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Evaluation of the Effective Factors in Locating a Photovoltaic Solar Power Plant Using Fuzzy Multi-Criteria Decision-Making Method

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ABSTRACT

The energy of processes is mainly supplied by fossil fuels. Short life of fossil energy sources and increasing environmental pollution caused by fossil fuels and increasing demand have made researchers introduce new solutions for supply of energy. Energy production in a photovoltaic solar power plant is cost-effective due to being clean and renewable. The power generation of these plants is affected by their site due to climate conditions, effective radiation periods, and the rate of solar radiation absorption. Therefore, finding the optimal location to establish a solar power plant is important. Identifying effective location criteria and the importance of these criteria is effective in choosing the optimal location.In this research, in the first phase, the effective criteria in locating a photovoltaic solar power plant were investigated based on the Delphi method. Then, in the second phase, based on the criteria identified in the first phase, fuzzy hierarchy method was used to compare the criteria with each other and determine the importance of each of them. The results of the study showed that the rate of solar radiation and average temperature were the most important criteria in locating photovoltaic solar power plant. Moreover, the criteria of slope, distance to main roads, distance to power lines, and land use were of highest importance in locating a photovoltaic solar power plant.

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1. INTRODUCTION

Almost all processes are performed through using energy [1]. Fossil fuels are sources for supply of energy, but they cause environmental pollution in proportion to their use. In addition, increasing growth of population and increasing energy demand have made energy suppliers seek alternative energy sources [2]. Solar energy is a clean and renewable source that is suitable for meeting global energy needs. As energy production affects all aspects of the social, economic, and environmental aspects [3], the criteria for selecting the optimal site for the construction of a photovoltaic solar power plant should be in accordance with these aspects. Identifying and investigating the role (and its extent) of the influential criteria in locating a photovoltaic solar power plant is essential for more and better energy absorption [4]. Fuzzy multi-criteria decision-making methods are used to examine different aspects of locating in the uncertainty state. Thus, they can help managers achieve optimal site.

One of the multi-criteria decision-making methods is the hierarchical method. Some of the advantages of using the hierarchical method can be mentioned in the following:

1) Breaking the problem into different levels that lead to more precise and better decision-making.
2) More accurate recognition of the level relationship of criteria related to the problem [5].

Many studies have been conducted on the location of solar power plants using decision-making techniques. Some of these studies are listed in Table 1.

In this research, in the first phase, the effective criteria in locating a photovoltaic solar power plant were identified using Delphi methods. In order to recognize the criteria, a questionnaire proportionate for the studies mentioned in Table 1 was designed and distributed among the experts of solar power plants. The following questionnaires were designed and distributed according to the consensus of experts. Eventually, the effective criteria for the location of photovoltaic solar power plants were determined and collected. Then, in the second phase, the problem was broken into three levels by the fuzzy hierarchy method and investigated. Aim of the problem, group, and criteria were placed in the first, second, and third levels, respectively. In this phase, the experts were asked to perform the paired comparisons among the criteria. By adding the data to the Super Decision software using a hierarchical method, the calculations were done using hierarchical method. Finally, the importance of these criteria over each other was determined.

2. LITERATURE REVIEW AND BACKGROUND OF THE STUDY

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Locating is the optimal selection of sites for a specific purpose based on certain criteria. Selecting a suitable site for a photovoltaic solar power plant reduces the cost of energy production and transfer [5]. One of the technologies for using solar energy is photovoltaic systems. Photovoltaic systems consist of semiconducting devices that absorb the sunlight and store energy through the battery [1]. As there are some criteria with a varying degree of importance in locating a photovoltaic solar power plant, examining the importance of each of these criteria is necessary. A fuzzy hierarchical method can be used to determine the importance of the criteria involved in locating a photovoltaic solar power plant and comparing these criteria. A fuzzy hierarchical method is one of the multi-criteria decision-making methods [30].

Table 1. Applications of multi-criteria decision-making techniques in different studies

Method	RES	Location	Reference
AHP & GIS	GPPPs	Southern Spain	[6]
GIS	Solar PV and wind	Colorado	[7]
GIS	PV	Oman	[8]
GIS & AHP	PV	Konya/Turkey	[3]
GIS & MCDM	PV	Cartagena/Southeast Spain	[9]
GIS & Fuzzy	Solar PV and wind	Turkey	[10]
AHP	PV	Egypt	[11]
GIS & Electere3	PV	Murcia/Southeast Spain	[12]
MCDM	Solar PV and wind	Southern England	[13]
GIS & MCDM	PV	Southeast of Spain	[14]
GIS	PV	Nigeria	[15]
GIS	PV	Morocco	[5]
GIS	PV	United Arab Emirates	[16]
GIS & AHP	PV	Spain	[17]
GIS & MCDM	Solar PV and wind	Afghanistan	[18]
AHP & FTOPSIS	PV	India	[19]
GCP	PV	Northwest China	[20]
GIS & MCDM	PV & CSP	Africa	[21]
GIS	PV	Malaysia	[22]
GIS & AHP	PV	Saudi Arabia	[23]
FAHP	PV	Iran	[24]
Gray Number	PV	Global	[25]
GIS & MCDM	PV & CSP	West Africa	[26]
DEA	PV	Iran	[27]
GIS & MCDM	PV	Mauritius	[28]
GIS & MCAM	PV	The State of Arizona	[29]

Several studies have been conducted to identify the effective factors in locating a photovoltaic solar power plant. Suitable criteria for locating a photovoltaic solar power plant were distance from the river, population density, and distance from the main roads, slope, flood, earthquake, and solar radiation. Ref. [10] considered distance from power lines, distance from urban areas, and slope and direction as suitable criteria for locating a photovoltaic solar power plant. In Ref. [12], land use, distance from river, distance from villages, distance from power lines, distance from transporting stations, distance from urban areas, and distance from main roads, slope, slope direction and average temperature were effective criteria for locating a photovoltaic solar power plant. In Ref. [16], the slope, the direction of slope, the distance from the main road, and the average temperature were considered as effective criteria for locating photovoltaic solar power plant. Ref. [23] considered land use, distances from power lines, distance from urban areas, distance from main lines, slope, solar radiation, and average temperatures as effective criteria in locating a photovoltaic solar power plant. Ref. [25] considered the criteria of land use, distance from river, distance from stations, flood, storm, earthquake, and solar radiation as suitable criteria for locating a photovoltaic solar power plant. In Ref. [31], the criteria for locating a photovoltaic solar power plant were reported to be distance from river, distance from power lines, distance from main roads, the slope, and the rate of solar radiation. In Ref. [28], the distance from main lines, slope, rate of solar radiation, average temperature, and humidity were effective criteria for locating the photovoltaic solar power plant. In Ref. [29], land use, distance from river, distance from main lines, flood, storm, and earthquake were considered as effective criteria for locating the photovoltaic solar power plant.

A review of previous research papers in this field indicates that they have only dealt with the location of solar power plants using decision methods and GIS software; however, the present study first employs the Delphi method, comprehensive criteria, and appropriate water conditions. Then, the climate of the study area is considered. In addition, the location of the solar power plant and the importance of these criteria are examined.

3. METHOD

3.1. Methodology

This study was conducted in two phases. First, effective criteria for locating a photovoltaic solar power plant were identified based on the conducted studies and the views of experts in this area using the Delphi method. Then, in the second phase, using the fuzzy hierarchical method, the importance of each criterion was examined. Additionally, the criteria were compared with each other. Figure 1 illustrates the phases of the research method.

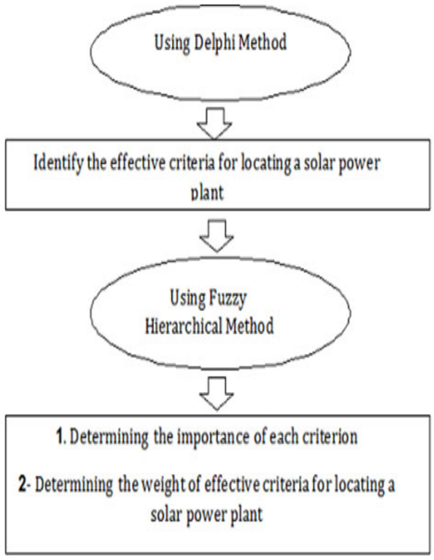

Figure 1. Research phases

3.1.1. Delphi method

The Delphi method is one of the methods used for gaining group knowledge. It is applied to making decision in qualitative issues. The Delphi method is used to collect experts' views to reach a consensus on the importance of decision making criteria for locating a photovoltaic solar power plant. The steps in the Delphi method are as follows [32]:

Step 1: Identification of criteria for locating a photovoltaic solar power plant.

At this step, the criteria related to locating solar power plant are identified using a comprehensive review of the theoretical principles of criteria, previous studies, and the views of the experts.

Step 2: Selection of the number of decision-makers.

The views of the experts participating in the Delphi method play a central role in identifying efficient criteria for locating a photovoltaic solar power plant. The participants comprised 60 experts in the area of distribution, generation, operation, and installation of photovoltaic solar power plants.

Step 3: Distribution of questionnaire.

First, a questionnaire containing the criteria extracted from previous studies and experts' views was prepared. In distributing the questionnaire, the experts were asked to express their views on the importance and quality of the criteria for locating the photovoltaic solar power plant and to add new criteria, if needed. Then, the next modified questionnaire based on the information extracted from the total responses to the first questionnaire was designed and re-distributed among experts. The number of repetitions of the distribution of the questionnaire to determine the criteria depends on Kendall's coefficient of concordance, calculated at each step.

Step 4: Determining the level of consensus.

At this step, using Kendall's coefficient of concordance derived from Equation (1), the level of consensus among decision-makers is determined. As the value of this coefficient gets closer to 1, it would indicate high consensus among the decision-makers and thus, the final questionnaire and the criteria in the final questionnaire could be identified as selection criteria. Moreover, Delphi method would stop when the value of the Kendall's coefficient of concordance be at least 0.95.

$$W = \frac{12s}{m^2(n^2-n)} \quad (1)$$

where W indicates the Kendall's coefficient of concordance, s is the sum of the total deviations squared, n is the number of ranked criteria, and m is the number of ranked groups.

3.1.2. Fuzzy analytic hierarchy process

In multi-criteria decision-making methods, multiple criteria are used rather than one criterion for decision making [33]. Multi-criteria decision-making methods reduce decision-making costs and increase decision-making accuracy and provide a good framework for solving problems [34]. Fuzzy Analytic Hierarchy Process is one of the multi-criteria decision-making methods based on experts' views. In the Fuzzy Analytic Hierarchy Process, it is possible to define problem criteria as a hierarchical structure and determine the importance of each criterion by making a paired comparison between the criteria [30].

The steps of the fuzzy hierarchy process are as follows [35]:

Step 1: Drawing a hierarchical chart.

At this step, the objective is considered at Level 1 and the criterion is placed at Level 2 of the chart. Figure 2 illustrates the hierarchy of the objective as well as the structure of the hierarchy of criteria and sub-criteria.

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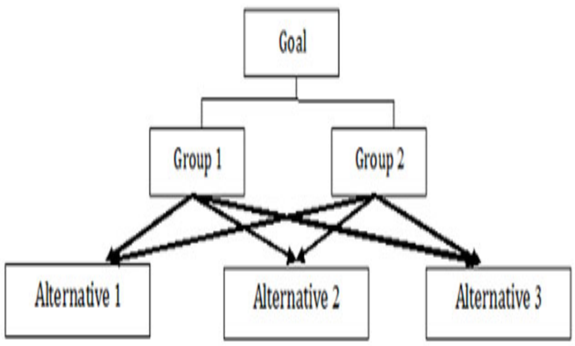

Figure 2. Hierarchical chart

Step 2: Defining fuzzy numbers.

At this step, the pairwise comparisons of sub-criteria expressed as linguistic variables based on experts' views are expressed as fuzzy numbers for mathematical calculations. The theory of fuzzy sets has been proposed to solve the non-accurate issues that exist in real world. A triangular fuzzy number is denoted by $\tilde{M} = (l, m, u)$. The membership function $\mu_{\tilde{M}}(x)$ is also in the form of Equation (2).

$$\mu_{\tilde{M}}(x) = \begin{cases} \frac{x-l}{m-l} & l \le x \le m \\ \frac{u-x}{u-m} & m \le x \le u \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

L is lower limit, m is the part that has the maximum membership degree, and u is also the upper limit of the fuzzy number $\tilde{M}$ [36].

If a (a_1, a_2, a_3) and b (b_1, b_2, b_3) are two triangular fuzzy numbers, a = b is when $a_1=b_1$, a = b, $a_3=b_3$. The mathematical relations between fuzzy numbers are shown in Equations (3) and (4) [37].

$$A + B = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \quad (3)$$

$$a \times b = (a_1b_1, a_2b_2, a_3b_3) \qquad \text{if } a_1, b_1 \ge 0 \quad (4)$$

Table 2 indicates the linguistic variables used to evaluate the importance of the criteria in the pairwise comparison.

Table 2. Linguistic variables for evaluating the importance of criteria [38]

Fuzzy number	Importance
(0.1,0.1,0.2)	Very low
(0.1,0.3,0.5)	Low
(0.2,0.5,0.8)	Moderate
(0.5,0.7,1)	High
(0.7,1,1)	Very high

Step 3: Formation of a pairwise comparison matrix.

The pairwise comparison matrix of the criteria is formed using the fuzzy numbers of Table 1. The pairwise comparison matrix was in the form of Equation (5).

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} \quad (5)$$

One of the most important features of a paired comparison matrix is as follows:

$$\tilde{a}_{ji} = \frac{1}{\tilde{a}_{ij}} \quad (6)$$

where $\tilde{a}_{ij}$ represents the importance of the i^{th} criterion rather than j^{th} criterion.

Step 4: Calculating the value of each alternative compared to each criteria.

For each row of the pairwise comparison matrix, the value of S_i has been calculated by Equation (10).

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (7)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (8)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (9)$$

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (10)$$

where $M_i = (l_i, m_i, u_i)$ is a triangular fuzzy number inside the pairwise comparisons matrix; u_i, m_i, and l_i are the upper, middle, and upper triangular fuzzy numbers of M_i, respectively. In computing the matrix S, each of the components of the fuzzy number is summed up and multiplied by the inverse fuzzy of the sum total.

Step 5: Ranking.

At this step, if $S_1 = (l_1, m_1, u_1)$ and $S_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of S_1 versus S_2 can be calculated as in Equation (11).

$$V(S_1 \ge S_2) = \begin{cases} 1 & \text{if } m_1 \ge m_2 \\ 0 & \text{if } l_2 \ge u_1 \\ \frac{l_2-u_1}{(m_1-u_1)-(m_2-l_2)} & \text{otherwise} \end{cases} \quad (11)$$

Step 6: Calculating the weight of the criteria in the pairwise comparisons matrix.

At this step, the weight of the criteria is calculated using Equation (12) and the non-normalized weight is obtained.

$$d'(A_i) = \text{Min } V(S_i \ge S_k) \qquad k = 1, 2, \ldots, n \qquad k \ne i \quad (12)$$

Step 7: Calculating the final weight vector.

The final weight vector of each criterion was derived by dividing the non-normalized weight of each criterion by the sum of non-normalized weights of the total criteria.

4. ANALYSIS OF THE RESULTS

In this research, three types of questionnaires were used to collect the data. First, the first questionnaire was developed based on theoretical foundations and previous research on locating the solar photovoltaic power plant. Table 3 presents a number of photovoltaic solar power plant locating studies along with locating criteria.

Table 3. Solar PV site suitability criteria

References	Criteria	Group
Climatology	Solar irradiation	[6, 7, 8, 23, 24, 25, 26, 27,28,31, 39]
	Average temperature	[3, 8, 9,12,14, 16, 17, 23, 28,40,41]
	Wetland	[28]
Topography	Orientation slope	[3, 6, 9, 10, 11, 12, 16, 42]
	Slope	[3, 6, 9,10,11,12,14,16, 17, 23, 28, 31]
Economic-Social	Distance to main roads	[5,6, 7, 8, 9, 12,13,14,15,17, 22, 23, 24, 26, 28, 29,31]
	Distance to urban	[3,6, 7, 9,10, 11, 12,13,17,23]
	Population density	[8,22,26,27,43]
	Transformer substation	[12]
Electrical issue	Distance to substations	[9, 12, 14, 17, 25]
	Distance to power line	[3, 5,6, 7, 8, 9, 10, 11, 12, 13,14,15,17, 22,23, 6, 40,44,45]
	Distance to village	[12]
Environment	Distance to river	[12,25,29,31]
	Land use & cover	[3,6,7,12,22,23,24,25,29,42,43]

A questionnaire was distributed among 60 experts in the solar power plant location and they were asked to classify the criteria and express their views on the importance and quality of the criteria. After collecting the questionnaire and entering the data in SPSS software, Kendall's coefficient of concordance was calculated 0.68. Then, another questionnaire was designed according to the information extracted from the first questionnaire and distributed among the experts. In the second questionnaire, the criteria increased and changed. The value of Kendall's coefficient of concordance of the second questionnaire was calculated as 0.87. The third questionnaire was designed and distributed according to the views of experts. The Kendall's coefficient of concordance was calculated as 0.95; therefore, the Delphi method stopped. Accordingly, the criteria were classified into five groups of topography, environment, climatological, socioeconomic, power distribution lines. The information derived from the third questionnaire is presented in Table 4.

Table 4. Effective criteria for locating a photovoltaic solar power plant

Group	Climatology	Environment	Electrical issues	Economic-Social	Topography
Criteria	Average temperature	Distance to river	Distance to power posts	Distance to main roads	Fault
	Solar irradiation			Distance to urban	Slope
	Wetland	Land use	Distance to power line	Distance to village	Height
	Evaporation				

After identifying the criteria using the Delphi method, in the second phase, the importance of each of the criteria has been determined using the fuzzy hierarchical analysis method. The reason for the importance of each criterion is presented in Table 5.

Table 5. The type of the effect of criteria on locating a photovoltaic solar power plant

Group	Criteria	Type of effect in locating
Economic-Social	Distance to main roads	The proximity of solar power plant to main roads will reduce the cost
	Distance to urban	It can be used to supply power and human resource
	Distance to village	It can be used to supply power and human resource
Climatology	Solar irradiation	More solar radiation will generate more electrical energy
	Average temperature	As average temperature of environment increases, the power of solar panels decreases
	Evaporation	Increasing evaporation reduces the power of solar panels.
	Wetland	Increasing the humidity reduces the power of solar panels
Electrical issues	Distance to power line	Proximity of power plant to power transmission lines reduces the cost
	Distance to power posts	Proximity of power plant to power transmission posts reduces the cost.
Environment	Land use	It reduces the environmental damages
	Distance to river	As the distance of power plant to river increases, future costs will decrease
Topography	Fault	As the distance of power plant to fault increases, future costs will decrease
	Slope	As slope is lower, the power of solar panels will be higher
	Height	By increasing the height, the power of solar panels will increase

Based on the factors and criteria identified in the Delphi method, the hierarchical chart for determining the importance of criteria for locating photovoltaic solar power plants was plotted at three levels. The first level was related to the goal of the problem, the second level to the group, and the third level to criteria. Figure 3 represents the hierarchical chart of these three levels. The identified criteria for locating a photovoltaic solar power plant included five groups of socioeconomic, climatological, topographic, environment, and electrical energy related issues such as distance to village (C1), distance to electricity posts (C2), distance to urban areas (C3), distance to river (C4), height (C5), fault (C6), evaporation (C7), humidity (C8), distance to power lines (C9), land use (C10) distance to main roads (C11), mean temperature (C12), rate of solar radiation (C13), and slope (C14).

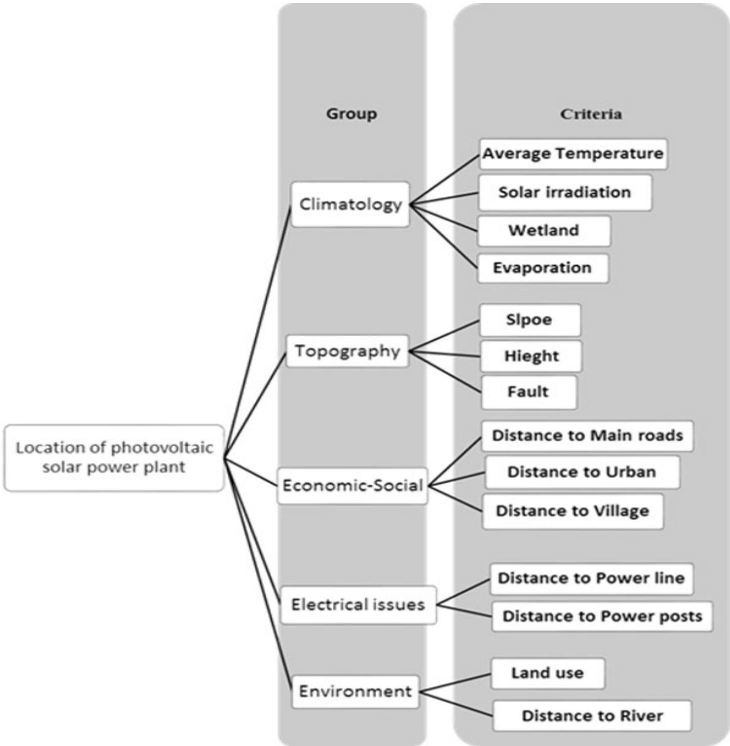

Figure 3. Hierarchical chart of locating a photovoltaic solar power plant

After plotting the hierarchical chart, decision-makers were asked to compare the criteria with each other and to express the relative importance of the elements using the linguistic variables of Table 2. By adding data to the Super Decision software, the weight of each criterion was extracted and the results are presented in Table 6.

Table 6. The matrix of pairwise comparisons of sub-criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
C_1	(1,1,1)	(5,10,10)	(1,1,1.4)	(5,10,10)	(1,1.4,2)	(2,3.3,10)	(1,1,1.4)	(1,1.4,2)	(1,1,1.4)	(1,1.4,2)	(2,3.3,10)	(5,10,10)	(5,10,10)	(2,3.3,10)
C_2	(0.1,0.1,0.2)	(1,1,1)	(2,3.3,10)	(1,1,1.4)	(1.25,2,5)	(1,1.4,2)	(2,3.3,10)	(1.25,2,3.3)	(2,3.3,10)	(1.25,2,5)	(1,1.4,2)	(1,1,1.4)	(1,1,1.4)	(1,1.4,2)
C_3	(0.7,1,1)	(0.1,0.3,0.5)	(1,1,1)	(5,10,10)	(1.25,2,5)	(2,3.3,10)	(1,1.4,2)	(1.25,2,3.3)	(1,1.4,2)	(1.25,2,3.3)	(2,3.3,10)	(5,10,10)	(5,10,10)	(2,3.3,10)
C_4	(0.1,0.1,0.2)	(0.7,1,1)	(0.1,0.1,0.2)	(1,1,1)	(1.25,2,5)	(1,1.4,2)	(2,3.3,10)	(1.25,2,5)	(2,3.3,10)	(1.25,2,5)	(1,1.4,2)	(1,1,1.4)	(1,1,1.4)	(1,1.4,2)
C_5	(0.5,0.7,1)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(1,1,1)	(1,1.4,2)	(2,3.3,10)	(1.25,2,5)	(2,3.3,10)	(1.25,2,5)	(1,1.4,2)	(1,1,1.4)	(1,1,1.4)	(1,1.4,2)
C_6	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.5,0.7,1)	(1,1,1)	(2,3.3,10)	(1.25,2,5)	(2,3.3,10)	(1.25,2,5)	(1,1.4,2)	(1,1,1.4)	(1,1,1.4)	(1,1.4,2)
C_7	(0.7,1,1)	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(1,1,1)	(1.25,2,5)	(1,1.4,2)	(1.25,2,5)	(2,3.3,10)	(5,10,10)	(5,10,10)	(2,3.3,10)
C_8	(0.5,0.7,1)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(1,1,1)	(2,3.3,10)	(1.25,2,5)	(1,1.4,2)	(1,1,1.4)	(1,1,1.4)	(1,1.4,2)
C_9	(0.7,1,1)	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.1,0.3,0.5)	(1,1,1)	(1.25,2,5)	(2,3.3,10)	(5,10,10)	(5,10,10)	(2,3.3,10)
C_{10}	(0.5,0.7,1)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(1,1,1)	(1,1.4,2)	(1,1,1.4)	(1,1,1.4)	(1,1.4,2)
C_{11}	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.5,0.7,1)	(0.5,0.7,1)	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.1,0.3,0.5)	(0.5,0.7,1)	(1,1,1)	(1,1,1.4)	(1,1,1.4)	(1,1.4,2)
C_{12}	(0.1,0.1,0.2)	(0.7,1,1)	(0.1,0.1,0.2)	(0.7,1,1)	(0.7,1,1)	(0.7,1,1)	(0.1,0.1,0.2)	(0.7,1,1)	(0.1,0.3,0.5)	(0.7,1,1)	(0.7,1,1)	(1,1,1)	(1,1,1.4)	(1,1.4,2)
C_{13}	(0.1,0.1,0.2)	(0.7,1,1)	(0.1,0.1,0.2)	(0.7,1,1)	(0.7,1,1)	(0.7,1,1)	(0.1,0.1,0.2)	(0.7,1,1)	(0.1,0.1,0.2)	(0.7,1,1)	(0.7,1,1)	(0.7,1,1)	(1,1,1)	(1,1.4,2)
C_{14}	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.5,0.7,1)	(0.5,0.7,1)	(0.1,0.3,0.5)	(0.5,0.7,1)	(0.1,0.3,0.5))	(0.5,0.7,1)	(0.5,0.7,1)	(0.5,0.7,1)	(0.5,0.7,1)	(1,1,1)

According to Equations (7) to (10), the value of S_i was calculated for each row of the pairwise comparison matrix. The general results of calculations are given in Table 7.

$$\sum_{i=1}^{14}\sum_{j=1}^{14} M_{gi}^{j} = (205.25, 331.1, 547.3)$$

$$\left[\sum_{i=1}^{14}\sum_{j=1}^{14} M_{gi}^{j}\right]^{-1} = (0.0018, 0.003, 0.0048)$$

Table 7. Mean value of each criterion

S_1	S_2	S_3	S_4	S_5	S_6	S_7
(0.0096,0.022,0.045)	(0.019,0.055,0.101)	(0.011,0.028,0.092)	(0.028,0.085,0.15)	(0.016,0.042,0.12)	(0.02,0.061,0.16)	(0.022,0.057,0.23)
S_8	**S_9**	**S_{10}**	**S_{11}**	**S_{12}**	**S_{13}**	**S_{14}**
(0.022,0.056,0.17)	(0.026,0.067,0.28)	(0.026,0.065,0.22)	(0.03,0.075,0.27)	(0.053,0.15,0.25)	(0.053,0.15,0.25)	(0.032,0.08,0.28)

At this step, according to Equation (11), for each criterion, the degree of preference of Si over Sk was obtained and the results are presented in Table 8.

According to the values given in Table 8, each of the ratios was calculated for each row according to Equation (12). The weights presented in Table 8 were normalized by dividing each weight by the total weights. The results of calculation are given in Table 9.

Table 8. Comparison of the mean value of each criterion

$S_1>S_2$	0.43	$S_2>S_1$	1	$S_3>S_1$	1	$S_4>S_1$	1	$S_5>S_1$	1	$S_6>S_1$	1	$S_7>S_1$	1
$S_1>S_3$	0.85	$S_2>S_3$	1	$S_3>S_2$	0.72	$S_4>S_2$	1	$S_5>S_2$	0.89	$S_6>S_2$	1	$S_7>S_2$	1
$S_1>S_4$	0.21	$S_2>S_4$	0.76	$S_3>S_4$	0.53	$S_4>S_3$	1	$S_5>S_3$	1	$S_6>S_3$	1	$S_7>S_3$	1
$S_1>S_5$	0.57	$S_2>S_5$	1	$S_3>S_5$	0.83	$S_4>S_5$	1	$S_5>S_4$	0.7	$S_6>S_4$	0.84	$S_7>S_4$	0.85
$S_1>S_6$	0.39	$S_2>S_6$	1.03	$S_3>S_6$	0.69	$S_4>S_6$	1	$S_5>S_6$	0.86	$S_6>S_5$	1	$S_7>S_5$	1
$S_1>S_7$	0.47	$S_2>S_7$	1	$S_3>S_7$	0.76	$S_4>S_7$	1	$S_5>S_7$	0.94	$S_6>S_7$	1	$S_7>S_6$	0.95
$S_1>S_8$	0.39	$S_2>S_8$	1.08	$S_3>S_8$	0.7	$S_4>S_8$	1	$S_5>S_8$	0.77	$S_6>S_8$	1	$S_7>S_8$	1.43
$S_1>S_9$	0.29	$S_2>S_9$	0.93	$S_3>S_9$	0.62	$S_4>S_9$	1	$S_5>S_9$	0.8	$S_6>S_9$	0.94	$S_7>S_9$	1.47
$S_1>S_{10}$	0.29	$S_2>S_{10}$	0.96	$S_3>S_{10}$	0.63	$S_4>S_{10}$	1	$S_5>S_{10}$	0.82	$S_6>S_{10}$	0.95	$S_7>S_{10}$	1.43
$S_1>S_{11}$	0.2	$S_2>S_{11}$	0.85	$S_3>S_{11}$	0.56	$S_4>S_{11}$	1	$S_5>S_{11}$	0.75	$S_6>S_{11}$	0.89	$S_7>S_{11}$	1.46
$S_1>S_{12}$	1	$S_2>S_{12}$	0.35	$S_3>S_{12}$	0.24	$S_4>S_{12}$	0.59	**$S_5>S_{12}$**	**0.42**	$S_6>S_{12}$	0.54	**$S_7>S_{12}$**	**0.63**
$S_1>S_{13}$	1	**$S_2>S_{13}$**	**0.34**	**$S_3>S_{13}$**	**0.23**	**$S_4>S_{13}$**	**0.58**	$S_5>S_{13}$	0.42	**$S_6>S_{13}$**	**0.54**	$S_7>S_{13}$	0.64
$S_1>S_{14}$	**0.17**	$S_2>S_{14}$	0.61	$S_3>S_{14}$	0.53	$S_4>S_{14}$	1	$S_5>S_{14}$	0.72	$S_6>S_{14}$	0.86	$S_7>S_{14}$	0.86
$S_8>S_1$	1	$S_9>S_1$	1	$S_{10}>S_1$	1	$S_{11}>S_1$	1	$S_{12}>S_1$	1	$S_{13}>S_1$	1	$S_{14}>S_1$	1
$S_8>S_2$	1	$S_9>S_2$	1	$S_{10}>S_2$	1	$S_{11}>S_2$	1	$S_{12}>S_2$	1	$S_{13}>S_2$	1	$S_{14}>S_2$	1
$S_8>S_3$	1	$S_9>S_3$	1	$S_{10}>S_3$	1	$S_{11}>S_3$	1	$S_{12}>S_3$	1	$S_{13}>S_3$	1	$S_{14}>S_3$	1
$S_8>S_4$	0.79	$S_9>S_4$	0.94	$S_{10}>S_4$	0.9	$S_{11}>S_4$	0.96	$S_{12}>S_4$	1	$S_{13}>S_4$	1	$S_{14}>S_4$	0.98
$S_8>S_5$	1	$S_9>S_5$	1	$S_{10}>S_5$	1	$S_{11}>S_5$	1	$S_{12}>S_5$	1	$S_{13}>S_5$	1	$S_{14}>S_5$	1
$S_8>S_6$	0.98	$S_9>S_6$	1	$S_{10}>S_6$	1	$S_{11}>S_6$	1	$S_{12}>S_6$	1	$S_{13}>S_6$	1	$S_{14}>S_6$	1
$S_8>S_7$	1	$S_9>S_7$	1	$S_{10}>S_7$	1	$S_{11}>S_7$	1	$S_{12}>S_7$	1	$S_{13}>S_7$	1	$S_{14}>S_7$	1
$S_8>S_9$	0.93	$S_9>S_8$	1	$S_{10}>S_8$	1	$S_{11}>S_8$	1	$S_{12}>S_8$	1	$S_{13}>S_8$	1	$S_{14}>S_8$	1
$S_8>S_{10}$	0.94	$S_9>S_{10}$	1	$S_{10}>S_9$	0.98	$S_{11}>S_9$	1	$S_{12}>S_9$	1	$S_{13}>S_9$	1	$S_{14}>S_9$	1
$S_8>S_{11}$	0.88	$S_9>S_{11}$	0.97	$S_{10}>S_{11}$	0.95	$S_{11}>S_{10}$	1	$S_{12}>S_{10}$	1	$S_{13}>S_{10}$	1	$S_{14}>S_{10}$	1
$S_8>S_{12}$	0.56	**$S_9>S_{12}$**	**0.73**	**$S_{10}>S_{12}$**	**0.66**	**$S_{11}>S_{12}$**	**0.74**	$S_{12}>S_{11}$	1	$S_{13}>S_{11}$	1	$S_{14}>S_{11}$	0.77
$S_8>S_{13}$	**0.55**	$S_9>S_{13}$	0.73	$S_{10}>S_{13}$	0.66	$S_{11}>S_{13}$	0.74	**$S_{12}>S_{13}$**	**1**	**$S_{13}>S_{12}$**	**1**	**$S_{14}>S_{12}$**	**0.77**
$S_8>S_{14}$	0.85	$S_9>S_{14}$	0.95	$S_{10}>S_{14}$	0.93	$S_{11}>S_{14}$	0.95	$S_{12}>S_{14}$	1	$S_{13}>S_{14}$	1	$S_{14}>S_{13}$	1

Table 9. Normalized weight of criteria

	Criteria	Normalized weight	Ranking
C_1	Distance to village	0.02	13
C_2	Distance to power posts	0.04	11
C_3	Distance to urban	0.027	12
C_4	Distance to rives	0.07	7
C_5	Height	0.05	10
C_6	Fault	0.064	9
C_7	Evaporation	0.075	6
C_8	Wetland	0.065	8
C_9	Distance to power line	0.087	4
C_{10}	Land use	0.078	5
C_{11}	Distance to main roads	0.088	3
C_{12}	Average temperature	0.12	1
C_{13}	Solar irradiation	0.12	1
C_{14}	Slope	0.091	2

Based on Table 9, the rates of solar radiation and average temperature were the most important criteria for locating the photovoltaic solar power plant. Moreover, the criteria of slope, distance to main roads, distance to power lines, and land use were of the highest importance in locating a photovoltaic solar power plant. Sunny hours represented the total monthly sunny hours of the regions and the rate of energy received from sunlight. As the power of photovoltaic solar panels depended on ambient temperature and solar radiation, the average temperature and sunny hours were of great importance in the establishment of photovoltaic solar power plants. Previous studies suggested that the criteria identified in this research for locating solar power plants were very consistent and similar to previous studies (12 and 23), some of which are given in Table 10.

Table 10. Similar studies

Reference	**Environment**		**Electrical issues**			**Economic-Social**				**Topography**		**Climatology**		
	Land use & cover	River	Distance to village	Distance to power line	Distance to substations	Transformer substation	Population density	Distance to urban	Distance to main roads	Slope	Orientation slope	Solar irradiation	Average temperature	Wetland
[6]	✦			✦				✦	✦	✦	✦	✦		
[7]	✦			✦			✦	✦	✦			✦		
[43]		✦					✦		✦	✦		✦		
[3]	✦			✦				✦		✦	✦			
[9]				✦	✦			✦	✦	✦	✦		✦	
[11]				✦				✦	✦	✦	✦			
[12]	✦	✦	✦	✦	✦	✦		✦	✦	✦	✦		✦	
[14]				✦	✦			✦	✦	✦			✦	
[17]				✦	✦			✦	✦	✦			✦	
[23]	✦			✦				✦	✦	✦		✦	✦	
[25]	✦	✦			✦							✦		
[26]				✦			✦		✦			✦		
[31]		✦		✦					✦	✦		✦		
[28]									✦	✦		✦	✦	✦
[29]	✦	✦							✦					

5. CONCLUSIONS

Fossil fuels are the main source of energy. Environmental pollutions caused by fossil fuels and increasing energy demand have forced energy suppliers seek other sources. Solar energy is one of the sources of clean energy. Solar energy is available to humans without any restriction. The establishment of a photovoltaic solar power plant is an essential. Selecting a suitable site increases the absorption of more sunlight leading to storage of more solar energy. Thus, it is important to identify effective criteria for locating a solar photovoltaic power plant. In this research, two types of questionnaires were used to collect the data. The first questionnaire was developed based on the theoretical foundations of the subject and the previous studies as well as the views of the experts on locating the photovoltaic solar power plant. This questionnaire assesses the importance of effective factors in locating the power plant. These factors were presented in five topographic, environment, climatologic, socio-economic, and power distribution lines groups. Data derived from the first questionnaire were collected and classified through the Delphi method. Then, in the second phase, the criteria identified in the first phase were evaluated to determine the importance of the criteria using the hierarchical method.

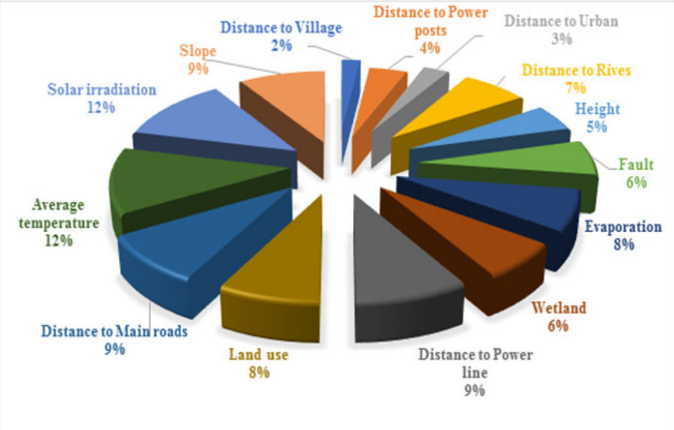

Figure 4. The importance of criteria to each other

According to Figure 4, the importance of average temperature and solar radiation is 13 %. Therefore, these two criteria are of greater importance than other criteria in constructing the solar power plant. More solar radiation and more solar absorption will be on photovoltaic panels. The average temperature is very important for panels. Establishing temperature balance in panels improves the efficiency of panels in solar radiation.

Based on the results of this research, it is recommended that other effective criteria according to the climate conditions of each region, other decision making methods, and GIS software be considered in locating a photovoltaic solar power plant.

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