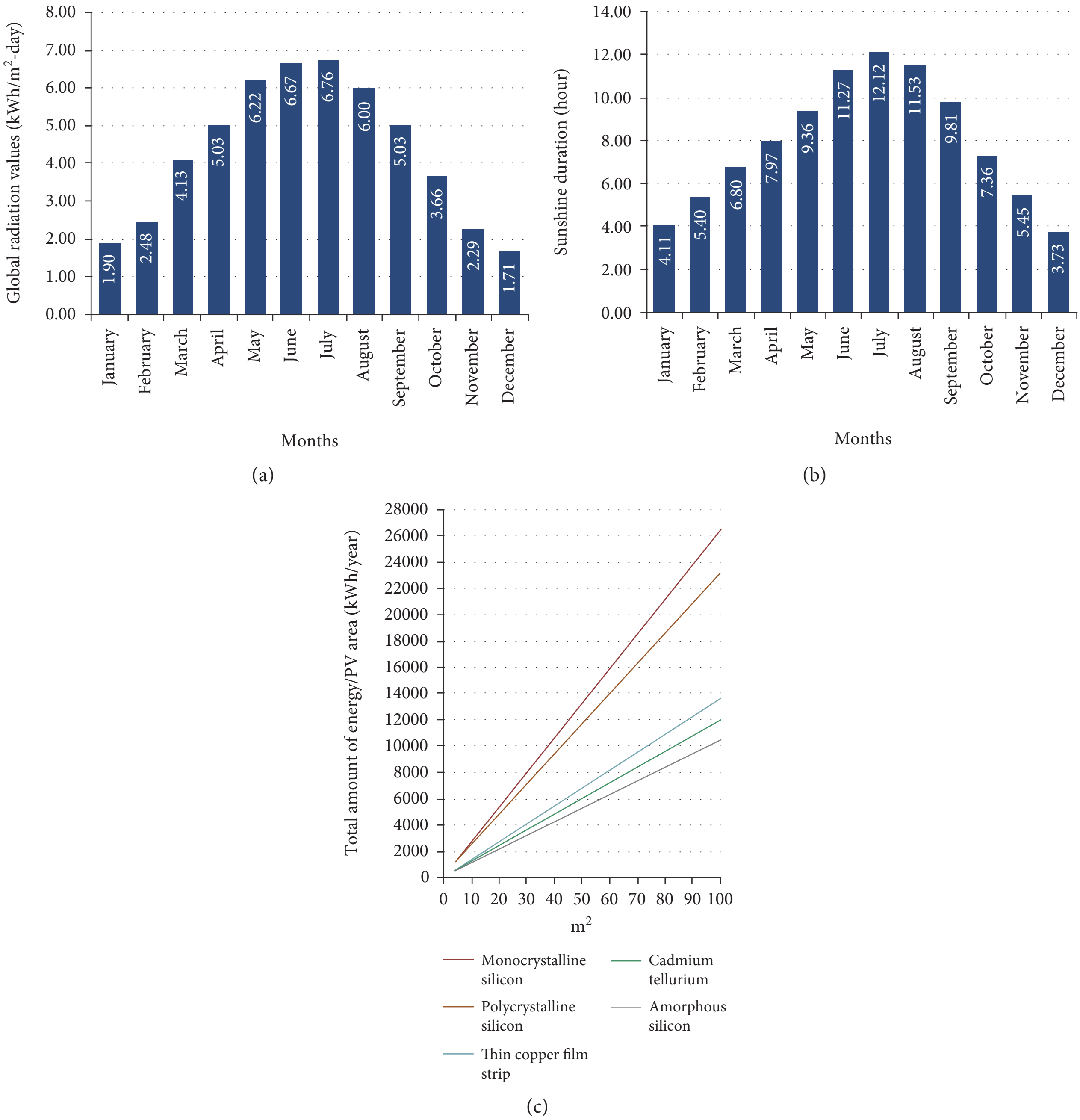

Figure 5: Aksaray province (a) global radiation values, (b) sunshine duration, and (c) total amount of energy/PV area.

In this study, the value of RI is taken as 0.58 from the table since there are 3 criteria.

$$\mathrm{CI} = \frac{\lambda - k}{k - 1}, \quad (10)$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}. \quad (11)$$

In the final step, percentage importance distribution (PID) at m decision points is found for each factor. In other words, the comparisons and matrix operations are repeated k times. However, the size of the comparison matrix that will be used as the decision points of each factor will be mxm. After each comparison operation, column vector S that shows percentage distribution and has a size of mx1 is obtained. The column vector S is shown in

$$S_m = \begin{bmatrix} s_{11} \\ s_{21} \\ \vdots \\ s_{m1} \end{bmatrix}. \quad (12)$$

The decision matrix K is formed with mxn size, and it consists of n column vector S which has the size of mx1. It is shown in

Table 1: Rating scale of AHP method.

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	More important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate values	When compromise is needed.

Table 2: The values of RI.

k	RI	k	RI
1	0	6	1.24
2	0	7	1.32
3	0.58	8	1.41
4	0.90	9	1.45
5	1.12	10	1.49

$$K = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix}. \quad (13)$$

As a result, the column vector L is obtained by multiplying the decision matrix with column vector W (weighting vector) as shown in (14). The column vector L gives the percentage distribution of decision points, and the sum of its elements is 1.

$$L = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} l_{11} \\ l_{21} \\ \vdots \\ l_{m1} \end{bmatrix}. \quad (14)$$

3.2. Elimination and Choice Translating Reality English (ELECTRE). The method depends on dual superiority comparisons among the decision points for each evaluation factor. This method basically consists of 8 steps [21]. Firstly, the decision matrix A is formed. There are decision points and evaluation factors in rows and columns of the decision matrix. The matrix A is the initial matrix that is formed by the decision maker. The number of decision points and the number of the evaluation factors are represented by m and n in the A_{mn} matrix. The resulting decision matrix is shown in

$$A_{mn} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}. \quad (15)$$

In the second step, standard decision matrix, X, is formed. It is shown in

$$X_{mn} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}. \quad (16)$$

X is formed by the help of matrix A. The elements of matrix X are calculated as shown in

$$x_{mn} = \frac{a_{mn}}{\sqrt{\sum_{k=1}^{m} a_{kn}^2}}, \quad (17)$$

where m is the number of the decision points, n is the number of the columns, and a is the element of matrix A.

In the third step, the weighted standard decision matrix, Y, is formed. The matrix Y is used to reflect importance differences of the criteria to the solution. The matrix Y is obtained by multiplying matrix X with a weighting vector w_i as shown in

$$Y_{mn} = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \cdots & w_n x_{1n} \\ w_1 x_{21} & w_2 x_{22} & \cdots & w_n x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_1 x_{m1} & w_2 x_{m2} & \cdots & w_m x_{mn} \end{bmatrix}. \quad (18)$$

In the fourth step, consistency (C_{kl}) and inconsistency (D_{kl}) sets are determined. Matrix Y is used to determine the consistency sets. The decision points are evaluated in terms of the criteria. Equation (19) is used in this evaluation process. Every consistency set corresponds to one inconsistency set in this method. Inconsistency set consists of the elements that are not in the consistency set.

$$C_{kl} = \{n, y_{kn} \geq y_{\text{ln}}\}. \quad (19)$$

In the fifth step, consistency (C) and inconsistency (D) matrices are formed with the help of the consistency and inconsistency sets. The elements of the consistency matrix are found with (20), and the elements of the inconsistency matrix are found with (21).

$$c_{kl} = \sum_{n \in C_{kl}} w_n, \quad (20)$$

$$d_{kl} = \frac{\max_{n \in D_{kl}} |y_{kn} - y_{\text{ln}}|}{\max_{n} |y_{kn} - y_{\text{ln}}|}. \quad (21)$$

The matrix C is obtained with (20) as shown in (22), and the matrix D is obtained with (21) as shown in (23).

$$C = \begin{bmatrix} - & c_{12} & c_{13} & \cdots & c_{1m} \\ c_{21} & - & c_{23} & \cdots & c_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ c_{m1} & c_{m2} & c_{m3} & \cdots & - \end{bmatrix}, \quad (22)$$

$$D = \begin{bmatrix} - & d_{12} & d_{13} & \cdots & d_{1m} \\ d_{21} & - & d_{23} & \cdots & d_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ d_{m1} & d_{m2} & d_{m3} & \cdots & - \end{bmatrix}. \quad (23)$$

In the sixth step, consistency superiority (F) and inconsistency superiority (G) matrices are formed.

The matrix F is in the size of mxm, and the elements of the matrix F are obtained by the comparison of a consistency threshold value ($\underline{c}$) and the elements of consistency matrix (c_{kl}). Consistency threshold value is found with

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl}. \quad (24)$$

The elements of the matrix $F\,(f_{kl})$ take a value of 1 or 0, and there are no values on the diagonal of the matrix because the diagonal elements show the same decision point. If $c_{kl} \geq \underline{c} \Rightarrow f_{kl} = 1$, and if $c_{kl} < \underline{c} \Rightarrow f_{kl} = 0$.

The matrix G is in the size of mxm, and it is formed in the same manner as matrix F. Inconsistency threshold value ($\underline{d}$) is found with

$$\underline{d} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl}. \quad (25)$$

The elements of the matrix $G\,(g_{kl})$ take a value of 1 or 0, and there are no values on the diagonal of the matrix because the diagonal elements show the same decision point. If $d_{kl} < \underline{d} \Rightarrow g_{kl} = 1$, and if $d_{kl} \geq \underline{d} \Rightarrow g_{kl} = 0$.

In the seventh step, total dominance matrix (E) is formed. E is obtained with the multiplication of matrices F and K and consists of 1's and 0's. Finally, the order of importance of the decision points is determined.

3.3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). In the first step of this method, the decision matrix A is formed. There are decision points in the rows of the decision matrix and evaluation factors at the columns of the decision matrix. The matrix A is an initial matrix that is formed by the decision maker [22]. The resulting decision matrix is shown in

$$A_{mn} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}. \quad (26)$$

In the second step, standard decision matrix R is formed. The matrix R is shown in

$$R_{mn} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}. \quad (27)$$

The elements of the matrix R are calculated with the help of the matrix A as shown in

$$r_{mn} = \frac{a_{mn}}{\sqrt{\sum_{k=1}^{m} a_{kn}^2}}. \quad (28)$$

In the third step, standard weighted decision matrix V is formed. Firstly, weight values (w_n) related to evaluation factors are determined. Then, elements for each column in the matrix R are multiplied with related w_n value. The matrix V is shown in

$$V_{mn} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix}. \quad (29)$$

In the fourth step, ideal (A^*) and nonideal (A^-) solutions are formed. The biggest value of the weighted evaluation factors of matrix V is chosen to form an ideal solution set. Equation (30) shows the finding of the ideal solution set.

$$A^* = \left\{ \left(\max_m v_{mn} \middle| n \in N \right), \left(\min_m v_{mn} \middle| n \in N' \right) \right\}. \quad (30)$$

The smallest value of weighted evaluation factors of matrix V is chosen to form a nonideal solution set. Equation (31) shows the finding of the nonideal solution set.

$$A^- = \left\{ \left(\min_m v_{mn} \middle| n \in N \right), \left(\max_m v_{mn} \middle| n \in N' \right) \right\}. \quad (31)$$

In the fifth step, discrimination measurements are calculated. The deviation values related to the decision points are calculated with the help of Euclidean distance approach. Ideal discrimination (S_m^*) and nonideal discrimination (S_m^-) measurement values are found with

$$S_m^* = \sqrt{\sum_{n=1}^{n} (v_{mn} - v_n^*)^2}, \quad (32)$$

$$S_m^- = \sqrt{\sum_{n=1}^{n} (v_{mn} - v_n^-)^2}. \quad (33)$$

In the final step, the relative proximity of the ideal solution is calculated. The ideal and nonideal discrimination values are used to calculate relative proximity of the ideal solution for each decision point. The calculation is shown in

$$C_m^* = \frac{S_m^-}{S_m^- + S_m^*}. \quad (34)$$

In (34), the value of C_m^* is between 0 and 1 as shown in

Table 3: Comparison matrix for solar energy potential.

Solar energy potential	Aksaray	Konya	Karaman	Nevşehir	Niğde
Aksaray	1	1/3	1/7	3	1/5
Konya	3	1	1/5	5	1/3
Karaman	7	5	1	9	3
Nevşehir	1/3	1/5	1/9	1	1/7
Niğde	5	3	1/3	7	1

Table 4: Comparison matrix for maximum capacity that can be allocated.

Maximum capacity that can be allocated	Aksaray	Konya	Karaman	Nevşehir	Niğde
Aksaray	1	1/3	3	5	8
Konya	3	1	5	7	9
Karaman	1/3	1/5	1	2	5
Nevşehir	1/5	1/7	1/2	1	3
Niğde	1/8	1/9	1/5	1/3	1

$$0 \leq C_m^* \leq 1. \tag{35}$$

If C_m^* equals 1, it shows the absolute proximity of related decision point to the ideal solution, and if C_m^* equals 0, it shows the absolute proximity of the related decision point to the nonideal solution.

3.4. Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR). This method solves the problems by calculating the best and the worst values of all the criteria functions. The best ($f_m{}^*$) and the worst ($f_m{}^-$) values are found with [22, 23]

$$f_m{}^* = \max f_{mn}, \tag{36}$$

$$f_m{}^- = \min f_{mn}, \tag{37}$$

where m represents criteria and n represents alternatives.

Then, the values of S_n and R_n are calculated with [22, 23]

$$S_n = \sum_{m=1}^{n} \frac{w_m (fm^* - fmn)}{fm^* - fm^-}, \tag{38}$$

$$R_n = \max \left[\frac{w_m (fm^* - fmn)}{fm^* - fm^-} \right], \tag{39}$$

where w_m represents the weight of the mth criteria.

After that, the value of Q_n that represents the maximum group benefit is found with (40) for each alternative.

$$Q_n = \frac{v(S_n - S^*)}{S^- - S^*} + \frac{(1-v)(R_n - R^*)}{R^- - R^*}, \tag{40}$$

where $S^* = \min^n S_n$, $S^- = \max^n S_n$, $R^* = \min^n R_n$, and $R^- = \max^n R_n$. v refers to the weight for the strategy that ensures maximum group utility, and $(1-v)$ refers to the weight of the minimum regret in dissent. The value of v changes between 0 and 1. Generally, the value of v is taken as 0.5.

Table 5: Comparison matrix for surface slope.

	Aksaray	Konya	Karaman	Nevşehir	Niğde
Aksaray	1	1/3	2	8	5
Konya	3	1	5	9	7
Karaman	1/2	1/5	1	6	3
Nevşehir	1/8	1/9	1/6	1	1/3
Niğde	1/5	1/7	1/3	3	1

Table 6: Decision matrix.

	Solar energy potential	Surface slope	Capacity
Aksaray	4	8	8
Konya	6	10	10
Karaman	10	6	6
Nevşehir	2	2	4
Niğde	8	4	2

Table 7: Matrix *E*.

	Aksaray	Konya	Karaman	Nevşehir	Niğde
Aksaray	—	0	0	1	0
Konya	1	—	0	1	0
Karaman	1	1	—	1	1
Nevşehir	0	0	0	—	0
Niğde	1	0	0	1	—

Table 8: Proximity values based on ideal solution.

	C^*
Aksaray	0.34
Konya	0.56
Karaman	0.83
Nevşehir	0.07
Niğde	0.62

Finally, the calculated values of S_n, R_n, and Q_n are ranked in a decreasing order. Q_n with the smallest value is expressed as the best option among alternatives.

4. Simulation and Results

In this study, a simulation is implemented by using the MATLAB program to establish the location of the solar power plants for the suggested cities with the help of the methods that are described next. The results obtained from the methods according to the problem definition have been explained in this section.

4.1. AHP Results. In this method, the matrices to be found for the three main criteria described in the previous chapters will

Table 9: Values of S_n, R_n, Q_n, and decreasing order.

	S_n	Order of S_n	R_n	Order of R_n	Q_n	Order of Q_n
Aksaray	0.575	4	0.4875	4	0.6086	4
Konya	0.325	2	0.325	3	0.2939	2
Karaman	0.175	1	0.115	1	0	1
Nevşehir	0.9425	5	0.65	5	1	5
Niğde	0.4825	3	0.23	2	0.3077	3

Table 10: Results with AHP, ELECTRE, TOPSIS, and VIKOR methods.

Method	1	2	3	4	5
AHP	Karaman	Konya	Niğde	Aksaray	Nevşehir
ELECTRE	Karaman	Konya/Niğde	Konya/Niğde	Aksaray	Nevşehir
TOPSIS	Karaman	Niğde	Konya	Aksaray	Nevşehir
VIKOR	Karaman	Konya	Niğde	Aksaray	Nevşehir

be shown in a tabular form. These matrices are the comparative matrices of the solar energy potential, the allocated capacity, and the surface slope. The data to be used for this purpose is taken from the study in [14]. Since the rows and columns have the same cities, the diagonal values of Table 3 are 1. However, the other elements of the matrices are composed of different values found by using the AHP equations. These values show which city is superior to the others.

The comparison matrix that is formed by comparing the cities is shown in Table 3. Here, the row side shows the main variable. (This will also be applied to all other tabs throughout the article.) So, the order of importance will also be extracted according to the row. For example, Karaman has more solar energy potential than Aksaray, because when Karaman is written in a row and Aksaray is written in a column, the intersection point of the two cities in the table is determined as 7. However, for the opposite case, the element at the intersection point is 1/7. When the whole table is examined in this way, it can be seen that Karaman has the greatest solar potential. This city is followed by Niğde, Konya, Aksaray, and Nevşehir, respectively.

After that, the CR value is calculated with the help of (11). This value is 0.054 for the solar energy potential criterion. A CR value that is less than 0.10 indicates consistency.

Similar to the above procedures, maximum allocated capacity values are found. The data of the maximum capacity are taken from the study in [15]. According to the data, Konya has the highest maximum capacity that can be allocated. Aksaray, Karaman, Nevşehir, and Niğde follow Konya, respectively. The comparison matrix among alternatives for the maximum allocated capacity criterion is given in Table 4.

After that, the CR value is calculated with the help of 11. This value is 0.042 for the maximum allocated capacity criterion. Since this value is also smaller than 0.10, CR of the maximum allocated capacity value is consistent.

With the same repeated operations, the surface gradient matrix is also constructed using the data from the study [17]. The generated matrix, as Table 5, is given next. According to the table, Konya has the most suitable city and is followed by Aksaray, Karaman, Niğde, and Nevşehir, respectively.

The value of the CR for the surface slope criteria is calculated with (11) and found as 0.047. It is less than 0.10, and it shows the consistency.

Equation (14) is used to combine all the results. As a result, it is found where the PVPS should be installed. Accordingly, installation should be done in the cities of Karaman, Konya, Niğde, Aksaray, and Nevşehir, respectively. The percentage values for this situation are listed as 37%, 26%, 18%, 14%, and 5%, respectively.

4.2. ELECTRE Results. In this method, the decision matrix is formed as mentioned in (15). The decision points (Aksaray, Konya, Karaman, Nevşehir, and Niğde) are put in the rows, and evaluation factors (solar energy potential, surface slope, and capacity) are put in the columns of the decision matrix. While forming the decision matrix, 2, 4, 6, 8, and 10 points are given to alternatives by considering their importance. For example, Karaman has the biggest point 10 due to having the highest solar energy potential. This city is followed by Niğde, Konya, Aksaray, and Nevşehir with 8, 6, 4, and 2 points, respectively, for the solar energy potential criterion. The decision matrix is shown in Table 6.

After forming the decision matrix, total dominance matrix called matrix E is found by doing solution steps of ELECTRE method that are shown in (16)–(25). The matrix E is shown in Table 7.

When results in Table 7 are examined, the order of importance of decision points is determined by looking at the values of 1. It is seen that Karaman is more dominant than all of the other cities. Konya and Niğde are more dominant than Aksaray and Nevşehir. It is observed that Konya and Niğde are not superior to each other. Therefore, the second choice can be Konya or Niğde. Aksaray is more dominant than Nevşehir. Nevşehir is not more dominant than any of the other cities. When the results are combined, the order of priority for the solution is found as Karaman > Konya = Niğde > Aksaray > Nevşehir.

4.3. TOPSIS Results. In this method, decision matrix is needed to obtain proximity values. Therefore, the decision matrix in Table 6 that is used in the solution with ELECTRE method is taken. After that, the solution steps of the TOPSIS method that are shown in (27)–(35) are performed. The results helping us to find the ideal decision points are obtained with calculating proximity values based on the ideal solution. They are shown in Table 8.

The alternative, which has C^* value closest to 1, is the ideal solution as mentioned in (35). According to the results in Table 8, Karaman which has the biggest C^* is the ideal city for the problem solution. This city is followed by Niğde, Konya, Aksaray, and Nevşehir, respectively.

4.4. VIKOR Results. In this method, the decision matrix in Table 6 that is used in the solution with the ELECTRE method is taken again. After that, the solution steps of VIKOR method that are shown in (36)–(40) are performed. The values of S_n, R_n, and Q_n are calculated. These values are ordered decreasingly. The results are shown in Table 9.

According to the VIKOR method, Q_n with the smallest value is expressed as the best option among the alternatives as mentioned in the solution steps of this method. When Table 9 is examined, Karaman has the smallest value of Q_n. Therefore, Karaman is the first choice among the alternatives. This city is followed by Konya, Niğde, Aksaray, and Nevşehir, respectively, for solar power plant installation by looking at the value of Q_n.

4.5. Comparative Results of All Methods. Table 10 is obtained by combining the results of the 4 MCDM methods used above. Thus, it is aimed that all the results could be seen together.

5. Conclusions

In this study, deciding on the most suitable location for a solar power plant installation is investigated. The results are obtained with the AHP, ELECTRE, TOPSIS, and VIKOR methods from MCDM submethods. The cities of Aksaray, Konya, Karaman, Nevşehir, and Niğde from the Central Anatolian Region of Turkey are selected for the study. The solar energy potential, the allocated feeder connection capacity, and the surface slope are chosen as criteria for the study. According to the chosen criteria, it has shown that Karaman has been identified as the most suitable city for solar power plant installation for all of the methods. Moreover, current practical works are also in the line with our study's results. Therefore, this is a verification of the methods used in this study and they can be proposed for a solar power plant location selection.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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