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SELECTION OF A SOLAR POWER PLANT LOCATION BY USING AHP METHOD

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Abstract

In recent years, investments of Solar Power Plant (SPP) have increased since the cost of photovoltaic has decreased. Nevertheless, feasibility studies remain important as the cost of installation is still relatively high. One of the most important parameters in the feasibility studies is the appropriate location selection. In this study, the appropriate location selection for the SPP was studied with the Analytical Hierarchy Process (AHP) which is one of the Multi Criteria Decision Making (MCDM) methods. For the application, Elazığ, Kahramanmaraş and Malatya cities, which are located on the same plane, are selected as examples. As criteria, solar energy potential, earth slopes and feeder capacities, which are important in feasibility studies, are considered. In the results of the study, Kahramanmaraş is found as the most suitable city for establishment of SPP. It is followed by the cities of Malatya and Elazığ. The results are approved by considering the sunshine duration and radiation value data of the cities in Solar Energy Potential Atlas (GEPA). It is also proven that the method can be used for SPP installations.

Key words: *Renewable energy, Solar power plant, Multi Criteria Decision Making, Analytic Hierarchy Process*

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1. Introduction

Renewable energy sources (RES) are drawn increased attention as a result of limited supply of fossil fuels and environmental concerns. They are crucial part of reducing greenhouse gases that cause climate change and polluting emissions. In energy generation processes, they do not emit greenhouse gases and it makes them the cleanest solution for prevention of environmental damage. The pace of investment in renewable energy has greatly increased since the cost of technologies falls and efficiency maintains to rise. Most renewable energy investments are spent on materials and workmanship to build and maintain facilities.

Solar energy is one of the most important RES and it has been widely used in recent years. Energy generation from solar power is growing at a rapid rate. Large-scale solar power plants are being set up by using great quantities acres of land globally. Huge investment of land, money and manpower is required to install SPPs [1]. Therefore, SPP location selection is a crucial strategic decision at installation and operation phase for investors in terms of maximizing the overall performance.

Multi Criteria Decision Making (MCDM) is one of the methodologies that is used by decision makers in determination problems. In this study, it is used to decide a suitable location for the installation of power plants. This method can be applied in many different planning problems. It defines problem, identifies the alternatives, selects the criteria, prepares the decision matrix and assigns weight to criteria [2]. Here, a number of widely used MCDM methods are listed: 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 Visa Kriterijumska Optimizacija I Kompromisno Resnje (VIKOR).

In the literature, there are many and valuable studies that use MCDM methods about determination and selection. Sindhu et al. applied AHP and TOPSIS to select appropriate site in an Indian case. They revealed that Sonepat is the best location for solar installation followed by Rohtak, Chandigarh, Gurgaon and Hisar in state of Haryana, India [1]. Sanchez-Lozano et al. used AHP to obtain the weights of the criteria and fuzzy TOPSIS to evaluate the alternatives for determination of the best location to host a solar thermoelectric power plant [2]. Balo and Şağbanşua have used AHP to select the best solar panel for the photovoltaic system design [3]. Aragones-Beltran et al. have applied ANP for the selection of photovoltaic solar power projects [4]. Aragones-Beltran et al. have applied AHP and ANP to help the managing board of a Spanish solar power investment company [5]. Guptha and Puppala have used Fuzzy Analytical Hierarchy Process for the location allocation of solar plant [6]. Samanlioglu and Ayağ have evaluated solar power plant location alternatives by integrating the Analytic Hierarchy Process and PROMETHEE II with fuzzy logic. They presented real-life case study in Turkey [7]. Uyan have used Geographic Information System (GIS) and AHP to determine suitable site selection for solar farms [8].

In this study, AHP method from MCDM is used for the study because AHP method is robust and flexible MCDM tool for dealing with complex decision problems. The most suitable city among 3 cities which are located on the same plane in Turkey is selected by using AHP method. The aim is to determine the city to get maximum power output with minimum cost. The cities of Elazığ, Kahramanmaraş and Malatya are selected as alternatives for comparison. They are chosen by considering their geographical conditions. These cities are in the same plane and their total radiation values are high and similar. Solar energy potential, earth slope and feeder capacities, which are important in feasibility studies, are considered as criteria. In the result of study, the most appropriate city for establishment of solar plant station is found for the city of Kahramanmaraş. This city is followed by Malatya and Elazığ. When the values of cities' solar duration and radiation value are examined by looking at Solar Energy Potential

Atlas (GEPA), the results are approved. Therefore, the method in this study can be used for the determination of location selection for SPP.

2. Problem Definition

The location selection of SPPs becomes increasingly crucial to the investment and has positive effect on the environment and society [9]. It is a critical problem for the system investors and planners to determine the suitable geographical areas for SPPs and install them at a proper site. Before construction of expensive solar plants, the feasible areas should be identified and prioritized.

There are a lot of criteria that have been used to determine the location of SPP. Some of them are solar radiation, infrastructural connections, distance from national highways and transmission line, site attributes, local climatic conditions, slope, etc. In this study, 3 criteria are determined: Solar energy potential, feeder capacity of distribution center and surface slope. They are main parameters for the problem to reach a more accurate result. Therefore, these criteria are selected for the study. They are explained below.

2.1. Solar Energy Potential

Solar energy potential is an important criterion for determination of SPP location. Global radiation values (kWh/m^2-day), sunshine duration (hours) and PV-type area energy generation (kWh/year) are sub-criteria of it. Sustained operation of SPP depends on sufficient solar radiation. It is very important to get accurate and readily available data whether SPP is to be established [1]. In this study, the data of global radiation value, sunshine duration and PV-type area energy generation of each city is obtained from Solar Energy Potential Atlas (GEPA) of Directorate General of Renewable Energy in Turkey [10]. These data of the cities of Elazığ, Kahramanmaraş and Malatya are shown in Fig. 1-3, respectively. According to it, the priority order among cities for solar energy potential is listed as: Kahramanmaraş, Malatya and Elazığ.

2.2. Feeder Capacity of Distribution Center

The feeder capacity of transformer center should be examined while installing energy generation facility in a region. Therefore, this data is obtained from the notification of Directorate General of Turkish Electricity Transmission Corporation (TEİAŞ) [11]. According to it, Elazığ has a number of 4, Kahramanmaraş has a number of 7 and Malatya has a number of 12 allocated capacity of feeders.

2.3. Surface Slope

One concern regarding location selection of SPPs is surface slope. Generally, lands with a slope greater than 4% have a lower priority because panels shadow the next row and affect the efficiency of system adversely [12,13]. The average slope data of the cities is obtained from the study in [14]. According to it, the priority order among cities for slope is listed as: Malatya, Elazığ and Kahramanmaraş.

3. The Proposed Method

In this study, AHP is used to solve multi-criteria problem. The main steps of AHP are the following [1].

Step 1: Firstly, the aim followed by the selection of alternatives and criteria is set.

Step 2: Paired comparisons are got for both among criteria and among alternatives using each criterion. Matrixes of pair-wise comparisons are formed by using Saaty's Fundamental Scale from 1 to 9. It is shown in Table 1 [5,15]. The comparison matrix is formed. It is (m x n) matrix for alternatives using each criterion and (n x n) matrix for criteria where m is the number of alternatives and n is the number of criteria.

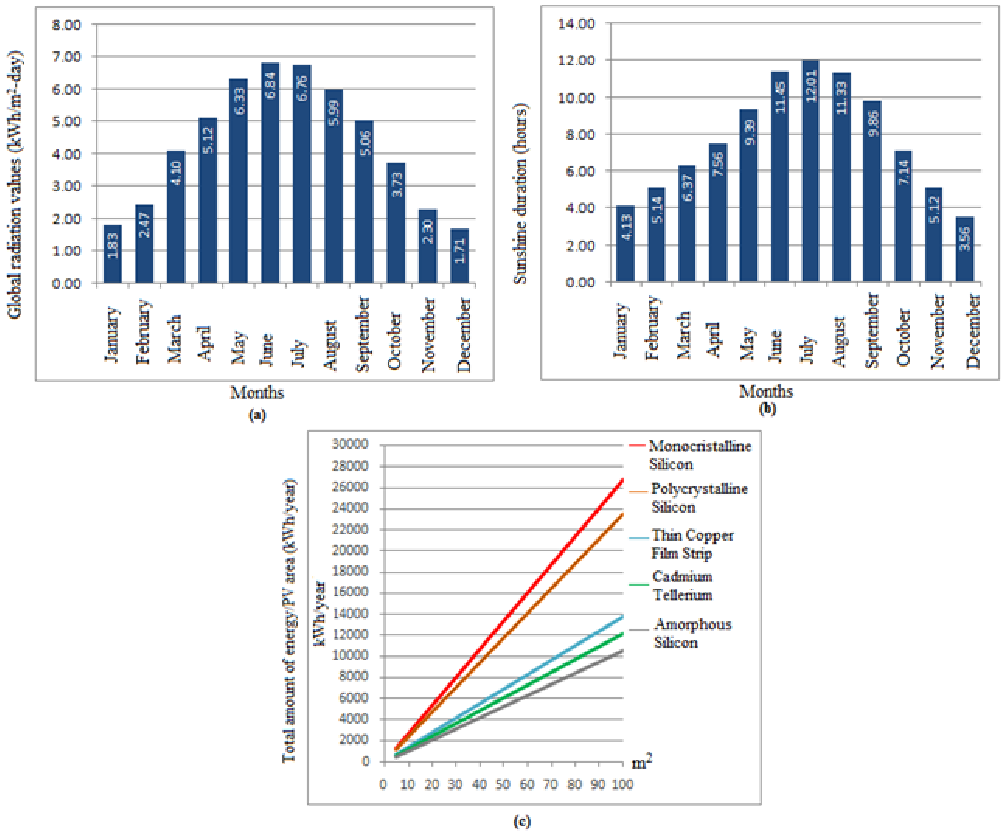

Fig. 1. a. Global radiation values of Elazığ, **b.** Sunshine duration of Elazığ
c. Total amount of Energy/ PV area of Elazığ

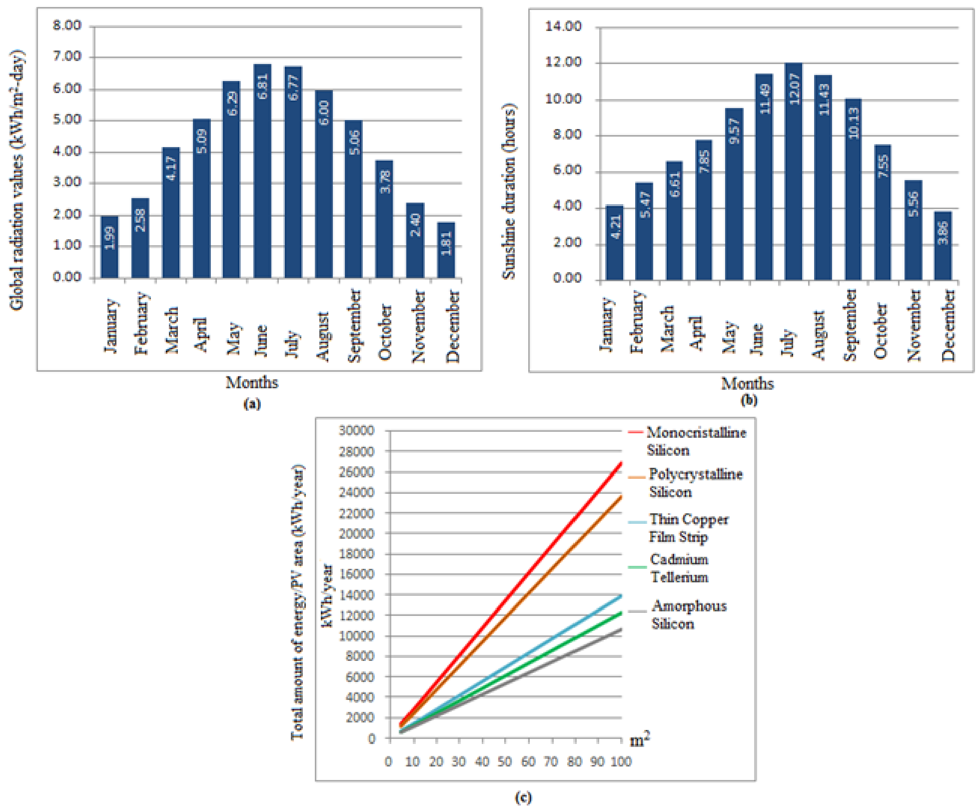

Fig. 2. a. Global radiation values of Kahramanmaraş, **b.** Sunshine duration of Kahramanmaraş
c. Total amount of Energy/ PV area of Kahramanmaraş

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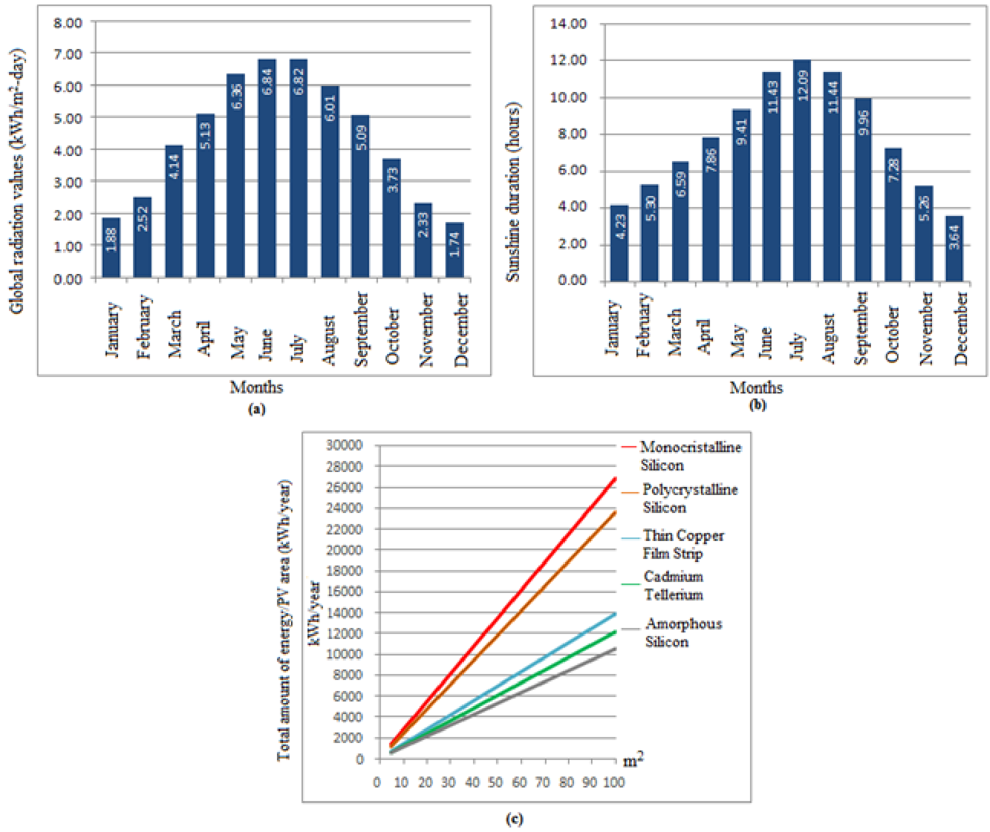

Fig. 3. a. Global radiation values of Malatya, **b.** Sunshine duration of Malatya
c. Total amount of Energy/ PV area of Malatya

Step 3: Let X_{ij} denotes the order of importance of i^{th} factor as compared to j^{th} factor. Then $X_{ji}=1/X_{ij}$. The comparison matrix is shown in Equation 1 [16].

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Table 1. Saaty's Fundemental Scale

Intensity of Importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong importance
8	Very, very strong
9	Extreme importance

Step 4: The sum of every column is calculated. Every element of the matrix is divided respectively by its obtained column sum. The average of the rows is taken to get relative weights.

Step 5: Percentage distribution of decision points is obtained by multiplying decision matrix with weighted vector of criteria.

Step 6: Consistency Index (CI) is computed using Equation 2.

$$CI = \frac{\lambda - n}{n-1} \tag{2}$$

where λ is Eigenvalue of paired comparison matrix.

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Step 7: In final step, Consistency Ratio (CR) is calculated using Equation 3 and percentage distribution of decision points is obtained by multiplying decision matrix with weighted vector of criteria.

$$CR = \frac{CI}{RI} \tag{3}$$

Table 2. RI Values

n	RI	n	RI
1	0	7	1.35
2	0	8	1.40
3	0.52	9	1.45
4	0.89	10	1.49
5	1.11	11	1.51
6	1.25	12	1.54

where RI is referred as Random Index and takes different values by the number of criteria. RI values are shown in Table 2 [5].
If CR is less than 0.10, the comparisons are acceptable [17]. Otherwise, the judgment in decision matrix should be reviewed.

4. Case Study

In this study, AHP is applied to establish the location of SPPs for suggested cities. These cities are the alternatives of the problem and decided as Elazığ, Malatya and Kahramanmaraş. The criteria of the problem are determined as solar energy potential, feeder capacity of distribution center and surface slope.
The comparison matrix for solar energy potential is formed as shown in Table 3. As mentioned before, Kahramanmaraş has the highest solar energy potential. Malatya and Elazığ follows it, respectively.
The comparison matrix for surface slope is formed as shown in Table 4. The province with the smallest slope is Malatya so it is selected as the primary province. Elazığ and Kahramanmaraş follow it, respectively.

Table 3. Comparison Matrix for Solar Energy Potential

Solar Energy Potential	Elazığ	Kahramanmaraş	Malatya
Elazığ	1	1/7	1/5
Kahramanmaraş	7	1	3
Malatya	5	1/3	1

Table 4. Comparison Matrix for Surface Slope

Surface Slope	Elazığ	Kahramanmaraş	Malatya
Elazığ	1	5	1/3
Kahramanmaraş	1/5	1	1/7
Malatya	3	7	1

The comparison matrix for allocated maximum feeder capacity is formed as shown in Table 5. Elazığ has a number of 4, Kahramanmaraş has a number of 7 and Malatya has a number of 12 allocated capacity of feeders, as mentioned before. Therefore, Malatya is selected as the primary province for feeder capacity criteria. Kahramanmaraş and Elazığ follow it, respectively.
The comparison matrix for criteria is formed as shown in Table 6. The priority order among criteria is determined as solar energy potential, feeder capacity and surface slope, respectively.

Table 5. Comparison Matrix for Feeder Capacity

Feeder Capacity	Elazığ	Kahramanmaraş	Malatya
Elazığ	1	1/5	1/7
Kahramanmaraş	5	1	1/3
Malatya	7	3	1

Table 6. Comparison Matrix for Criteria

Criteria	Solar Energy Potential	Surface Slope	Feeder Capacity
Solar Energy Potential	1	5	3
Surface Slope	1/5	1	1/2
Feeder Capacity	1/3	2	1

The weights of each criteria is obtained as 0.65 for solar energy potential criterion, 0.12 for surface slope criterion and 0.23 for feeder capacity criterion.
The values of CR are calculated as less than 0.10 for all comparison matrixes, which shows the consistency by applying Equations 2-3.

After all the steps of AHP carried out, percentage distribution of alternatives is obtained. Kahramanmaraş has 49%, Malatya has 41% and Elazığ has 10% share.

5. Conclusions

In this study, the location selection of SPPs is studied for optimal installation. AHP from MCDM methods is used for this work. The cities of Elazığ, Kahramanmaraş and Malatya in Turkey, which are located on the same plane, are selected as examples. It is decided that which city is the most suitable location for a SPP installation. Solar energy potential, allocated feeder capacity and surface slope are determined as criteria for the study. In the result, Kahramanmaraş is found as the most suitable city for establishment of SPPs. It can be verified by considering its having the biggest value of solar duration and radiation value among cities. Therefore, it is proved that AHP method can deal with this problem efficiently and it can be used for other provinces and other renewable energy systems such as hydroelectric and wind power plants.

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