JREE: Vol. 8, No. 1, (Winter 2021) 28-43

Journal of Renewable Energy and Environment

Research Article

Journal Homepage: www.jree.ir

Solar PV Power Plant Site Selection Using GIS-FFDEA Based Approach with Application in Iran

Aychar Khajavi Pour[a], Mohammad Reza Shahraki[a*], Faranak Hosseinzadeh Saljooghi[b]

[a] *Department of Industrial Engineering, School of Engineering, University of Sistan and Baluchestan, Zahedan, Sistan and Baluchestan, Iran.*
[b] *Department of Mathematics, School of Mathematics, University of Sistan and Baluchestan, Zahedan, Sistan and Baluchestan, Iran.*

PAPER INFO

Paper history:
Received 30 May 2020
Accepted in revised form 26 October 2020

Keywords:
Renewable Energy,
Full Fuzzy Data Envelopment Analysis,
Delphi Method,
Location Planning,
Geographic Information System,
Iran

ABSTRACT

Photovoltaic energy is a good alternative to fossil fuels due to the abundance of solar energy. In this research, the criteria for locating photovoltaic solar power plants were identified using previous studies and experts' views and by using the Delphi method based on five socioeconomic, topographic, power generation and distribution issues, climatological, and environmental criteria. Then, by using the GIS software, the layers of sub-criteria were classified for locating photovoltaic solar power plants. Upon identifying the proposed decision-maker units for location finding, their efficiency was calculated using the full fuzzy data envelopment analysis method in three steps. The information extracted from the layers of the sub-criteria of GIS was coded using the MATLAB software in the first step of the full fuzzy data envelopment analysis model and the decision-making units were classified into three classes of efficient, weak, and inefficient. In the second step, the values of output shortages and input surplus were determined. Finally, in the third step, efficient decision-making units were ranked using Anderson-Pearson Super Efficiency Method in full fuzzy data envelopment analysis. In order to validate the proposed method, a case study was carried out. The results of calculations showed that the north, central, and southeast areas of Sistan and Baluchestan province were among the favorable areas for photovoltaic solar power plant construction. Therefore, approximately 66 % of the province's area has appropriate efficiency matching the sub-criteria considered to construct a photovoltaic solar power plant.

https://doi.org/10.30501/jree.2020.230490.1110

1. INTRODUCTION

Growing population and the ensuing high energy consumption will increase the pollution from use of fossil fuels; thus, energy supply chains have shifted to the use of clean and renewable energies [1]. In the past years, the high initial cost of photovoltaic solar systems and the supply of cheap oil and gas have prevented the use of photovoltaic solar energy systems. In 1973, an increase in oil prices forced developed countries to use other strategies to supply energy from other sources. Due to the abundance and availability compared to renewable energies, solar energy is an appropriate alternative to supplying sustainable energy [2]. Based on the scientific estimates, about six thousand million years have passed since the birth of the sun. Moreover, the sun's weight is three hundred and thirty-three times the weight of the earth; therefore, it can be considered a huge source of energy for the next five billion years [3].

Photovoltaic solar power plants are used to convert sunlight into electrical energy [4]. The rapid growth and development of photovoltaic solar power plants over the recent few years to meet community demand has led countries to take photovoltaic solar power plants more seriously [5]. Determining an optimal location has a major impact on the efficiency ratio of storing energy for power supply in exploiting photovoltaic solar power plants. Since the amount of energy produced by photovoltaic solar power plants is influenced by various criteria [6, 7], the criteria for selecting the optimum location for the construction of a photovoltaic solar power plant should be in line with these criteria. Identifying effective criteria for locating a photovoltaic solar power plant requires using the knowledge of experts in this field [8]. The Delphi method is one of the methods for summarizing and compiling comprehensive criteria based on the group decisions of experts and this research has used this method to identify effective criteria for locating photovoltaic solar power plants. The previous researchers have identified effective criteria for locating and have applied TOPSIS, ELECTRE, Hierarchical Analysis, and Data Envelopment Analysis methods to evaluate deployment locations. In recent years, researchers have also used Geographic Information System (GIS) along with decision-making methods in locating researches.

Given that GIS is an electronic system for managing and analyzing geographic information, by exploiting it, all locating-related information is displayed in a layered format and the possibility to make spatial decision makings by

*Corresponding Author's Email: mr.shahraki@eng.usb.ac.ir (M.R. Shahraki)
URL: http://www.jree.ir/article_118411.html

Please cite this article as: Khajavi Pour, A., Shahraki, M.R. and Hosseinzadeh Saljooghi, F., "Solar PV power plant site selection using GIS-FFDEA based approach with application in Iran", ***Journal of Renewable Energy and Environment (JREE)***, Vol. 8, No. 1, (2021), 28-43. (https://doi.org/10.30501/jree.2020.230490.1110).

entering all the descriptive and spatial information and then separating the spatial information of the layers into a map, table, and graph formats is provided for people. On the other hand, investigating the efficiency ratio of locations following the criteria to absorb sunlight is more effective in achieving an optimal decision. A Full-Fuzzy Data Envelopment Analysis method is used for measuring the relative efficiency in which there is the possibility of using several inputs and outputs. By using the full-fuzzy data envelopment analysis method, the efficiency of each one of the options is calculated by forming appropriate mathematical linear programming models [9].

Following the above information, this research uses the Delphi method to identify the criteria for locating and classifying them and then, extracting fuzzy data completely using cover analysis method. Eventually, efficient locations are ranked.

Determining the optimal site is crucial to constructing a solar photovoltaic power plant [10, 11]. Given that the amount of energy generated by photovoltaic solar power plants is affected by various criteria [6], the criteria for selecting the optimal site to construct a solar photovoltaic power plant should follow these criteria [12]. Some studies have been conducted to identify efficient criteria for locating [13, 14]. In previous studies, TOPSIS, ELECTRE, Analytical Hierarchy Process (AHP), and Data Envelopment Analysis (DEA) methods were used to evaluate the sites [15, 16]. In this study, socioeconomic, climatological, power generation and distribution issues, the environmental, and topographic criteria were identified for locating using the Delphi method. Then, using the GIS, the layers of each of the sub-criteria of each criterion were classified. Finally, using the Full Fuzzy Data Envelopment Analysis Method, the decision-making units were measured in terms of efficiency level in three steps. Then, the values of output shortages and input surplus were calculated. Finally, efficient units were ranked. The second section of the study presents the literature and background of the study. The third section of the study presents the methodology. The fourth section presents the analysis of the results of the research with numerical data and a case study. Finally, the fifth section presents the conclusion and the recommendations.

According to the studies reviewed in this article, most of the previous articles have only examined the location of solar power plants using decision-making methods. Previous articles have also used decision-making methods to identify effective criteria for location. This article identified effective criteria for the study area by designing and distributing a questionnaire among the experts and beneficiaries of the solar power plant and using the Delphi method. It also positioned solar power plants based on the efficiency of candidate sites using all-fuzzy data envelopment analysis. In some previous papers, only fuzzy criteria were considered; however, in the method used in this paper, all parameters were considered to be triangular fuzzy.

2. EXPERIMENTAL

Solar energy as photovoltaic and thermal energy can be used to provide electrical energy. In the photovoltaic phenomenon, solar energy is directly converted to electricity [17]. The solar power plant is a power plant that receives its energy directly from the sun [18]. Locating is the optimal selection of sites for a specific purpose based on certain criteria. Locating a photovoltaic solar power plant is important given the criteria related to the amount of solar energy absorption [11]. The efficient criteria for locating the solar power plant can be identified using the Delphi method. The Delphi method is performed in several steps by experts to achieve a consensus on locating a photovoltaic solar power plant [19, 20]. In addition, the construction of a photovoltaic solar power plant requires information management and natural resource management. This requires the use of information technology, which considers the dimensions of natural and social structures altogether. Among the database processing software products, GIS software can process these two dimensions altogether with a geographical vision and can express them in simple words along with a graphical display [21]. The geographic information system is an electronic system through which all of the information related to locating is displayed as layers. By entering all the descriptive and spatial information and then separating the layers, the spatial information is provided to people in the form of a map, a table, and a graph [22]. The parameters involved in spatial information processing are inaccurate and fuzzy. The use of fuzzy processing functions and operators in the GIS software facilitates the processing and provides better solutions. As layers of all the criteria in the GIS environment have different units, for example, the height has the unit of the meter of distance from the sea level or slope has the unit of degree, to combine the layers of criteria with different units, they must be converted to a common unit. For this purpose, the layers can be homogenized. Classification is one of the ways for homogenizing. In the classification of the layers, each of the criteria is converted to squares, and the membership of the layers with different units is defined by a square unit. As a result, by overlapping the classified layers, they are combined. Accordingly, locating is performed based on the squares of the layers [23]. After identifying the sites, decision-making methods can be used to assess the efficiency of the sites. The Full Fuzzy Data Envelopment Analysis Method is a tool used to assess the performance in uncertain situations [24]. Full fuzzy data envelopment analysis method is a method used to measure the relative efficiency. In this method, it is possible to use multiple inputs and outputs. In the Full Fuzzy Data Envelopment Analysis Method, the efficiency of each option is calculated with the formation of appropriate linear programming models [9]. In Ref. [25], the modeling and optimization of the photovoltaic supply chain were performed in two steps using the data envelopment analysis method. In the first step, they located the solar energy supply plant. In Ref. [11], they examined the feasibility of installing and initiating a photovoltaic power plant using GIS. In Ref. [5], a solar power plant was located using multi-criteria decision-making methods. In Ref. [6], the sites of the solar system were selected using Cronbach's alpha and a hierarchical analysis method. In Ref. [24], the fuzzy data envelopment analysis method and a flexible neuro-fuzzy approach were used to locate the solar power plant. In Ref. [13], a photovoltaic solar power plant was located using GIS software and multi-criteria decision-making methods. Their research results showed that the use of GIS-MCDM tools facilitated the locating of power plants. In Ref. [26], in order to locate and implement photovoltaic pumping systems for irrigation in two steps, spatial analysis and BeWhere model were used. In Ref. [15], the thermal power plant was located using the multi-criteria decision-making methods of TOPSIS and STEEP-Fuzzy-based hierarchy analysis. In Ref. [16], a photovoltaic solar power plant was located in two steps and the efficiency of selected sites was assessed using fuzzy hierarchy process analysis and data envelopment analysis, respectively. In Ref. [27], a photovoltaic power plant was located using a multi-criteria decision-making method. In Ref. [28], the selection of the most appropriate solar house system package was examined using hierarchical analysis method. In Ref. [29], the combined wind and solar power plant was located using the hierarchical analysis method. The results showed that knowing the advantages and disadvantages of candidate sites contributes significantly to making decisions by project managers. In Ref. [30], the installation of a thermal power plant was investigated using GIS, TOPSIS, AHP, and ELECTRE Methods. In Ref. [31], the solar power plant was located using the NDEA algorithm. Their results showed that the selected sites had a high potential for absorbing sunlight. In this paper, socioeconomic, climatological, power generation and distribution issues, environmental, and topographic criteria were identified for locating solar power plants. As the parameters involved in the spatial information processing are inaccurate and fuzzy, the layers of each of the criteria are classified in the GIS environment. Then, using the full-fuzzy data envelopment super analysis method, the relative efficiency of the sites was assessed and ranked.

3. METHOD

In this paper, the efficient criteria for locating the solar power plant were first identified based on the studies conducted and the views of the experts in this area using the Delphi method. Then, GIS software was a fuzzy data envelopment analysis method and the efficiency of the proposed sites was assessed in three steps. In the first step, the sites extracted from the GIS environment were classified into three classes of efficient, weak, and inefficient. In the second step, the value of inputs surplus and output shortages were calculated. In the third step, efficient sites were ranked using the full fuzzy data envelopment analysis method. Figure (1) shows this procedure.

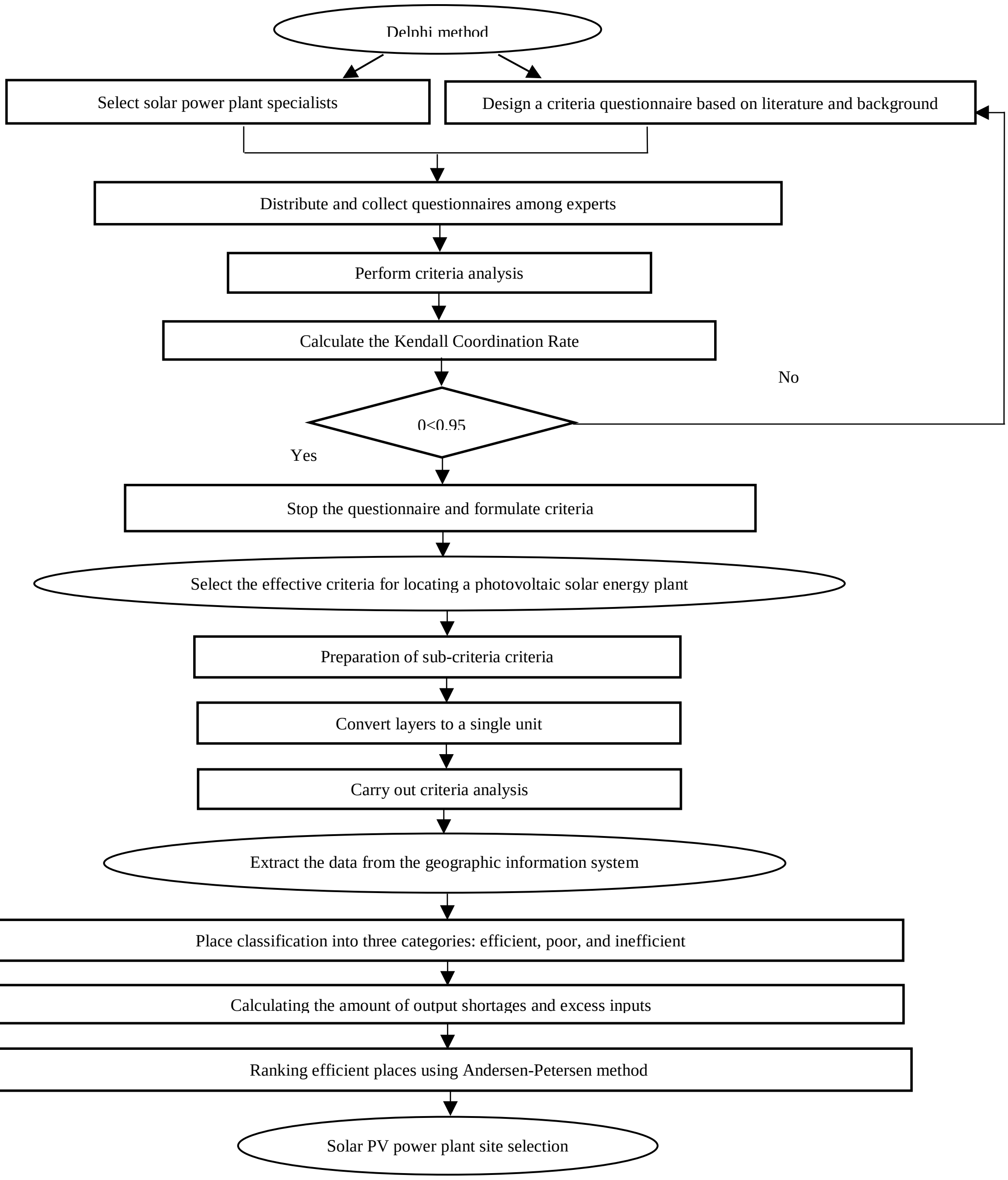


Figure 1. Research steps

3.1. Delphi method

The Delphi method is used to decide on the qualitative issues by collecting expert views to achieve a consensus on the efficient criteria in locating photovoltaic solar power plants. The steps of the Delphi method are as follows [32]:

Step 1: Identification of solar power plant locating criteria
At this step, the criteria are identified by using a comprehensive review of the theoretical principles of the criteria related to locating solar power plant and the views of the experts on the importance and quality of the criteria in locating the solar power plant.

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 the efficient criteria for locating a photovoltaic solar power plant. The participants of this research included 60 experts in the area of distribution, generation, operation, and installation of photovoltaic solar power plants.

Step 3: Distribution of questionnaires
First, a questionnaire containing the criteria extracted from previous studies and experts' views was prepared. In distributing the questionnaires, 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 in each subsequent step.

Step 4: Determining the level of consensus
In this step, using Kendall's coefficient of concordance derived from Equation (1), the level of consensus among the decision-makers is determined. Delphi method stops when the value of Kendall's coefficient of concordance is at least 0.95. Therefore, the final questionnaire and the criteria in the final questionnaire are identified as selected criteria.

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

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

3.2. GIS

Considering the site of phenomena, GIS processes and analyzes spatial data and land predictions. Due to the high cost of measuring data or the lack of access to all of the information of a spatial community, spatial data analysis plays a major role in executive plans. Having the information of specified points, it is possible to estimate and measure the levels of that area and the percentage probability of occurrence of certain events [33]. Moreover, GIS is a management tool for decision-making based on spatial data. By integrating data of different sources, it is possible to extract the required information and discover the complex and invisible relationships among the various phenomena so that the ultimate goal of the GIS is supporting and its basic function is to obtain information derived from the combination of different data layers with various ways [34]. Figure 2 shows the locating geographic information system environment.

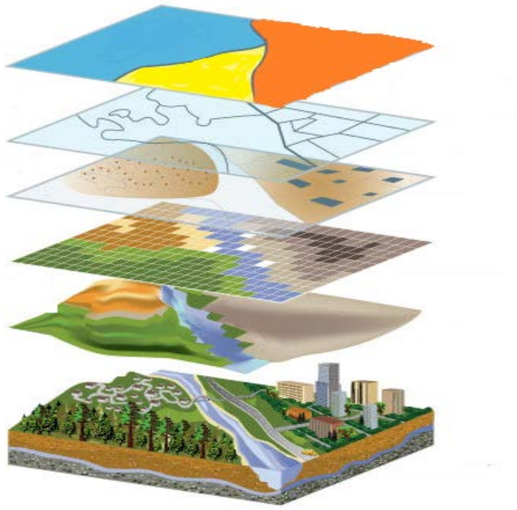


Figure 2. Locating levels with GIS software

In this research, the following cases were investigated using GIS software:

1. Using data from synoptic stations of Sistan and Baluchestan, Hormozgan, and Kerman provinces for the interpolation of solar radiation, evaporation, temperature, and humidity parameters.
2. Using the ASTER satellite Digital Elevation Model (DEM) with cell size or pixels (30 meters) received from the USGS website for the preparation of the layers of height.
3. Using the layers of the province area, the main roads, urban and rural areas and the main rivers received from Sistan and Baluchestan provincial governorate.
4. Using fault and land-use layers of Sistan and Baluchestan province received from National Geo-science Database.
5. Using layers of power substations and power transmission lines received from Sistan and Baluchestan Provincial Electric Power Distribution General Administration.

3.3. Fuzzy set and full fuzzy data envelopment analysis method

As knowledge of individuals is expressed qualitatively, the theory of fuzzy sets is used to transform knowledge of individuals into a mathematical relation. The theory of fuzzy sets is a theory that can transform many of the inaccurate and vague concepts and variables and systems into mathematical relations and provide the conditions for reasoning, inferring, and making decision in uncertain situations.

In this theory, membership of the set members is displayed by the function μ (x) given in Equation (2), in which $\tilde{a} = (a_1.a_2.a_3)$ is a triangular fuzzy number and μ is a function that determines the membership degree x in $\tilde{a}$ set [34].

$$\mu_{\tilde{a}}\left(x\right) = \begin{cases} \frac{x-a_1}{a_2-a_1} & a_1 \le x \le a_2 \\ \frac{a_3-x}{a_3-a_2} & a_2 \le x \le a_3 \\ 0 & o.w \end{cases} \tag{2}$$

For a triangular fuzzy number, if $\tilde{a}.\tilde{b}$ are two triangular fuzzy numbers, $\tilde{a} = \tilde{b}$ is true only when a_1=b_1 , a_2=b_2 , a_3=b_3 are the mathematical relations between fuzzy numbers and fuzzy and definite numbers in Relations (3) to (6).

$$k\tilde{a} = (ka_1, ka_2, ka_3) \quad \text{if} \quad k \geq 0 \tag{3}$$

$$k\tilde{a} = (ka_3, ka_2, ka_1) \quad \text{if} \quad k \leq 0 \tag{4}$$

$$\tilde{a} + \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \tag{5}$$

$$\tilde{a} \times \tilde{b} = (a_1 b_1, a_2 b_2, a_3 b_3) \quad \text{if } a_1, b_1 \geq 0 \tag{6}$$

K is a real and definite number.

The parameters are involved in the processing of information related to performance assessment to calculate the efficiency, inaccurate, and fuzzy state. One of the methods for assessing the efficiency of the options is the full fuzzy data envelopment analysis method. The full fuzzy data envelopment analysis method is a mathematical programming method for generating an efficiency boundary to assess the efficiency of the options with multiple inputs and outputs. In the full fuzzy data envelopment analysis method, all variables, parameters, and the efficiency of the options are calculated in a fuzzy manner, and the options are divided into three classes of efficient, weak, and inefficient. As inefficient options do not displace the boundary of efficiency, efficient options are ranked by using the full fuzzy data envelopment analysis method. In the fuzzy data envelopment analysis method, a set with n to DMU of inputs x_{ij} generates outputs of y_{rj}. A set with the possibility of generating y_{rj} by x_{ij} is called Tγ (Tγ can be introduced based on the return to the CRS constant scale or return to the VRS variable scale). Equation (7) represents the set of possible input and output combinations of the full fuzzy data envelopment analysis method [34].

$$T = \{(x.y) \in R_+^{m+s} \mid x \text{ can produce } y\} \tag{7}$$

One of the capabilities of the full fuzzy data envelopment analysis method is the application of models with the input and output nature corresponding to return to the same and different scales. In the input nature with a return to constant scale, each number of inputs generates the same number of outputs displayed by TCRS. In the nature of the output with return to the variable scale, each number of inputs can generate the same, small or large number of outputs displayed by the TVRS. Equation (8) displays a model with the nature of input and output.

$$F = F((x.y), \theta_p) = \max \{\theta_p \in R_+ \mid (x, \theta_p y) \in T(\gamma)\} \tag{8}$$

where θ_p is the efficiency score for each DMU. The full fuzzy data envelopment analysis method is performed in three steps.

Step 1: Calculation of relative efficiency

In this step, the relative efficiency of the DMUs using the CRS input model is as follows:

$$\min \tilde{\theta}_p^{CRS} \tag{9}$$

s.t.

$$\sum_{j=1}^{n} \tilde{\lambda}_j \times \tilde{x}_{ij} + \tilde{s}_i^- = \tilde{\theta}_p^{CRS} \times \tilde{x}_{ip} \quad i = 1, 2, \cdots, m \tag{10}$$

$$\sum_{j=1}^{n} \tilde{\lambda}_j \times \tilde{y}_{rj} = \tilde{s}_r^+ + \tilde{y}_{rp} \quad r = 1, 2, \cdots, s \tag{11}$$

$$\lambda_j \in TF(R)^+, \quad j = 1, 2, \cdots, n$$

$$\tilde{s}_i^- \in TF(R)^+, \quad i = 1, 2, \cdots, m$$

$$\tilde{s}_i^+ \in TF(R)^+, \quad r = 1, 2, \cdots, n$$

Phrase (9) is the objective function of the problem and represents the minimization of the efficiency of the decision-making units. Phrases (10) and (11) represent the set of constraints related to inputs and outputs, respectively.

The numerical value $0 < \theta_p \leq 1. \tilde{\theta}_p^{CRS}$ is the variable of efficiency in model with input nature, $\tilde{x}_{ij}$ is the i^th^ input of DMUj and its value is fuzzy. $\tilde{y}_{rj}$ is the j^th^ output of DMUj, and $\tilde{\lambda}_j$ is DMUj weight. In addition, $\tilde{s}_i^-$ *and* $\tilde{s}_r^+$ are auxiliary variables.

Given that all variables and parameters are triangular fuzzy numbers, by using Relations (3) to (6), the above phrases can be rewritten as follows:

$$\min (\theta_{p,1}^{CRS}, \theta_{p,2}^{CRS}, \theta_{p,3}^{CRS}) \tag{12}$$

s.t.

$$\sum_{j=1}^{n} (\lambda_{j,1} x_{ij,1}, \lambda_{j,2} x_{ij,2}, \lambda_{j,3} x_{ij,3}) + (s_{i,1}^-, s_{i,2}^-, s_{i,3}^-) = (\theta_{p,1}^{CRS} x_{ip,1}, \theta_{p,2}^{CRS} x_{ip,2}, \theta_{p,3}^{CRS} x_{ip,3})$$

$$i = 1, 2, \cdots, m$$

$$\sum_{j=1}^{n} (\lambda_{j,1} y_{rj,1}, \lambda_{j,2} y_{rj,2}, \lambda_{j,3} y_{rj,3}) = (s_{r,1}^+, s_{r,2}^+, s_{r,3}^+) + (y_{rp,1}, y_{rp,2}, y_{rp,3})$$

$$r = 1, 2, \cdots, s$$

$$\lambda_{j,1} \geq 0; \; \lambda_{j,2} - \lambda_{j,1} \geq 0; \; \lambda_{j,3} - \lambda_{j,2} \geq 0 \quad j = 1, 2, \cdots, n$$

$$s_{i,1}^- \geq 0; \; s_{i,2}^- - s_{i,1}^- \geq 0; \; s_{i,3}^- - s_{i,2}^- \geq 0 \quad i = 1, 2, \cdots, m$$

$$s_{r,1}^+ \geq 0; \; s_{r,2}^+ - s_{r,1}^+ \geq 0; \; s_{r,3}^+ - s_{r,2}^+ \geq 0 \quad r = 1, 2, \cdots, s$$

$$\theta_{p,2}^{VRS} - \theta_{p,1}^{VRS} \geq 0; \; \theta_{p,3}^{VRS} - \theta_{p,2}^{VRS} \geq 0$$

In this section, in order to solve the multi-objective programming problem function while maintaining the triangular shape, Phrase (12) is transformed to three separate objective functions (13), (14), and (15).

$$\min \theta_{p,1}^{CRS} \tag{13}$$

$$\min \theta_{p,2}^{CRS} \tag{14}$$

$$\min \theta_{p,3}^{CRS} \tag{15}$$

s.t.

$$\sum_{j=1}^{n} \lambda_{j,k} x_{ij,k} + s_{i,k}^- = \theta_{p,k}^{CRS.*} x_{ip,k} \quad i = 1, 2, \cdots, m \quad , k = 1, 2, 3$$

$$\sum_{j=1}^{n} \lambda_{j,k} y_{rj,k} = s_{r,k}^+ + y_{rp,k} \quad r = 1, 2, \cdots, s \quad , k = 1, 2, 3$$

$$\lambda_j \geq 0 \quad j = 1, 2, \cdots, n$$

$$s_{i,1}^- \geq 0; \; s_{i,2}^- - s_{i,1}^- \geq 0; \; s_{i,3}^- - s_{i,2}^- \geq 0 \quad i = 1, 2, \cdots, m$$

$$s_{r,1}^+ \geq 0; \; s_{r,2}^+ - s_{r,1}^+ \geq 0; \; s_{r,3}^+ - s_{r,2}^+ \geq 0 \quad r = 1, 2, \cdots, s$$

$$\theta_{p,2}^{CRS} - \theta_{p,1}^{CRS} \geq 0; \; \theta_{p,3}^{CRS} - \theta_{p,2}^{CRS} \geq 0$$

The problem is solved by the Lexographic method. Accordingly, the problem is first solved for the objective function (15) and the best value of the phrase (15) is obtained. Then, by maintaining this optimal value, the objective function (14) is optimized and by maintaining the optimal value of the objective functions (15) and (14), the optimal value of the objective function (13) is obtained. Finally, by calculating the value of the efficiency variable of each decision-making unit relative to other decision-making unit, the decision-making units are classified in terms of efficiency. Therefore, decision-making units fall into three classes:

i: DMU_p is efficient if $\tilde{\theta}_p^{CRS*} = (1,1,1)$ and for all is $\tilde{s}_i^{+*} = (0,0,0)$ and for all rs $\tilde{s}_r^{+*} = (0,0,0)$

ii: DMU_p has low efficiency if $\tilde{\theta}_p^{CRS*} = (1,1,1), and \sum_{i=1}^{m} s_i^{+*} + \sum_{r=1}^{s} s_r^{+*} \neq (0,0,0)$

iii: DMU_p is inefficient if $\tilde{\theta}_p^{CRS*} \neq (1,1,1)$

Step 2: Calculating the amount of output shortage and input surplus consumed

Inefficient options cannot displace the border of efficiency; however, in inefficient decision-making units, some inputs remain and a shortage of outputs occurs. In this step, the number of inputs remained and the number of shortages of outputs of inefficient decision-making units is calculated using Equation (16).

$$\max \quad \sum_{i=1}^{m}\left(s_{i,1}^{-} + s_{i,2}^{-} + s_{i,3}^{-}\right) + \sum_{r=1}^{s}\left(s_{r,1}^{+} + s_{r,2}^{+} + s_{r,3}^{+}\right) \qquad (16)$$

s.t.

$$\sum_{j=1}^{n}\lambda_{j,k} x_{ij,k} + s_{i,k}^{-} = \theta_{p,k}^{CRS.*} x_{ip,k} \qquad i = 1,2,\cdots,m \quad , k = 1,2,3$$

$$\sum_{j=1}^{n}\lambda_{j,k} y_{rj,k} = s_{r,k}^{+} + y_{rp,k} \qquad r = 1,2,\cdots,s \quad , k = 1,2,3$$

$$\lambda_{j,1} \geq 0;\ \lambda_{j,2} - \lambda_{j,1} \geq 0;\ \lambda_{j,3} - \lambda_{j,2} \geq 0 \qquad j = 1,2,\cdots,n$$

$$s_{i,1}^{-} \geq 0;\ s_{i,2}^{-} - s_{i,1}^{-} \geq 0;\ s_{i,3}^{-} - s_{i,2}^{-} \geq 0 \qquad i = 1,2,\cdots,m$$

$$s_{r,1}^{+} \geq 0;\ s_{r,2}^{+} - s_{r,1}^{+} \geq 0;\ s_{r,3}^{+} - s_{r,2}^{+} \geq 0 \qquad r = 1,2,\cdots,s$$

Step 3: Ranking efficient decision-making units

Several efficient decision-making units might exist. In order to rank efficient decision-making units, the decision-making units are assessed in relation to the decision-making units of the reference set. Thus, the Anderson-Peterson super-efficiency model of the full fuzzy data envelopment analysis is written as follows [35]:

$$\min(\theta_{p,1}^{CRS}, \theta_{p,2}^{CRS}, \theta_{p,3}^{CRS}) \ (17) \qquad (17)$$

s.t.

$$\sum_{j=1, j\neq p}^{n}\left(\lambda_{j,1}x_{ij,1}, \lambda_{j,2}x_{ij,2}, \lambda_{j,3}x_{ij,3}\right) + \left(s_{i,1}^{-}, s_{i,2}^{-}, s_{i,3}^{-}\right) = \left(\theta_{p,1}^{CRS}x_{ip,1}, \theta_{p,2}^{CRS}x_{ip,2}, \theta_{p,3}^{CRS}x_{ip,3}\right)$$

$$; i = 1,2,\cdots,m$$

$$\sum_{j=1, j\neq p}^{n}\left(\lambda_{j,1}y_{rj,1}, \lambda_{j,2}y_{rj,2}, \lambda_{j,3}y_{rj,3}\right) = \left(s_{r,1}^{+}, s_{r,2}^{+}, s_{r,3}^{+}\right) + \left(y_{rp,1}, y_{rp,2}, y_{rp,3}\right)$$

$$r = 1,2,\cdots,s$$

$$\lambda_{j,1} \geq 0;\ \lambda_{j,2} - \lambda_{j,1} \geq 0;\ \lambda_{j,3} - \lambda_{j,2} \geq 0 \qquad j = 1,2,\cdots,n$$

$$s_{i,1}^{-} \geq 0;\ s_{i,2}^{-} - s_{i,1}^{-} \geq 0;\ s_{i,3}^{-} - s_{i,2}^{-} \geq 0 \qquad i = 1,2,\cdots,m$$

$$s_{r,1}^{+} \geq 0;\ s_{r,2}^{+} - s_{r,1}^{+} \geq 0;\ s_{r,3}^{+} - s_{r,2}^{+} \geq 0 \qquad r = 1,2,\cdots,s$$

$$\theta_{p,2}^{CRS} - \theta_{p,1}^{CRS} \geq 0;\ \theta_{p,3}^{CRS} - \theta_{p,2}^{CRS} \geq 0$$

Here, $\theta_{p,3}^{CRS*} \geq 1$ is the super efficiency. Thus, by solving Phrase (17), efficient decision-making units are ranked.

4. RESULTS AND DISCUSSION

In order to validate the proposed method, a case study was carried out for locating a photovoltaic solar power plant. The study area in this research is Sistan and Baluchestan Province, located in the southeastern of Iran. This province covers 11 percent of Iran's area with an area of about 180726 km^2. The province has a mainly warm and dry climate, while it has a climate diversity. The province has a latitude of 25 degrees and 3 minutes to 31 degrees and 27 minutes north latitude from the equator. In terms of geographical longitude, it has been located 58 to 50 degrees to 63 degrees and 21 minutes east longitude from the meridian. Moreover, it is very suitable for establishing solar power plants.

Given the possibility of using many criteria in locating the solar power plant and their effect on the performance of the solar power plant, the criteria considered should be appropriate in regional conditions [19]. The level of solar radiation, humidity, temperature, and evaporation affect the absorption and power of the power plant [35]. In addition, the construction of a solar power plant in different applications brings about different costs. The user layer reflects the way of using a piece of land [28]. It is important to have proper information on land use and distance to rivers for the construction of a solar power plant from the economic and environmental points of view [23, 36]. The height, slope, and direction of slope significantly affect the cost of construction of a solar power plant; thus, finding the height, slope, and direction of slope greatly reduces the cost of constructing a solar power plant and increases the power of generating the solar energy of plants. The proximity of the solar power plant to the main roads, power posts, and power lines reduces the cost of transportation of equipment to the power plant [37]. The proximity of power plants to the urban and rural areas reduces power transmission and distribution costs and reduces energy waste. Moreover, it is important to construct the power plants away from earthquake centers to ensure the security of the power plant equipment economically [37, 38]. In this research, for locating a photovoltaic solar energy system, the efficient criteria for locating the solar power plant were identified based on the previous studies and views of the experts in this area and using the Delphi method. Table (1) displays several locating studies along with the criteria considered for the construction of a solar photovoltaic power plant.

Questionnaire was distributed among 60 experts in solar power plant locating and they were asked to classify the criteria and express their views and opinions 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 as 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. Kendall's coefficient of concordance was calculated 0.95; thus, the

Delphi method was stopped. Accordingly, socioeconomic, climatological, power generation and distribution issues, environmental and topographic criteria were identified. The sub-criteria of each of them including the distance to the main roads, the distance to the rural and urban areas, the value of solar radiation, the average temperature, evaporation, humidity, distance to power lines and power posts, land use, distance to river, fault, slope, and height are shown in Table (2).

Table 1. Solar PV site suitability criteria

Criteria	Sub-criteria	References
Climatology	Solar irradiation	[25, 39-45]
	Average temperature	[6, 13, 16, 40, 43, 46-49]
	Wetland	[46]
Topography	Orientation slope	[6, 13, 16, 41, 47, 50-52]
	Slope	[6, 13, 30, 40, 41, 46-48, 51-54]
Economic-Social	Distance to main roads	[9, 13, 30, 39-43, 46-48, 51-53, 55-59]
	Distance to urban	[6, 13, 30, 40-42, 48, 51, 52, 54, and 56]
	Population density	[14, 39, 43, 58, and 60]
	Transformer substation	[51]
Electrical issue	Distance to substations	[13, 30, 44, 48, and 51]
	Distance to power line	[6, 11, 13, 38-43, 48, 51, 52, 54, 56-58, and 61]
	Distance to village	[51]
Environment	Distance to river	[44, 51, 53, 55, and 62]
	Land-use	[6, 40-42, 44, 50, 51, 55, 58, 60, 63 and 64]

Table 2. Criteria and sub-criteria identified for solar power station locating

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

Finally, by extracting and analyzing the criteria, this paper considers more comprehensive criteria for locating the solar power plant and added two criteria of power posts and power lines that were not considered in the previous studies. The reasons and the type of effect of each of the criteria in locating solar power plants are shown in Table (3).

Table 3. The type of effect of sub-criteria in locating the solar power plant [1, 31, and 40]

Group	Criteria	Type of effect in locating
Economic-Social	Distance to main roads	The proximity of solar power plant to the 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 distance of power plant to river increases, future costs will decrease
Topography	Fault	As 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

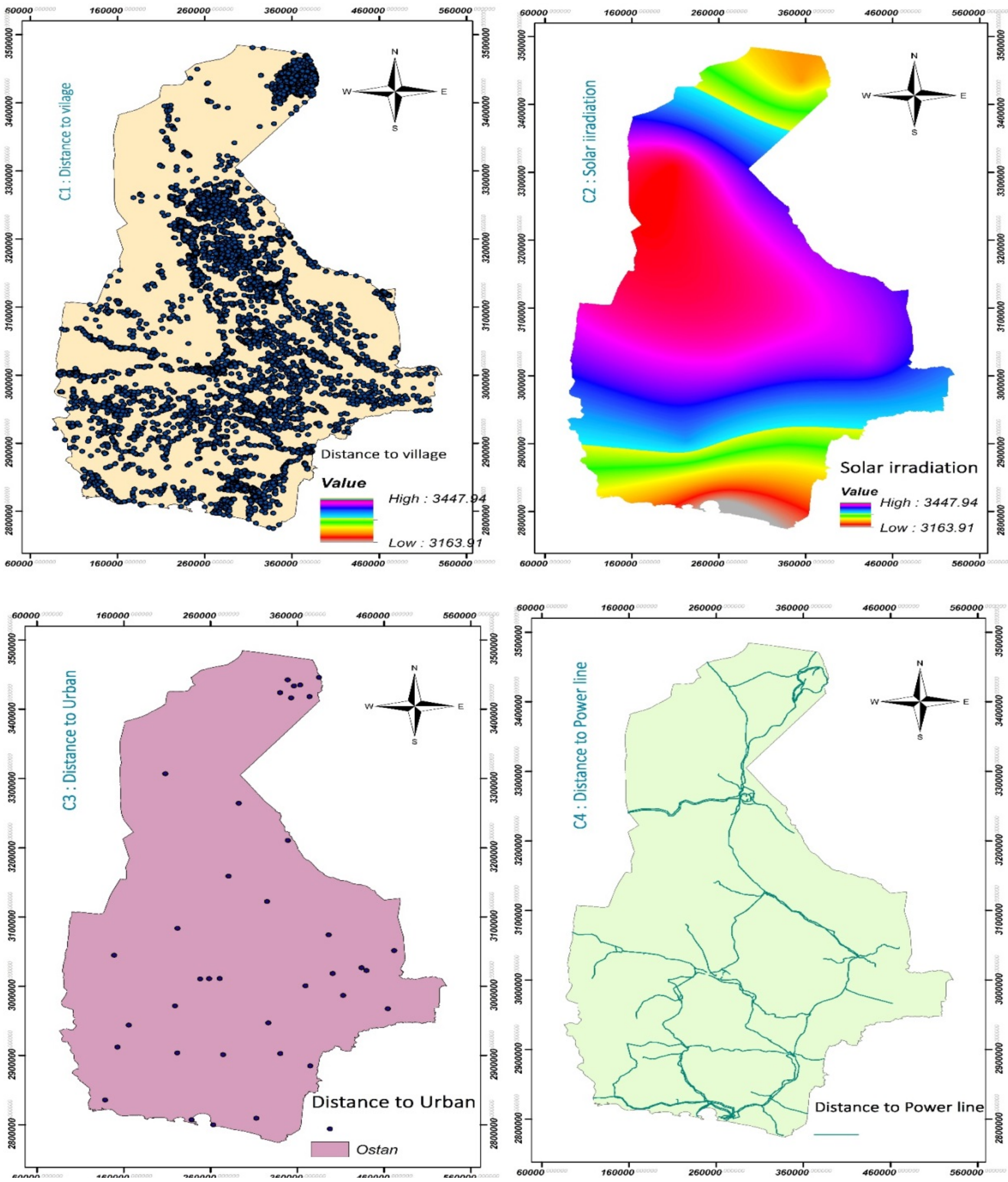
In the next step, according to the sub-criteria identified in the previous step, the layers of each sub-criterion were prepared in the GIS environment. These layers have been provided through the various sites and in-person visits to relevant departments. The layers of the fault and land use were obtained from the National Geoscience Database and the layers of average temperature, the value of solar radiation, evaporation, and humidity were obtained using synoptic stations data of Sistan and Baluchestan Meteorology Office. The layers of distance to urban and rural areas, main roads and rivers were provided by the provincial government of Sistan and Baluchestan province. Moreover, the layers of distance to power posts and power lines were provided by the Power Department of Sistan and Baluchestan province. Figure (3) represents the layers of the sub-criteria of locating solar power plant.

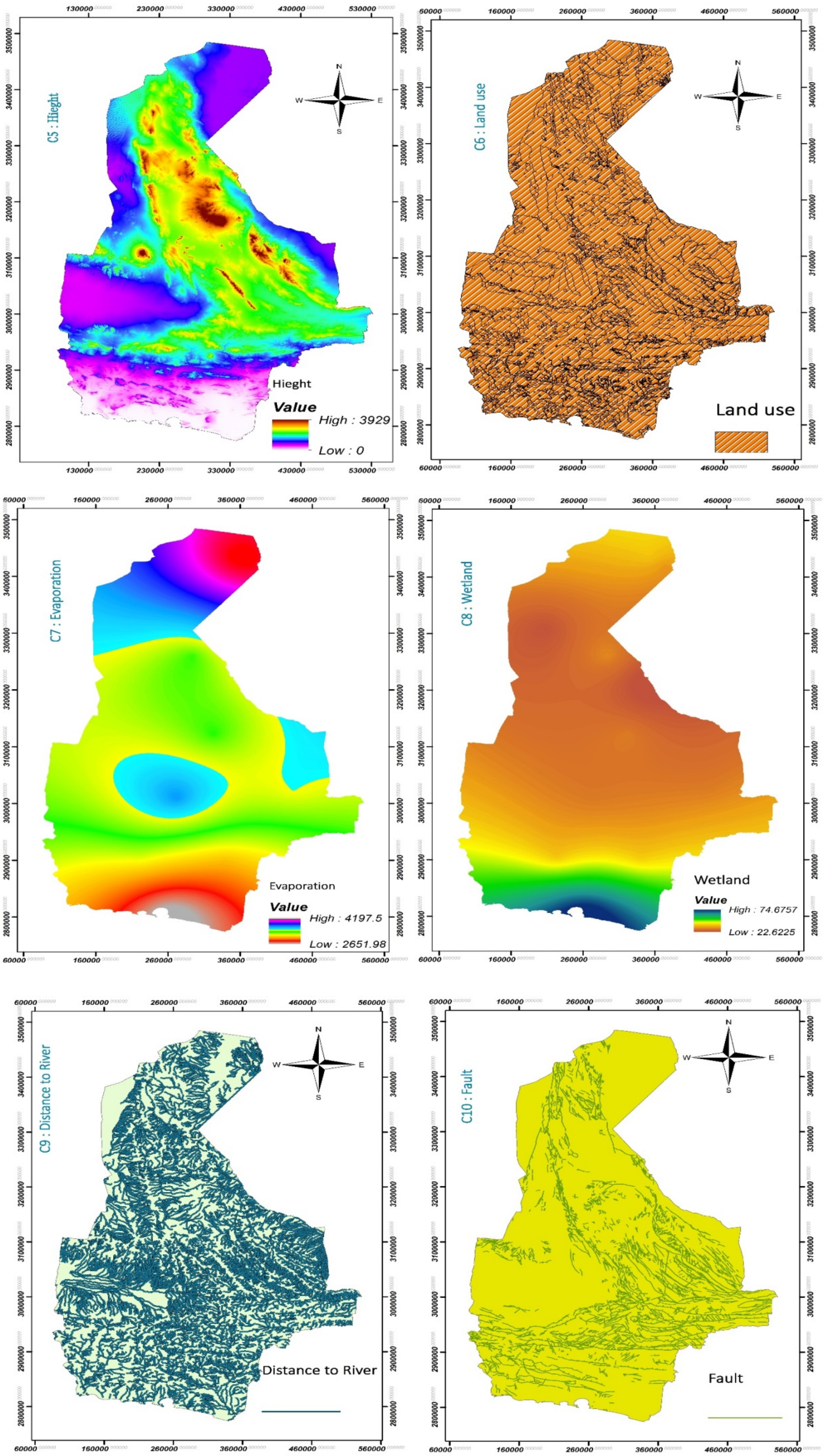
In order to prepare the required layers for locating, first, the cell size (pixel size) of all the required layers has been considered according to the extent of Sistan and Baluchestan province with the size of 500 × 500 meters. The imaging system of the above layers has been UTM Zone 41 with WGS 1984 datum which is metrical. All software calculations have been performed in GIS software (GIS 10.4).

Geo-statistical methods and techniques were used to prepare climate maps of the region including the maps of temperature, humidity, evaporation, and radiation. In this respect, in order to select the best type of torque and calculate the isotropic and anisotropic changes for interpolation, the desired parameters along with adding other factors such as altitude, slope direction, and geographic latitude were prepared by Simple Cokriging method. By using the digital elevation model, firstly, the elevation classification of the province was done and then, the map was prepared for the slope.

The Euclidean Distance Command or the same as Euclidean interval was used to convert (main roads, urban and rural points, main rivers, fault, power stations, and power transmission lines) layers into raster layers. The land-use layer was also converted into the raster.

For zoning the final map, each layer was first classified according to the geographical conditions of Sistan and Baluchestan province and the desired priorities and was combined using the Weighted Sum command. The final map was drawn after reclassifying. Ultimately, the areas suitable for solar power plant construction were specified. Figure (3) indicates the layers of criteria.




C5 : Hieght
Hieght
Value
High : 3929
Low : 0
C6 : Land use
Land use
C7 : Evaporation
Evaporation
Value
High : 4197.5
Low : 2651.98
C8 : Wetland
Wetland
Value
High : 74.6757
Low : 22.6225
C9 : Distance to River
Distance to River
C10 : Fault
Fault
N
S
W
E

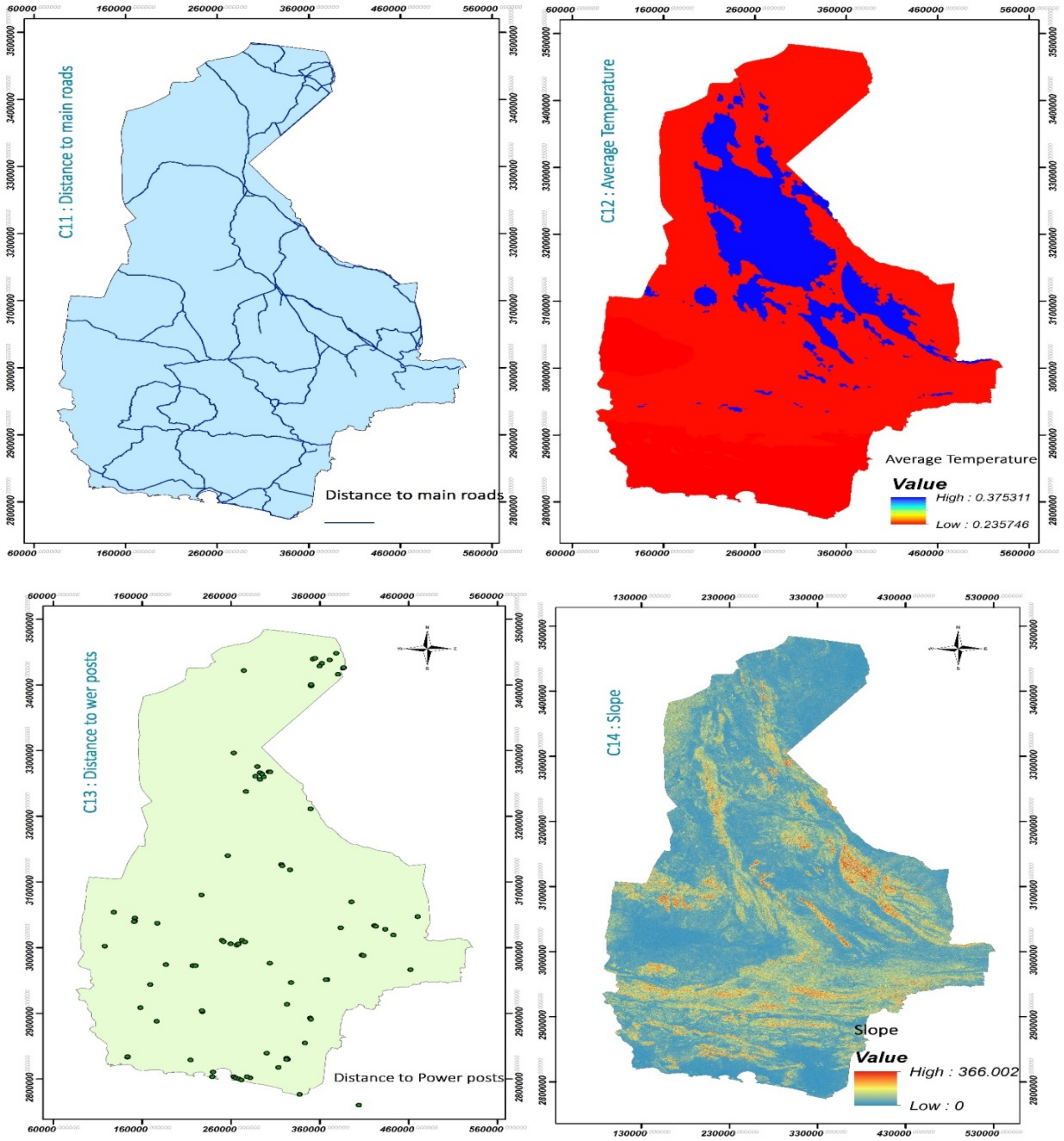
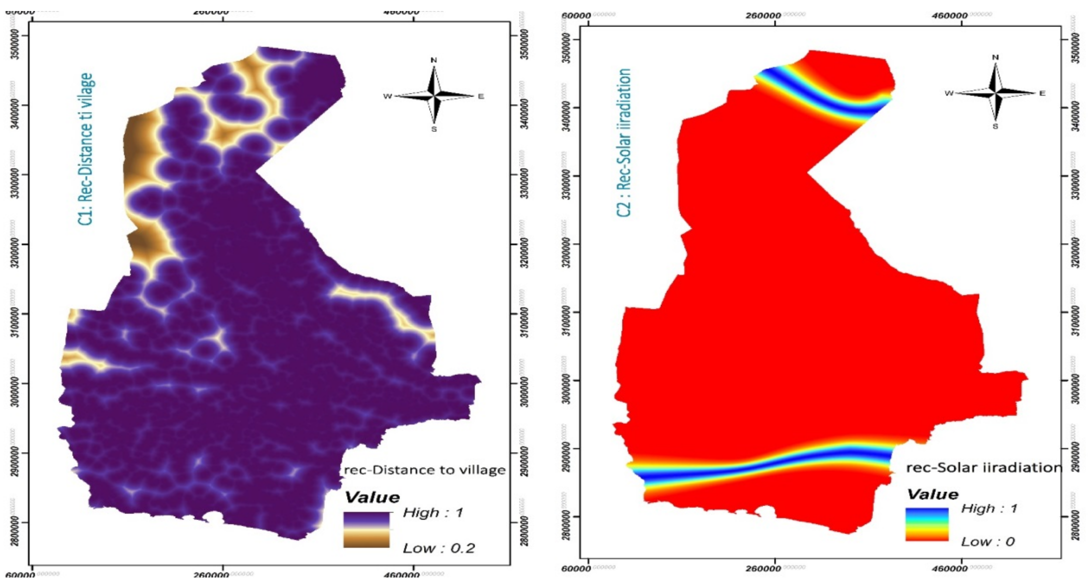
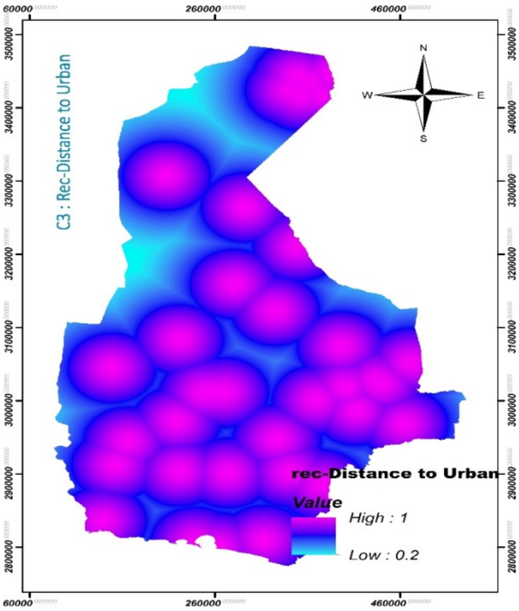
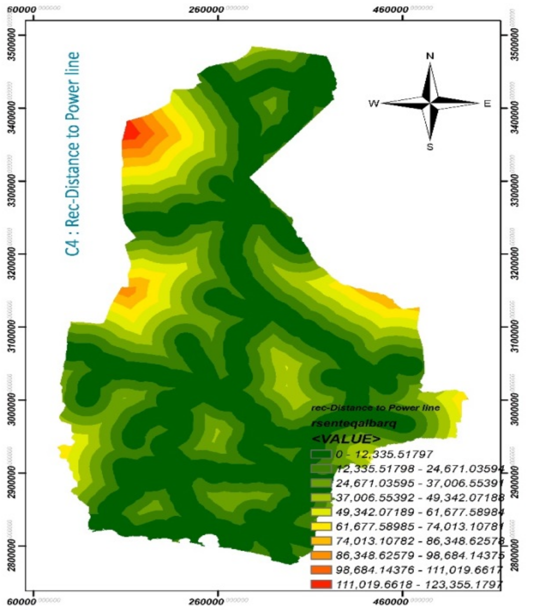


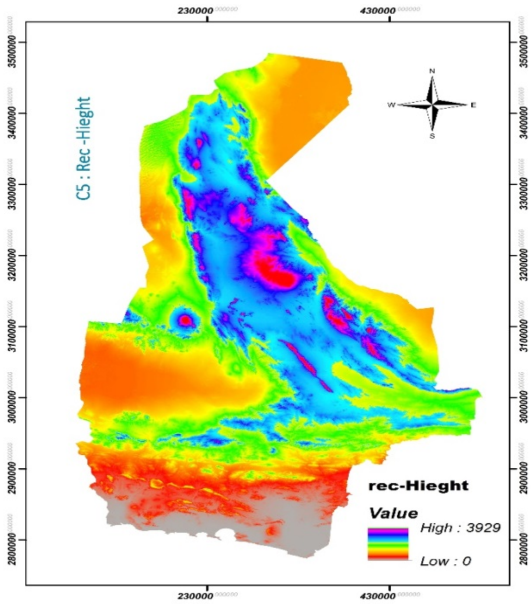
Figure 3. Substrate layers for locating solar power plants

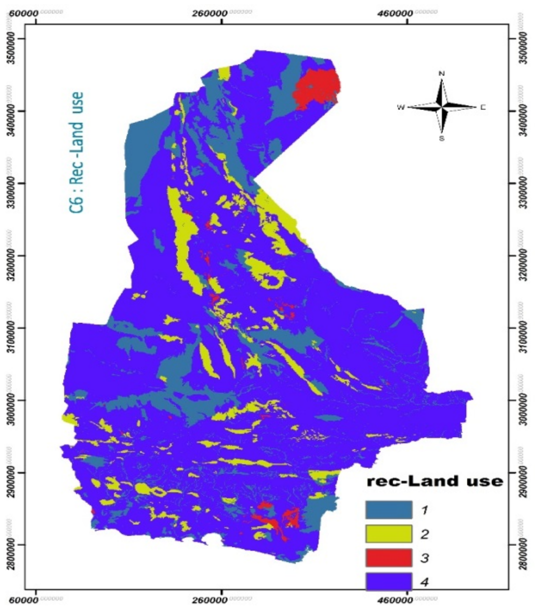
As the sub-criteria unit varies in the geographic information system environment, all layers were first rasterized for locating. Then, the size of the pixels and their image system were homogenized. Finally, according to the characteristics of any sub-criteria, the classification was performed on each layer. Figure (4) displays the classified map of the layers of each of the sub-criteria in the GIS environment.

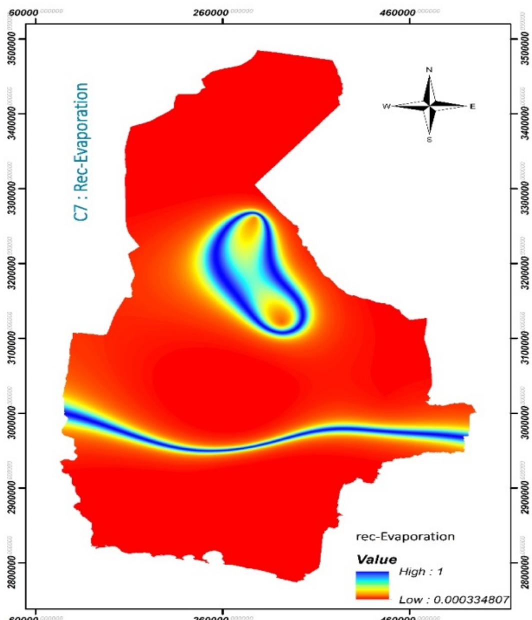


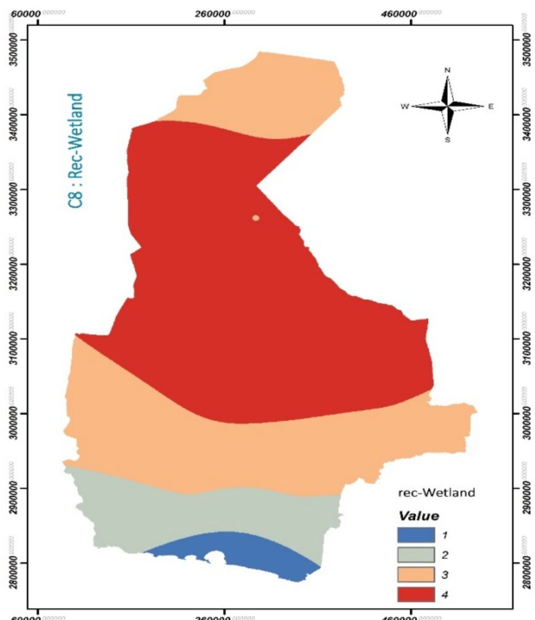

C3 : Rec-Distance to Urban
rec-Distance to Urban
Value
High : 1
Low : 0.2


C4 : Rec-Distance to Power line
rec-Distance to Power line
rsenteqalbarq
<VALUE>
0 - 12,335.51797
12,335.51798 - 24,671.03594
24,671.03595 - 37,006.55391
37,006.55392 - 49,342.07188
49,342.07189 - 61,677.58984
61,677.58985 - 74,013.10781
74,013.10782 - 86,348.62578
86,348.62579 - 98,684.14375
98,684.14376 - 111,019.6617
111,019.6618 - 123,355.1797


C5 : Rec -Hieght
rec-Hieght
Value
High : 3929
Low : 0


C6 : Rec -Land use
rec-Land use
1
2
3
4


C7 : Rec-Evaporation
rec-Evaporation
Value
High : 1
Low : 0.000334807


C8 : Rec-Wetland
rec-Wetland
Value
1
2
3
4

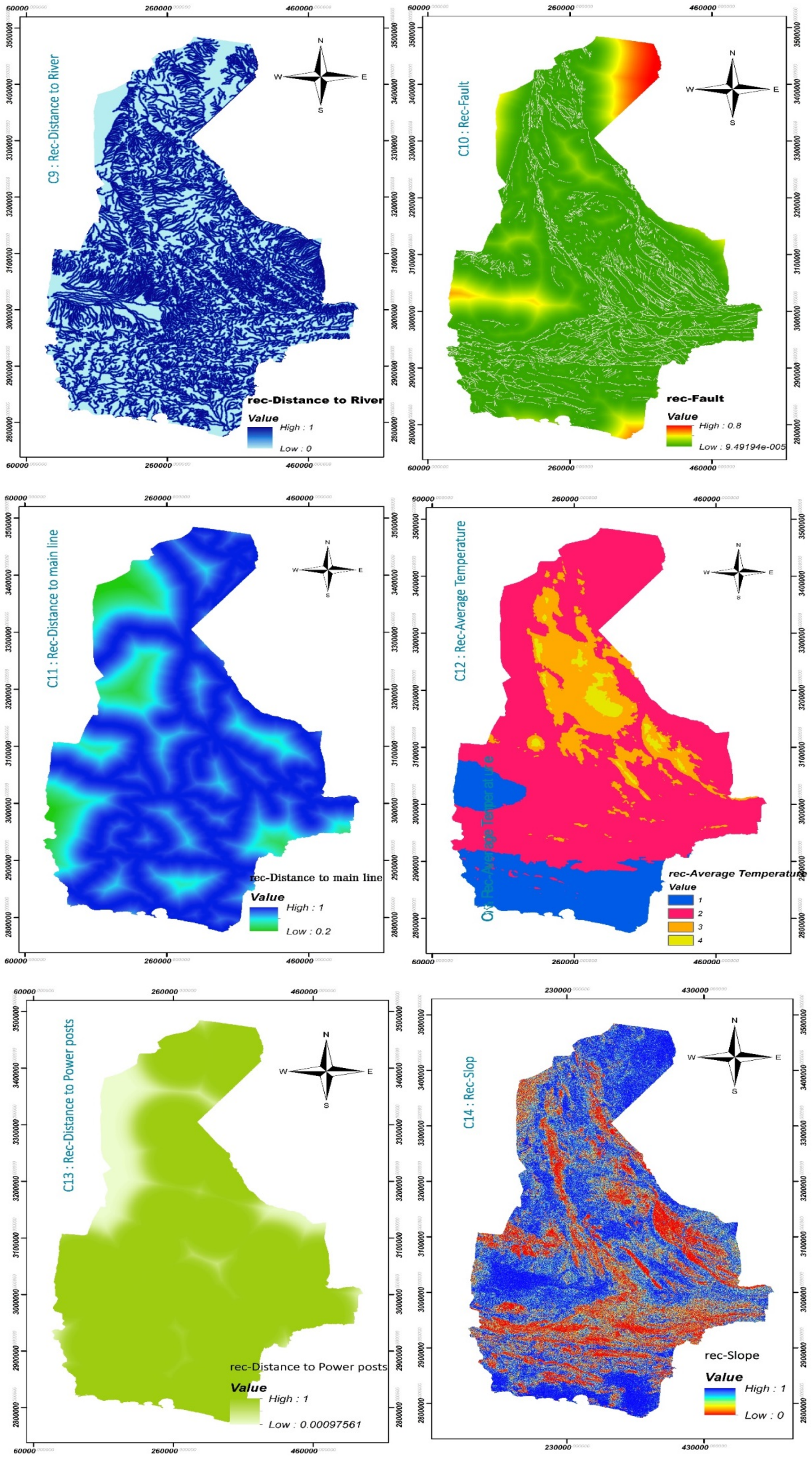


Figure 4. Classified sub-criteria

In this stage, the layers were classified using the fuzzy operators of the GIS environment. The values of each of the sites were extracted from the layers of each of the sub-criteria.

The results of calculations of the efficiency level and the input surplus and the output shortage of the full-fuzzy data envelopment analysis method are presented in Table (4).

Table 4. FFDEA relative fuzzy efficiencies and classification

DMU	Location	θ_p^{*CRS}	Optimal obj.func.value phase II	CRS classif. FFDEA
1	Hirmand	(1,1,1)	0.00	Efficient
2	Zahak	(0.14,0.47,0.6)	14.5	Inefficient
3	Zabol	(0.06,0.13,0.22)	7.02	Inefficient
4	Hamon	(0.05,0.16,0.29)	6.47	Inefficient
5	Nimroz	(1,1,1)	0.00	Efficient
6	Zahedan	(1,1,1)	0.00	Efficient
7	Mirjave	(0.05,0.11,0.19)	6.35	Inefficient
8	Khash	(1,1,1)	0.00	Efficient
9	Iranshahr	(0.13,0.25,0.42)	7.78	Inefficient
10	Dalgan	(0.98,0.99,0.99)	0.12	Inefficient
11	Phanoj	(0.09,0.24,0.35)	10.9	Inefficient
12	Nikshahr	(0.23,0.47,0.77)	12.4	Inefficient
13	Ghaserqand	(0.05,0.15,0.27)	8.06	Inefficient
14	Konarak	(0,0.07,0.16)	3.39	Inefficient
15	Chabahar	(0.007,0.07,0.17)	3.01	Inefficient
16	Sarbaz	(0.06,0.16,0.29)	6.33	Inefficient
17	Mehrestan	(1,1,1)	0.00	Efficient
18	SibSuran	(1,1,1)	0.00	Efficient
19	Saravan	(1,1,1)	0.00	Efficient

The first column represents the values of the efficiency variable of each unit of the decision-making unit. The decision-making units fall into three classes in terms of efficiency:

i: DMU_p is efficient if $\tilde{\theta}_p^{CRS*} = (1,1,1)$ and for all is $\tilde{s}_i^{+*} = (0,0,0)$ and for all rs $\tilde{s}_r^{+*} = (0,0,0)$

ii: DMU_p has low efficiency if $\tilde{\theta}_p^{CRS*} = (1,1,1)$, and $\sum_{i=1}^{m} s_i^{+*} + \sum_{r=1}^{s} s_r^{+*} \neq (0,0,0)$

iii: DMU_p is inefficient if $\tilde{\theta}_p^{CRS*} \neq (1,1,1)$

Figure 5 represents the efficient units.

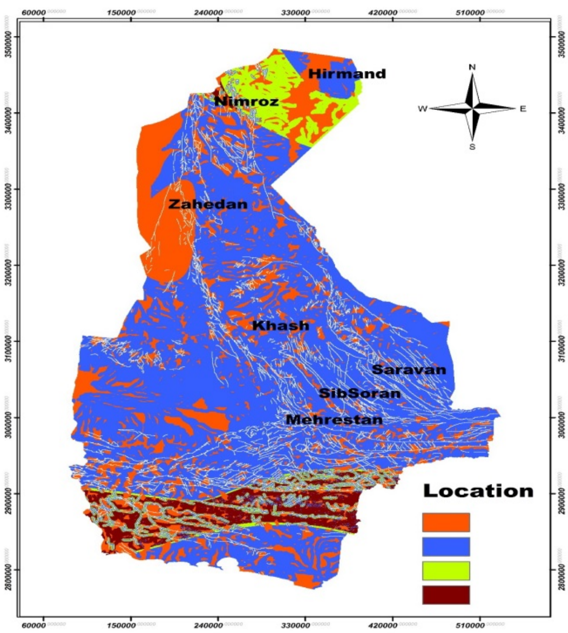


Figure 5. efficient sites

Therefore, according to the values presented in Table 4 and Figure 5, Units 1, 5, 6, 8, 17, 18, and 19 are efficient. These units are coded using the Anderson-Pearson method of full fuzzy data envelopment analysis using MATLAB software. The results of the ranking of efficient units are shown in Table (5).

Table 5. CRS FFDEA super-efficiency

DMU	Location	θ_p^*	Rank
1	Hirmand	0.898121	5
5	Nimroz	0.799603	6
6	Zahedan	1.533934	2
8	Khash	1.047819	4
17	Mehrestan	2.069703	1
18	SibSuran	1.523686	3
19	Saravan	0.597433	7

Based on Table (5), the value of the super efficiency of Mehrestan city is higher than that of other cities. Thus, Mehrestan is ranked first in locating a photovoltaic solar power plant.

5. CONCLUSIONS

Fossil fuels are limited resources that supply energy for millions of years. Moreover, the use of fossil fuels has led to harmful greenhouse gas emissions such as carbon dioxide, which contributes to air pollution and global warming. Thus, due to the limitation and harmful effects of fossil fuels on the environment, renewable energy is a good alternative for energy supply. Additionally, photovoltaic solar energy is easily and abundantly available. Hence, solar energy is a good alternative to fossil fuels. Based on three economic, social and environmental views, this paper identified efficient sub-criteria for locating solar power plants. Then, in order to construct the solar power plant, the sites were classified and their efficiency was assessed and they were ranked using the GIS software and super full fuzzy data envelopment analysis method, respectively. In order to assess the model presented, a case study in Iran was used. A case study of this study was Sistan and Baluchestan province. After entering the geographic information of each of the sub-criteria in the GIS environment, the sites were identified in order to construct a solar power plant. Then, using the full-fuzzy data envelopment analysis method, the efficiency of the sites was calculated.

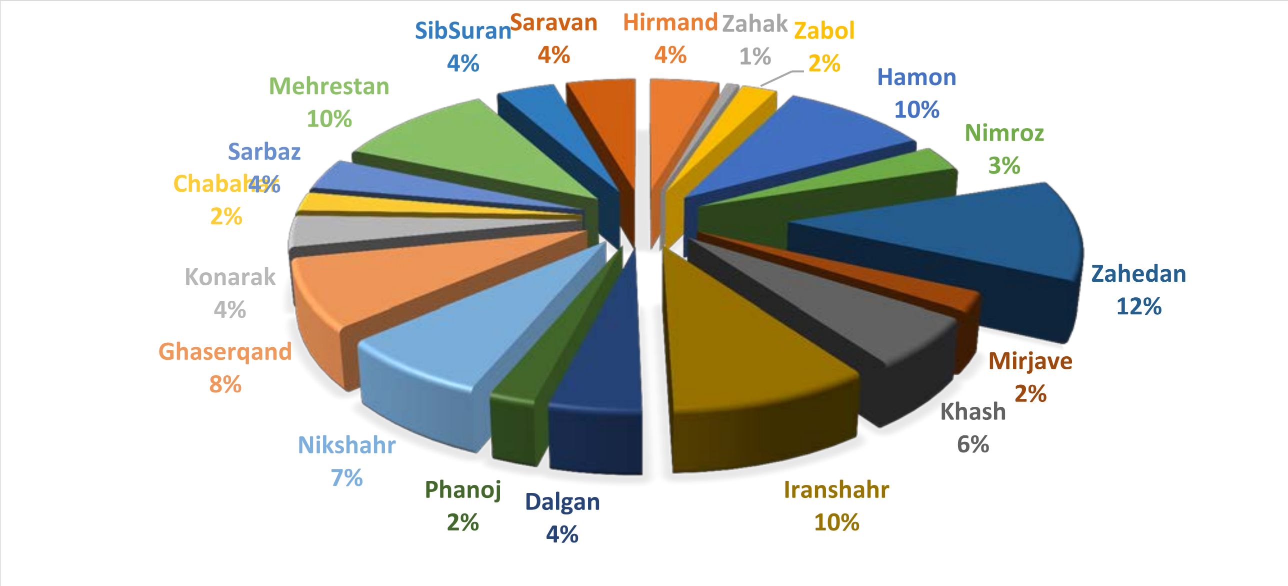


Figure 6. Area of cities

The results of the calculations showed that Hirmand, Nimruz, Zahedan, Khash, Mehrestan, Sib, Suran, and Saravan were identified as efficient units according to the sub-criteria considered for the construction of solar power plant in this province. Therefore, according to Figure 6, approximately 66 % of the area of Sistan and Baluchestan province with these sub-criteria has proper potential for solar power plant construction.

6. ACKNOWLEDGEMENT

The first author, Mohammad Reza Shahraki, likes to acknowledge Financial assistance under scholarship programs received from the University of Sistan and Baluchestan of Iran to conduct this research.

REFERENCES

1. Dehghani, E., Jabalameli, M.S., Jabbarzadeh, A. and Pishvaee, S., "Resilient solar photovoltaic supply chain network design under business-as-usual and hazard uncertainties", ***Computers & Chemical Engineering***, Vol. 111, (2018), 288-310. (https://doi.org/10.1016/j.compchemeng.2018.01.013).
2. Corcelli, F., Ripa, M., Leccisi, E., Cigolotti, V., Fiandra, V., Graditi, G., Sannino, L., Tammaro, M. and Ulgiati S., "Sustainable urban electricity supply chain–Indicators of material recovery and energy savings from crystalline silicon photovoltaic panels end-of-life", ***Ecological Indicators***, Vol. 94, (2016), 37-51. (https://doi.org/10.1016/j.ecolind.2016.03.028).
3. Boxwell, M., The solar electricity handbook-2017 edition: A simple, practical guide to solar energy–designing and installing solar photovoltaic systems, Greenstream Publishing Ltd., UK, (2017). (http://www.sabz-energy.com/solar%20electricity%20handbook%202017.pdf).
4. Olindo, I., Klaus, J., Arno, S., Rene, V.S. and Miro, Z., Solar energy: The physics and engineering of photovoltaic conversion, technologies and systems, UIT Cambridge Ltd., 1st edition, (2016). (https://www.amazon.com/Solar-Energy-Engineering-Photovoltaic-Technologies/dp/1906860327).
5. Akkas, O.P., Erten, M.Y., Cam, E. and Inanc, N., "Optimal site selection for a solar power plant in the central Anatolian region of Turkey", ***International Journal of Photoenergy***, Vol. 15, (2017), 1-13. (https://doi.org/10.1155/2017/7452715).
6. Uyan, M., "GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey", ***Renewable and Sustainable Energy Reviews***, Vol. 28, (2013), 11-17. (https://doi.org/10.1016/j.rser.2013.07.042).
7. Oprea, S.V. and Bara, A., Key technical performance indicators for power plants, Recent Improvements of Power Plants Management and Technology, Chapter 2, (2016). (https://doi.org/10.5772/67858).
8. Aragones-Beltran, P., Chaparro-Gonzalez, F., Pastor-Ferrando, J.P. and Rodriguez-Pozo, F., "An ANP-based approach for the selection of photovoltaic solar power plant investment projects", ***Renewable and Sustainable Energy Reviews***, Vol. 14, No. 1, (2010), 249-264. (https://doi.org/10.1016/j.rser.2009.07.012).
9. Skalna, I., Rębiasz, B., Gaweł, B., Basiura, B., Duda, J., Opiła, J. and Pełech-Pilichowski, T., Advances in fuzzy decision making, Theory and practice, Springer, Vol. 333, (2015), 1-162. (https://doi.org/10.1007/978-3-319-26494-3).
10. Rediske, G., Mairesse Siluk, J.C., Gava Gastaldo, N., Donaduzzi Rigo, P. and Brum Rosa, C., "Determinant factors in site selection for photovoltaic projects: A systematic review", ***International Journal of Energy Research***, Vol. 43, No. 5, (2019), 1689-1701. (https://doi.org/10.1002/er.4321).
11. Merrouni, A.A., Mezrhab, A. and Mezrhab, A., "PV sites suitability analysis in the Eastern region of Morocco", ***Sustainable Energy Technologies and Assessments***, Vol. 18, (2016), 6-15. (https://doi.org/10.1016/j.seta.2016.09.006).
12. Karimi Firozjaei, M., Nematollahi, O., Mijani, N., Nadizadeh Shorabeh, S., Karimi Firozjaei, H. and Toomanian, A., "An integrated GIS-based Ordered Weighted Averaging analysis for solar energy evaluation in Iran: Current conditions and future planning", ***Renewable Energy***, Vol. 136, (2018), 1130-1146. (https://doi.org/10.1016/j.renene.2018.09.090).
13. Sanchez-Lozano, J.M., Teruel-Solano, J., Soto-Elvira, P.L., Garcia-Cascales, M.S. and Socorro, M., "Geographical information systems and multi-criteria decision making methods for the evaluation of solar farms locations: Case study in south-eastern Spain", ***Renewable and Sustainable Energy Reviews***, Vol. 24, (2013), 544-556. (https://doi.org/10.1142/S0219622016500218).
14. Dehghani, E., Jabalameli, M.S., Pishvaee, M.S. and Jabarzadeh, A., "Integrating information of the efficient and anti-efficient frontiers in

DEA analysis to assess location of solar plants: A case study in Iran", ***Journal of Industrial and Systems Engineering***, Vol. 11, No. 1, (2018), 163-179. (www.jise.ir/article_50883.html).

15. Choudhary, D. and Shankar, R., "An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India", ***Energy***, Vol. 42, (2012), 510-521. (https://doi.org/10.1016/j.energy.2012.03.010).
16. Lee, A., Kang, H.Y., Lin, C.Y. and Shen, K.C., "An integrated decision-making model for the location of a PV solar plant", ***Sustainability***, Vol. 7, No. 10, (2015), 13522-13541. (https://doi.org/10.3390/su71013522).
17. Srivastava, Sh., Lohia, P. and Dwivedi, D.K., "Impact of hole transport layer on performance of perovskite solar cell", ***AIP Conference Proceedings***, Vol. 2220, No. 1, (2020), 1-288. (https://doi.org/10.1063/5.0001790).
18. Isabella, O., Jager, K., Smets, A., Swaaij, R.V. and Zeman, M., Solar energy: The physics and engineering of photovoltaic conversion technologies and systems, UIT Cambridge Ltd., (2016). (https://www.amazon.com/Solar-Energy-Engineering-Photovoltaic-Technologies/dp/1906860327).
19. Ozdemir, S. and Sahin, G., "Multi-criteria decision-making in the location selection for a solar PV power plant using AHP", ***Measurement***, Vol. 129, (2018), 218-226. (https://doi.org/10.1016/j.measurement.2018.07.020).
20. Bal, H., Orkcü, H. and Çelebioglu, S., "A new method based on the dispersion of weights in data envelopment analysis", ***Computers & Industrial Engineering***, Vol. 54, No. 3, (2008), 502-512. (https://doi.org/10.1016/j.cie.2007.09.001).
21. Tomlinson, R.F., Thinking about GIS: Geographic information system planning for managers, Fifth edition, Esri Press, (2007). (https://www.amazon.com/Thinking-About-GIS-Geographic-Information/dp/1589483480).
22. Sui D., "Opportunities and impediments for open GIS", ***Transactions in GIS***, Vol. 18, No. 1, (2014), 1-24. (https://doi.org/10.1111/tgis.12075).
23. Low, M. and Collins, A., Getting to know Arc GIS, Fourth edition, Esri Press, (2015). (https://www.amazon.com/Getting-Know-ArcGIS-10-3-10-3-1/dp/1589483820).
24. Azadeh, A., Sheikhalishahi, M., Firoozi, M. and Khalili, S.M., "An integrated multi-criteria Taguchi computer simulation-DEA approach for optimum maintenance policy and planning by incorporating learning effects", ***International Journal of Production Research***, Vol. 51, No. 18, (2013), 5374-5385. (https://doi.org/10.1080/00207543.2013.774496).
25. Dehghani, E., Jabalameli, M.S. and Jabbarzadeh, A., "Robust design and optimization of solar photovoltaic supply chain in an uncertain environment", ***Energy***, Vol. 142, (2018), 139-156. (https://doi.org/10.1016/j.energy.2017.10.004).
26. Campana, P.E., Leduc, S., Kim, M., Liu, J., Kraxner, F., Callum, I.M., Li, H. and Yan, J., "Optimal grassland locations for sustainable photovoltaic water pumping systems in China", ***Energy Procedia***, Vol. 75, (2015), 301-307. (https://doi.org/10.1016/j.egypro.2015.07.355).
27. Wang, T.C. and Tsai, S.Y., "Solar panel supplier selection for the photovoltaic system design by using fuzzy Multi-criteria decision making (MCDM) approaches", ***Energies***, Vol. 11, (2018), 1-22. (https://doi.org/10.3390/en11081989).
28. Ahammed, F. and Azeem, A., "Selection of the most appropriate package of Solar Home System using Analytic Hierarchy Process model in rural areas of Bangladesh", ***Renewable Energy***, Vol. 55, (2013), 6-11. (https://doi.org/10.1016/j.renene.2012.12.020).
29. Wu, Y. and Geng, Sh., "Multi-criteria decision making on selection of solar–wind hybrid power station location: A case of China", ***Energy Conversion and Management***, Vol. 81, (2014), 527-533. (https://doi.org/10.1016/j.enconman.2014.02.056).
30. Sanchez-Lozano, J.M., Garcia-Cascales, M.S. and Lamata, M.T., "Evaluation of suitable locations for the installation of solar thermoelectric power plants", ***Computers & Industrial Engineering***, Vol. 87, (2015), 343-355. (https://doi.org/10.1016/j.cie.2015.05.028).
31. Khanjarpanah, H., Jabbarzadeh, A. and Seyedhosseini, S.M., "A novel multi-period double frontier network DEA to sustainable location optimization of hybrid wind-photovoltaic power plant with real application", ***Energy Conversion and Management***, Vol. 159, (2018),175-188. (https://doi.org/10.1016/j.enconman.2018.01.013).
32. Habibi. A., Sarfarazi, R. and Izadyar, S., "Delphi technique theoretical framework in qualitative research", ***The International Journal Of Engineering And Science (IJES)***, Vol. 3, No. 4, (2014), 8-13. (https://doi.org/v3-i4/Version-4/B03404008013).
33. DeMers, M.N., GIS for dummies, 1st Edition, Kindle Edition, Wiley Publishing, (2009). (https://www.amazon.com/GIS-Dummies-Michael-N-DeMers-ebook/dp/B001FA0GMQ).
34. Hatami-Marbini, A., Tavana, M., Emrouznejad, A. and Saati, S., "Efficiency measurement in fuzzy additive data envelopment analysis", ***Industrial and Systems Engineering***, Vol. 10, (2017), 1-20. (https://doi.org/10.1504/IJISE.2012.044041).
35. Andersen, P. and Petersen, N.C., "A procedure for ranking efficient units in data envelopment analysis", ***Management Science***, Vol. 39, (1993), 1261-1264. (https://doi.org/10.1287/mnsc.39.10.1261).
36. Ghose, D., Naskar, S., Uddin, Sh. and Roy, A.K., "An open source software: Q-GIS based analysis for solar potential of Sikkim (India)", ***International Journal of Open Source Software and Processes***, Vol. 10, No. 1, (2019), 49-68. (https://doi.org/10.4018/IJOSSP.2019010104).
37. Aguayo, P., "Solar energy potential analysis at building scale using LiDAR and satellite data", University of Waterloo, Canada, (2013), 1-164. (http://hdl.handle.net/10012/7603).
38. Olufemi, A., Omitaomu, K., Brandon, R., Blevins, C., Gary, T., Stanton, W., Hadley, J., Harrison, J., Budhendra, L. and Amy, N., "Adapting a GIS based multicriteria decision analysis approach for evaluating new power generating sites", ***Applied Energy***, Vol. 96, (2012), 292-301. (https://doi.org/10.1016/j.apenergy.2011.11.087).
39. Yushchenko, A., Bono, A., Chatenoux, B., Patel, M.K. and Ray, N., "GIS-based assessment of photovoltaic (PV) and concentrated solar power (CSP) generation potential in West Africa", ***Renewable and Sustainable Energy Reviews***, Vol. 81, (2018), 2088-2103. (https://doi.org/10.1016/j.rser.2017.06.021).
40. Garni, H.Z.A. and Awasthi, A., "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia", ***Applied Energy***, Vol. 206, (2017), 1225-1240. (https://doi.org/10.1016/j.apenergy.2017.10.024).
41. Carrion, J.A., Espin Estrella, A., Aznar Dols, F. and Ramos Ridao, A., "The electricity production capacity of photovoltaic power plants and the selection of solar energy sites in Andalusia (Spain)", ***Renewable Energy***, Vol. 33, (2008), 545-552. (https://doi.org/10.1016/j.renene.2007.05.041).
42. Janke, J.R., "Multicriteria GIS modeling of wind and solar farms in Colorado", ***Renewable Energy***, Vol. 35, (2010), 2228-2234. (https://doi.org/10.1016/j.renene.2010.03.014).
43. Charabi, Y. and Gastli, A., "PV site suitability analysis, using GIS based spatial fuzzy multi-criteria evaluation", ***Renewable Energy***, Vol. 36, (2011), 2554-2561. (https://doi.org/10.1016/j.renene.2010.10.037).
44. Saracoglu, B.O., Ohunakin, O.S., Adelekan, D.S., Gill, J., Atiba, O.E., Okokpujie, I.P. and Atayero, A.A., "A framework for selecting the location of very large photovoltaic solar power plants on a global/supergrid", ***Energy Reports***, Vol. 4, (2018), 586-602. (https://doi.org/10.1016/j.egyr.2018.09.002).
45. Dawson, L. and Schlyter, P., "Less is more: Strategic scale site suitability for concentrated solar thermal power in Western Australia", ***Energy Policy***, Vol. 47, (2012), 91-101. (https://doi.org/10.1016/j.enpol.2012.04.025).
46. Doorga, J.R.S., Rughooputh, S.D.D.V. and Boojhawon, R., "Multi-criteria GIS-based modelling technique for identifying potential solar farm sites: A case study in Mauritius", ***Renewable Energy***, Vol. 133, (2019), 1201-1219. (https://doi.org/10.1016/j.renene.2018.08.105).
47. Gherboudj, I. and Ghedira, H., "Assessment of solar energy potential over the United Arab Emirates using remote sensing and weather forecast data", ***Renewable and Sustainable Energy Reviews***, Vol. 55, (2016), 1210-1224. (https://doi.org/10.1016/j.rser.2015.03.099).
48. Sanchez-Lozano, J.M., Garcia-Cascales, M.S. and Lamata, M.T., "Comparative TOPSIS-ELECTRE TRI methods for optimal sites for photovoltaic solar farms. Case study in Spain", ***Journal of Cleaner Production***, Vol. 127, (2016), 387-398. (https://doi.org/10.1016/j.jclepro.2016.04.005).
49. Borgogno Mondino, E., Fabrizio, E. and Chiabrando, R., "Site selection of large ground-mounted photovoltaic plants: A GIS decision support system and an application to Italy", ***International Journal of Green Energy***, Vol. 12, No. 5, (2015), 515-525. (https://doi.org/10.1080/15435075.2013.858047).
50. Wang, Q., M'Ikiugu, M. and Kinoshita, I., "A GIS-based approach in support of spatial planning for renewable energy: A case study of

Fukushima, Japan", ***Sustainability***, Vol. 6, No. 4, (2014), 2087-2117. (https://doi.org/10.3390/su6042087).

51. Sanchez-Lozano, J.M., Henggeler Antunes, C., Garcia-Cascales, M.S. and Dias, L.C., "GIS-based photovoltaic solar farms site selection using ELECTRE-TRI: Evaluating the case for Torre Pacheco, Murcia, Southeast of Spain", ***Renewable Energy***, Vol. 66, (2014), 478-494. (https://doi.org/10.1016/j.renene.2013.12.038).
52. Effat, H.A., "Selection of potential sites for solar energy farms in Ismailia Governorate, Egypt using SRTM and multicriteria analysis", ***International Journal of Advanced Remote Sensing and GIS***, Vol. 2, Cloud Publications, (2013), 205-220. (http://technical.cloud-journals.com/index.php/IJARSG/article/view/Tech-125).
53. Merrouni, A.A., Elalaoui, F.E., Mezrhab, A., Mezrhab, A. and Ghennioui, A., "Large scale PV sites selection by combining GIS and Analytical Hierarchy Process. Case study: Eastern Morocco", ***Renewable Energy***, Vol. 119, (2018), 863-873. (https://doi.org/10.1016/j.renene.2017.10.044).
54. Aydin, N.Y., Kentel, E., Sebnem Duzgun, H., "GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey", ***Energy Conversion and Management***, Vol. 70, (2013), 90-106. (https://doi.org/10.1016/j.enconman.2013.02.004).
55. Majumdar, D. and Pasqualetti, M.J., "Analysis of land availability for utility-scale power plants and assessment of solar photovoltaic development in the state of Arizona, USA", ***Renewable Energy***, Vol. 134, (2019), 1213-1231. (https://doi.org/10.1016/j.renene.2018.08.064).
56. Watson, J.J.W. and Hudson, M.D., "Regional scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation", ***Landscape and Urban Planning***, Vol. 138, (2015), 20-31. (https://doi.org/10.1016/j.landurbplan.2015.02.001).
57. Mentis, D., Welsch, M., Fuso Nerini, F., Broad, O., Howells, M., Bazilian, M. and Rogner., H., "A GIS-based approach for electrification planning—A case study on Nigeria", ***Energy for Sustainable Development***, Vol. 29, (2015), 142-150. (https://doi.org/10.1016/j.esd.2015.09.007).
58. Sabo, M.L., Mariun, N., Hizam, H., Mohd Radzi, M.A. and Zakaria, A., "Spatial matching of large-scale grid-connected photovoltaic power generation with utility demand in Peninsular Malaysia", ***Apllied Energy***, Vol. 191, (2017), 663-688. (https://doi.org/10.1016/j.apenergy.2017.01.087).
59. Tavana, M., Arteaga, F.J.S., Mohammadi, S. and Alimohammadi, M., "A fuzzy multi-criteria spatial decision support system for solar farm location planning", ***Energy Strategy Reviews***, Vol. 18, (2017), 93-105. (https://doi.org/10.1016/j.esr.2017.09.003).
60. Massimo, A., Dell'Isola, M., Frattolillo, A. and Ficco, G., "Development of a Geographical Information System (GIS) for the integration of solar energy in the energy planning of a wide area", ***Sustainability***, Vol. 6, No. 9, (2014), 5730-5744. (https://doi.org/10.3390/su6095730).
61. Yunna, W. and Geng, S., "Multi-criteria decision making on selection of solar–wind hybrid power station location: A case of China", ***Energy Conversion and Management***, Vol. 81, (2014), 527-533. (https://doi.org/10.1016/j.enconman.2014.02.056).
62. Kengpol, A., Rontlaong, P. and Tuominen, M., "A decision support system for selection of solar power plant locations by applying fuzzy AHP and TOPSIS: An empirical study", ***Journal of Software Engineering and Applications***, Vol. 6, No. 9, (2013), 1-12. (https://doi.org/10.4236/jsea.2013.69057).
63. Aly, A., Jensen, S.S. and Pedersen, A.B., "Solar power potential of Tanzania: Identifying CSP and PV hot spots through a GIS multicriteria decision making analysis", ***Renewable Energy***, Vol. 113, (2017), 159-175. (https://doi.org/10.1016/j.renene.2017.05.077).
64. Anwarzai, M.A. and Nagasaka, K., "Utility-scale implementable potential of wind and solar energies for Afghanistan using GIS multi-criteria decision analysis", ***Renewable and Sustainable Energy Reviews***, Vol. 71, (2017), 150-160. (https://doi.org/10.1016/j.rser.2016.12.048).