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Multi-Criteria Decision Making (MCDM) Approaches for Solar Power Plant Location Selection in Viet Nam

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Abstract: The ongoing industrialization and modernization period has increased the demand for energy in Viet Nam. This has led to over-exploitation and exhausts fossil fuel sources. Nowadays, Viet Nam's energy mix is primarily based on thermal and hydro power. The Vietnamese government is trying to increase the proportion of renewable energy. The plan will raise the total solar power capacity from nearly 0 to 12,000 MW, equivalent to about 12 nuclear reactors, by 2030. Therefore, the construction of solar power plants is needed in Viet Nam. In this study, the authors present a multi-criteria decision making (MCDM) model by combining three methodologies, including fuzzy analytical hierarchy process (FAHP), data envelopment analysis (DEA), and the technique for order of preference by similarity to ideal solution (TOPSIS) to find the best location for building a solar power plant based on both quantitative and qualitative criteria. Initially, the potential locations from 46 sites in Viet Nam were selected by several DEA models. Then, AHP with fuzzy logic is employed to determine the weight of the factors. The TOPSIS approach is then applied to rank the locations in the final step. The results show that Binh Thuan is the optimal location to build a solar power plant because it has the highest ranking score in the final phase of this study. The contribution of this study is the proposal of a MCDM model for solar plant location selection in Viet Nam under fuzzy environment conditions. This paper also is part of the evolution of a new approach that is flexible and practical for decision makers. Furthermore, this research provides useful guidelines for solar power plant location selection in many countries as well as a guideline for location selection of other industries.

Keywords: renewable energy; MCDM; solar power plant; DEA; fuzzy AHP; TOPSIS

1. Introduction

The Earth is facing global warming and climate change challenges. Many studies have been done to find solutions by exploiting renewable energy. This is the best way of reducing fossil fuel use, reducing greenhouse gas emissions and maintaining the Earth's temperature increase under 2 °C [1].

Solar energies, including solar energy, photovoltaic, and solar thermal, have many positive effects on the environment, contributing to the sustainable development of society and improving the quality of human life [2]. Nowadays, building solar power plants is becoming easier because the price of solar panels is decreasing [3,4]. The advantages of solar energies are increased CO_2 mitigation, they do not make noise, they minimize toxic wastes and they do not require environmental remediation treatments [5]. In this study, we introduced a MCDM approach including DEA, Fuzzy AHP and TOPSIS to select the best location for building a solar power plant.

Many studies have applied the MCDM approach to various fields of science and engineering and their number has been increasing over the past years. One of the fields where the MCDM model has been employed is the location selection problem. Location selection is an important use of MCDM models. Huang et al. [6], Loken [7] used MCDM models for selecting construction locations in the energy sector. The general procedure of MCDM is shown in Figure 1 [8].

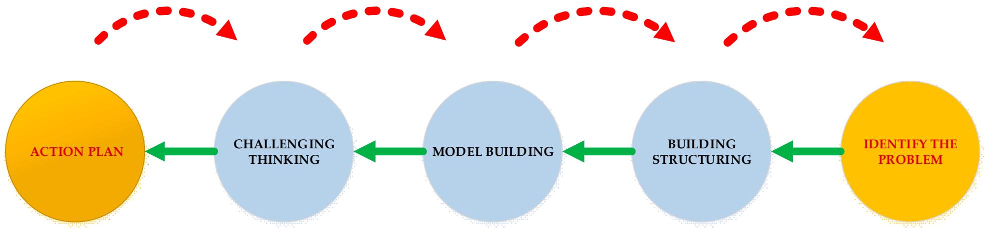

Figure 1. General methodology of MCDM procedure.

The AHP model was proposed by Saaty [9] in the 1980s.There are six steps in the AHP procedure as follows:

(1) Specifying the problem;
(2) Constructing the AHP hierarchy;
(3) Building a pairwise comparison matrix
(4) Defining the weight of factors.
(5) Checking Consistency Index.
(6) Obtaining the overall rating and making decision

The AHP model has many advantages, however, the AHP model cannot accommodate uncertainty and inaccuracies between the perceptions and judgment of the decision makers. Thus, the AHP model with fuzzy logic is proposed to address this problem. In the FAHP model, decision makers can approximate input data by using fuzzy numbers. As with capacity planning, decision makers need to follow a four step procedure when making location selection. These steps are as shown in the following Figure 2 [10,11]:

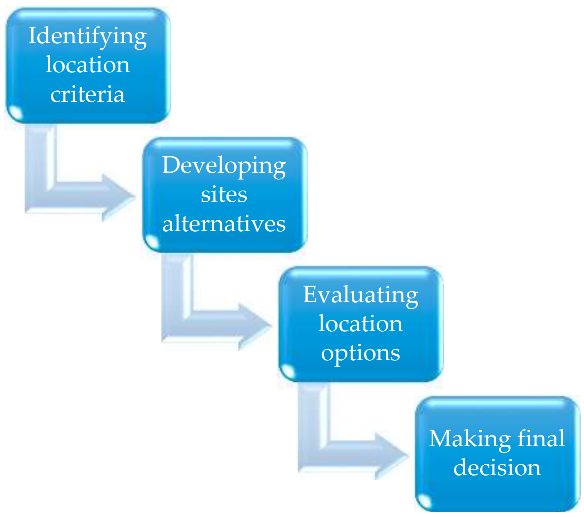

Figure 2. General methodology of location selection problem.

Stage 1. Identifying location criteria. In this stage, all criteria that affect a business will be defined.

Stage 2. Developing site alternatives. Once decision makers know what criteria affect a business, they can identify location options that satisfy the selected criteria.

Stage 3. Evaluating location options. After a set of location options are defined, decision makers will evaluate and rank options by quantitative or qualitative methods.

Stage 4: Making final decisions. The best location with the highest ranking score will be selected.

Azadeh et al. [12] proposed a hybrid MCDM model including DEA, PCA and NT for selecting solar power plant sites. A. Azadeh et al. [13] also presented a hybrid ANN and fuzzy DEA approach to select solar power plant locations. Lee et al. [14] introduced a MCDM model to select PV solar plant locations. Ali et al. combined GIS and MCDM approaches to determine the best place for wind farm location [15].

Gao et al. [16] determined the best enterprise location by using AHP and DEA models. Yang and Kuo [17] proposed an analytic hierarchy process and data envelopment analysis model for location selection. Kabir and Hasin [18] proposed a hybrid fuzzy analytic hierarchy process (FAHP) and PROMEETHE for locating power substation sites. Lee, Kang and Liou [19] proposed a hybrid model including ISM, FANP and VIKOR to select the most suitable PV solar plant site. Suh and Brownson applied GISFS and AHP approaches to select PV solar plant locations [20].

Noorollahi et al. [21] used GIS and FAHP for land analyses in solar farm location. Gan et al. [22] analyzed economic feasibility for renewable energy projects by using integrated TFN-AHP-DEA approaches. Liu et al. proposed a hybrid MCDM model for evaluating the total factor energy efficiency by combining DEA and the Malmquist index in the thermal power industry [23].

Samanlioglu and Ayagˇ [24] used the FAHP and F-PROMETHEE II for solar power plant location selection. Nazari, Aslani and Ghasempour [25] proposed TOPSIS approaches for analysising of solar farm site selection options. Al Garni and Awasthi [26] selected the best location for utility scale solar PV projects by using GIS and an MCDM approach. Merrouni et al. [27] used GIS and the AHP to assess the capacity of Eastern Morocco to host large-scale PV farms. Lozano, García-Cascales and Lamata [28] proposed a comparative TOPSIS-ELECTRE TRI method for photovoltaic solar farm site selection. Beltran et al. [29] used ANP for selection of photovoltaic solar power project sites.

The remainder of the paper provides background materials to assist in developing the MCDM model. Then, a hybrid DEA-FAHP-TOPSIS approach is proposed to select the best location for construction of a solar power plant from among 46 potential locations in Viet Nam. Discussions and the main contributions of this research are presented at the end of this article.

2. Material and Methodology

2.1. Research Development

In this study, the authors present a MCDM model including DEA, Fuzzy AHP and TOPSIS to select the best location for building a solar power plant in Viet Nam. There are four steps in our research, as shown in Figure 2:

Step 1: Determining evaluate criteria. In this step, the criteria for selecting the best location will be defined. The key criteria and sub-criteria have built through expert interviews and the results from others' research. All of the criteria are shown in Figure 3.

Step 2: Employing the DEA model. There are 46 location options that can be highly effective for a solar power plant construction. In this step, several DEA methods including the CCR model, BCC model, and SBM model are applied to rank all options. The options that reach EFF = 1 in all models are potential locations and will be considered in the next step.

Step 3: Applying FAHP model. The FAHP model is the most effective tool for addressing complex problems of decision making with a connection to various qualitative criteria. The weight of criteria will be defined in this step.

Step 4: Implementing the TOPSIS model. The TOPSIS model is employed to rank potential locations. The optimal options have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). The best potential site will be presented in this stage.

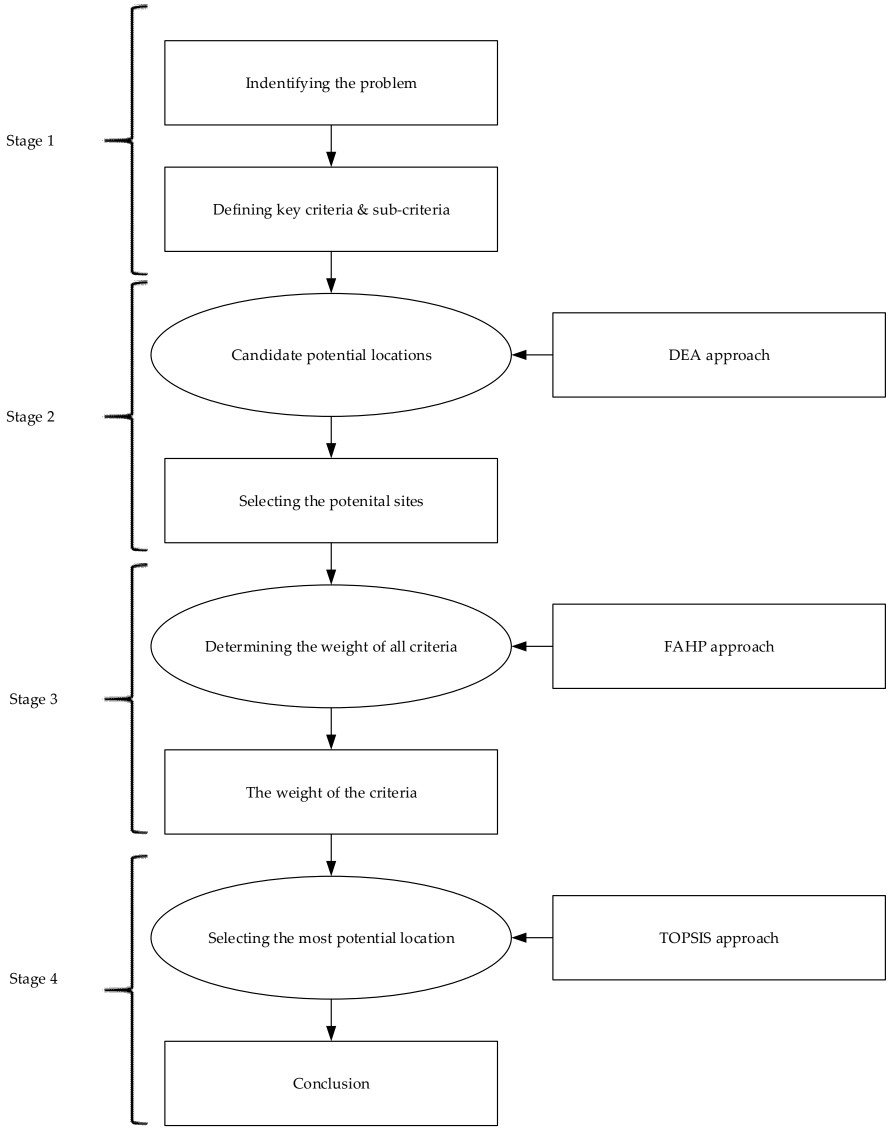

Figure 3. Research methodologies.

2.2. Methodology

2.2.1. Data Envelopment Analysis Model

(1) Charnes-Cooper-Rhodes model (CCR model)

The basis DEA model is CCR model [30], CCR model is defined as follows:

$$\max_{c.a} \xi = \frac{a^V y_0}{c^V x_0}$$

S.t :

$$\begin{aligned} a^V y_e - c^V x_e &\leq 0,\ e = 1,\ 2, \ldots, n \\ a &\geq 0 \\ c &\geq 0 \end{aligned} \quad (1)$$

Constraints mean that the ratio of virtual output to virtual input cannot exceed 1 per DMU. The goal is obtain a rate of weighted output for weighted inputs. Due to constraints, the optimal goal value ξ^* is at most 1.

DMU_0 is CCR efficient if $\xi^* = 1$ and the result must have at least 1 optima $a^* > 0$ and $c^* > 0$. In addition, the fractional program can be described as a linear program (LP) as follows [31]:

$$\max_{c.a} \xi = a^v y_0$$

S.t :

$$\begin{gathered} c^v x_0 - 1 = 0 \\ a^v y_e - c^v x_e \leq 0,\ e = 1,\ 2, .., n \\ c \geq 0 \\ a \geq 0 \end{gathered} \tag{2}$$

The fractional program (1) is equal to the linear program (2) [32]. The Farrell model of linear program (2) with variable ξ and a nonnegative vector $\alpha = \alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_f$ as [31]:

$$max \sum_{b=1}^{m} s_i^- + \sum_{r=1}^{q} s_r^+$$

S.t :

$$\begin{gathered} \sum_{e=1}^{n} x_{be}\alpha_b + s_b^- = \xi x_{b0},\ b = 1,\ 2, \ldots, p \\ \sum_{e=1}^{n} y_{re}\alpha_e - s_r^+ = y_{r0},\ r = 1,\ 2, \ldots, q \\ \alpha_e \geq 0,\ e = 1,\ 2, \ldots, n \\ s_b^- \geq 0, b = 1, 2, \ldots, p \\ s_r^+ \geq 0, r = 1, 2, \ldots, q \end{gathered} \tag{3}$$

The model (3) has a feasible solution, $\xi = 1, \alpha_0^* = 1, \alpha_j^* = 0, (j \neq 0)$, which affects optimal value when ξ^* is not greater than 1. The optimal solution, ξ^*, provides an effective point for a specific DMU. The process will be repeated for each DMU_e, $e = 1, 2, \ldots, n$. DMUs are inefficient when $\xi^* < 1$, while DMUs are boundary points if $\xi^* = 1$. We can avoid weakly efficient frontier points by invoking a linear program as follows [31]:

$$max \sum_{b=1}^{m} s_b^- + \sum_{r=1}^{s} s_r^+$$

S.t :

$$\begin{gathered} \sum_{e=1}^{n} x_{be}\alpha_e + s_b^- = \xi x_{b0},\ b = 1,\ 2, \ldots, p \\ \sum_{e=1}^{n} y_{re}\alpha_e - s_r^+ = y_{r0},\ r = 1,\ 2, \ldots, q \\ \alpha_e \geq 0,\ e = 1,\ 2, \ldots, n \\ s_b^- \geq 0, b = 1, 2, \ldots, p \\ s_r^+ \geq 0, r = 1, 2, \ldots, q \end{gathered} \tag{4}$$

In this case, we note that the choices of s_b^- and s_r^+ do not affect the optimal ξ^*.

DMU_0 achieves 100% efficiency if and only if both (1) $\xi = 1$ and (2) $s_b^{-*} = s_r^+ = 0$. The performance of DMU_0 is weakly efficient if and only if both (1) $\xi^* = 1$ and (2) $s_b^{-*} \neq 0$ and $s_r^+ \neq 0$ for i or r in optimal options. Thus, the preceding development amounts to solving the problem as follows [31]:

$$min\theta - \mu\left(\sum_{b=1}^{m} s_b^- + \sum_{r=1}^{s} s_r^+\right)$$

S.t :

$$\begin{array}{c}\sum_{b=1}^{n} x_{be}\alpha_e + s_b^- = \xi x_{b0},\ b = 1,\ 2, \ldots, p \\ \sum_{e=1}^{n} y_{re}\alpha_e - s_r^+ = y_{r0},\ r = 1,\ 2, \ldots, q \\ \alpha_e \geq 0,\ e = 1,\ 2, \ldots, n \\ s_b^- \geq 0, b = 1, 2, \ldots, p \\ s_r^+ \geq 0, r = 1, 2, \ldots, q\end{array} \quad (5)$$

In this case, s_b^- and s_r^+ variables will be used to convert the inequalities into equivalent equations. This is similar to solving (3) by minimizing ξ in first stage and then fixing $\xi = \xi^*$ as in (4), where the slacks variables achieve a maximum value but do not affect to previously determined value of $\xi = \xi^*$. The objective will be converted from max to min, as in (1), to obtain [31]:

$$\max_{c.a} \xi = \frac{c^V x_0}{a^V y_e}$$

S.t :

$$\begin{array}{c} a^V x_0 \leq c^V y_e,\ e = 1,\ 2, \ldots, n \\ c \geq \varepsilon > 0 \\ a \geq \varepsilon > 0 \end{array} \quad (6)$$

If the $\varepsilon > 0$ and the non-Archimedean element is defined, the input models are similar to model (2) and (5) as follows [31]:

$$\max_{c.a} \xi = c^V x_0$$

S.t :

$$\begin{array}{c} a^V y_0 = 1 \\ c^V x_o - a^V y_e \geq 0,\ e = 1,\ 2, \ldots, n \\ c \geq \varepsilon > 0 \\ a \geq \varepsilon > 0 \end{array} \quad (7)$$

and:

$$max\phi - \varepsilon\left(\sum_{b=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)$$

S.t :

$$\begin{array}{c}\sum_{e=1}^{n} x_{be}\alpha_e + s_b^- = x_{b0},\ b = 1,\ 2, \ldots, p \\ \sum_{e=1}^{n} y_{re}\alpha_e - s_r^+ = \varnothing y_{r0},\ r = 1,\ 2, \ldots, q \\ \alpha_e \geq 0,\ e = 1,\ 2, \ldots, n \\ s_b^- \geq 0, b = 1, 2, \ldots, p \\ s_r^+ \geq 0, r = 1, 2, \ldots, q\end{array} \quad (8)$$

The CCR input-oriented (CCR-I) has the dual multiplier model of is expressed as [31]:

$$\max z = \sum_{r=1}^{q} \partial_r y_{r0}$$

S.t :

$$\begin{array}{c} \sum_{r=1}^{q} \partial_r y_{re} - \sum_{r=1}^{q} a_r y_{re} \leq 0 \\ \sum_{b=1}^{p} a_b x_{b0} = 1 \\ c_r, a_b \geq \varepsilon > 0 \end{array} \tag{9}$$

The CCR output-oriented (CCR-O) has the dual multiplier model of is expressed as [31]:

$$\min q = \sum_{b=1}^{p} a_b x_{b0}$$

S.t :

$$\begin{array}{c} \sum_{b=1}^{p} a_b x_{be} - \sum_{r=1}^{q} \partial_r y_{re} \leq 0 \\ \sum_{r=1}^{q} \partial_r y_{r0} = 1 \\ c_r, a_b \geq \varepsilon > 0 \end{array} \tag{10}$$

(2) Banker Charnes Cooper model (BCC Model)

Banker et al. introduced input-oriented BBC model (BCC-I) [30], which is able to assess the efficiency of DMU_0 by solving the following linear program (11) [31]:

$$\xi_B = min\xi$$

S.t :

$$\begin{array}{c} \sum_{e=1}^{n} x_{be}\alpha_e + s_b^- = \xi x_{b0},\ b = 1,\ 2, \ldots, p \\ \sum_{e=1}^{n} y_{re}\alpha_e - s_r^+ = y_{r0},\ r = 1,\ 2, \ldots, q \\ \sum_{k=1}^{n} \alpha_k = 1 \\ \alpha_k \geq 0, k = 1, 2, \ldots, n \end{array} \tag{11}$$

We can avoid the weakly efficient frontier points by invoking a linear program as follows [31]:

$$max \sum_{b=1}^{m} s_b^- + \sum_{r=1}^{s} s_r^+$$

S.t :

$$\begin{array}{c} \sum_{e=1}^{n} x_{be}\alpha_e + s_b^- = \xi x_{b0},\ b = 1,\ 2, \ldots, p \\ \sum_{e=1}^{n} y_{re}\alpha_e - s_r^+ = y_{r0},\ r = 1,\ 2, \ldots, q \\ \sum_{k=1}^{n} \alpha_k = 1 \\ \alpha_k \geq 0,\ k = 1,\ 2, \ldots, n \\ s_b^- \geq 0, b = 1, 2, \ldots, p \\ s_r^+ \geq 0, r = 1, 2, \ldots, q \end{array} \tag{12}$$

Therefore, this is the first multiplier form to the solve problem as follows [31]:

$$\min \xi - \varepsilon\left(\sum_{b=1}^{m} s_b^- + \sum_{r=1}^{s} s_r^+\right)$$

S.t :

$$\begin{gathered} \sum_{e=1}^{n} x_{be}\alpha_e + s_b^- = \xi x_{i0},\ b = 1,\ 2, \ldots, p \\ \sum_{e=1}^{n} y_{re}\alpha_e - s_r^+ = y_{r0},\ r = 1,\ 2, \ldots, q \\ \sum_{k=1}^{n} \alpha_k = 1 \\ \alpha_k \geq 0,\ k = 1,\ 2, \ldots, n \\ d_b^- \geq 0, b = 1, 2, \ldots, p \\ d_r^+ \geq 0, r = 1, 2, \ldots, q \end{gathered} \tag{13}$$

The linear program (12) gives us the second multiplier form, which is expressed as [31]:

$$\max_{c.a,a_0} \xi_B = a^V y_0 - a_0$$

S.t :

$$\begin{gathered} c^V x_0 = 1 \\ a^V y_e - c^V x_e - a_0 \leq 0,\ e = 1,\ 2, \ldots, n \\ c \geq 0 \\ a \geq 0 \end{gathered} \tag{14}$$

In this case v and u, which are mentioned in the Formula (14), are vectors, and the scalar v_0 may be positive or negative or zero. Thus, the equivalent BCC fractional program is got from the dual program (14) as [31]:

$$\max_{c.a} \xi = \frac{a^V y_0 - a_0}{c^V x_0}$$

S.t :

$$\begin{gathered} \frac{a^V y_e - a_0}{c^V x_e} \leq 1,\ e = 1,\ 2, \ldots, n \\ c \geq 0 \\ a \geq 0 \end{gathered} \tag{15}$$

The DMU_0 can be called BCC efficient if an optimal solution $(\xi_B^*,\ s^{-*}, s^{+*})$ as claimed in this two phase processes for model (9) satisfies $\xi_B^* = 1$ and has no slack $s^{-*} = s^{+*} = 0$. On the other hand, it is BCC inefficient.

The improved activity $(\xi^* x - s^{-*}, y + s^{+*})$ also can be illustrated as BCC efficient [31]. A DMU, which has a minimum input value for any input item, or a maximum output value for any output item, is BCC-efficient.

The output-oriented BCC model (BCC-O) is:

$$\max \eta$$

S.t :

$$\begin{gathered} \sum_{e=1}^{n} x_{be}\alpha_e + s_b^- = \xi x_{b0},\ b = 1,\ 2, \ldots, p \\ \sum_{e=1}^{n} y_{re}\alpha_e - s_r^+ = \eta y_{r0},\ r = 1,\ 2, \ldots, q \\ \sum_{k=1}^{n} \alpha_k = 1 \\ \alpha_k \geq 0,\ k = 1,\ 2, \ldots, g \end{gathered} \tag{16}$$

From the linear program (16), we have the associate multiplier form, which is expressed as [31]:

$$\min_{c.a,c_0} a^V y_0 - a_0$$

S.t :

$$\begin{array}{c} a^V y_0 = 1 \\ c^V x_e - a^V y_e - a_0 \leq 0,\ e = 1,\ 2, \ldots, n \\ c \geq 0 \\ a \geq 0 \end{array} \tag{17}$$

In the envelopment model, the v_0 is the scalar combined with $\sum_{k=1}^{n} \alpha_k = 1$. In conclusion, the authors achieve the equivalent (BCC) fractional programming formulation for model (17) [31]:

$$\min_{c.a,c_0} \frac{c^V x_0 - c_0}{a^V y_0}$$

S.t :

$$\begin{array}{c} \frac{c^V x_e - a_0}{a^V y_e} \leq 1,\ e = 1,\ 2, \ldots, n \\ c \geq 0 \\ a \geq 0 \end{array} \tag{18}$$

(3) Slacks Based Measure model (SBM Model)

The SBM model is developed by Tone [33,34]. It has three elements, i.e., input-oriented, output-oriented, and non-oriented.

Input-Oriented SBM (SBM-I-C)

Input-oriented SBM under constant-returns-to-scale-assumption [31]:

$$\rho_I^* = \min_{\alpha,\ s^-, s^+} 1 - \frac{1}{m} \sum_{b=1}^{m} \frac{s_b^-}{x_{bh}}$$

S.t :

$$\begin{array}{c} x_{bc} = \sum_{e=1}^{m} x_{bc}\alpha_b + s_b^-\ ,\ b = 1,\ 2,\ \ldots p \\ y_{rc} = \sum_{e=1}^{m} y_{rc}\alpha_e - s_r^+\ ,\ r = 1,\ 2,\ \ldots q \\ \alpha_e \geq 0,\ k\ (\forall j),\ s_b^- \geq 0\ (\forall e), s_r^+ \geq 0\ (\forall e) \end{array} \tag{19}$$

is called the SBM input efficiency.

Output-Oriented SBM (SBM-O-C)

The output-oriented SBM efficiency ρ_O^* of $DMU_z = (x_z, y_z)$ is defined by [SBM-O-C] [32]:

$$\frac{1}{\rho_O^*} = \max_{\alpha, s^-, s^+} 1 + \frac{1}{s} \sum_{r=1}^{q} \frac{s_r^+}{y_{rz}}$$

S.t :

$$\begin{array}{c} x_{bz} = \sum_{e=1}^{n} x_{be}\alpha_e + s_e^- (b = 1, ..p) \\ y_{bz} = \sum_{e=1}^{n} y_{be}\alpha_e + s_b^+ (b = 1, \ldots p) \\ \alpha_e \geq 0 (\forall e),\ s_e^- \geq 0 (\forall b),\ s_e^+ \geq 0\ (\forall r) \end{array} \tag{20}$$

2.2.2. Fuzzy Analytic Hierarchy Process (FAHP)

(1) Fuzzy sets and fuzzy number

Fuzzy sets were proposed by Zadeh in 1965 [35] for solving problems existing in uncertain environments. A fuzzy set is a function that shows a degree of dependence of one fuzzy number on a set number, where each value of the membership function is between [0, 1] [36,37]. The triangular fuzzy number (TFN) can be defined as (l, m, u). The parameters l, m and u ($l \le m \le u$), indicate the smallest, the promising and the largest value. A triangular fuzzy number are shown in Figure 4.

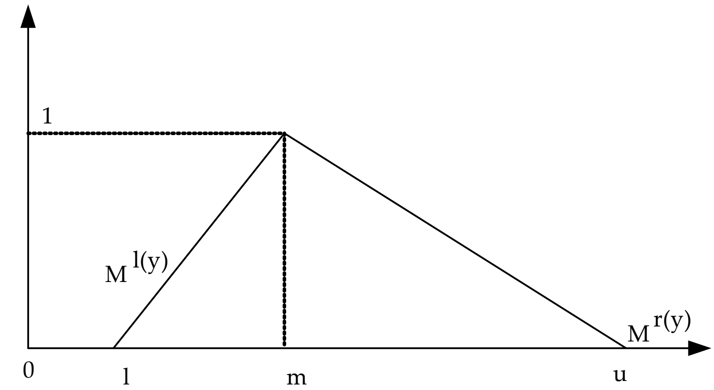

Figure 4. Triangular Fuzzy Number.

TFN can be defined as:

$$\mu\left(\frac{x}{\widetilde{M}}\right) = \begin{cases} 0, & x < l, \\ \frac{x-l}{m-l} & l \le x \le m, \\ \frac{u-x}{u-m} & m \le x \le u, \\ 0, & x > u, \end{cases} \tag{21}$$

A fuzzy number is given by the representatives of each level of membership are the following:

$$\widetilde{M} = (M^{l(y)}, M^{r(y)}) = [l + (m-l)y,\ u + (m-u)y], y\ \in [0,1] \tag{22}$$

l(y), *r(y)* indicates both the left side and the right side of a NF. Two positive triangular fuzzy numbers (l_1, m_1, u_1) and (l_1, m_2, u_2) are introduced as below:

$$\begin{aligned} (l_1,\ m_1,\ u_1) + (l_2,\ m_2,\ u_2) &= (l_1 + l_2,\ m_1 + m_2, u_1 + u_2) \\ (l_1,\ m_1,\ u_1) - (l_2,\ m_2,\ u_2) &= (l_1 - l_2,\ m_1 - m_2, u_1 - u_2) \\ (l_1,\ m_1,\ u_1) \times (l_2,\ m_2,\ u_2) &= (l_1 \times l_2,\ m_1 \times m_2, u_1 \times u_2) \\ \frac{(l_1,\ m_1,\ u_1)}{(l_2,\ m_2,\ u_2)} &= (l_1/u_2,\ m_1/m_2, u_1/l_2) \end{aligned} \tag{23}$$

(2) Analytical hierarchy process (AHP)

The AHP method uses a pairwise comparisons maxtrix for determing priorities on each level of the hierarchy that are quantified using a 1–9 scale are shown in Table 1.

Table 1. 1–9 Saaty Scale.

Importance Intensity	Definition
1	Equally importance
3	Moderate importance
5	Strongly more importance
7	Very strong more importance
9	Extremely importance
2,4,6,8	Intermediate values

(3) Fuzzy AHP

In this section, the weight of criteria are dedined by fuzzy AHP. There are eight steps in this process, as follows:

Step 1: Calculation of TFNs

A pairwise comparison of the criteria will be performed. Instead of a numerical value, the fuzzy analytical hierarchy process is a range of values that are combined for evaluating criteria in this step [38]. This scale is applied in Parkash's [39] fuzzy prioritization method. The fuzzy conversion scales are shown in Table 2.

Table 2. The fuzzy conversion scale.

Importance Intensity	Triangular Fuzzy Scale	Importance Intensity	Triangular Fuzzy Scale
1	(1, 1, 1)	1/1	(1, 1, 1)
2	(1, 2, 3)	1/2	(1/3, 1/2, 1/1)
3	(2, 3, 4)	1/3	(1/4, 1/3, 1/2)
4	(3, 4, 5)	1/4	(1/5, 1/4, 1/3)
5	(4, 5, 6)	1/5	(1/6, 1/5, 1/4)
6	(5, 6, 7)	1/6	(1/7, 1/6, 1/5)
7	(6, 7, 8)	1/7	(1/8, 1/7, 1/6)
8	(7, 8, 9)	1/8	(1/9, 1/8, 1/7)
9	(9, 9, 9)	1/9	(1/9, 1/9, 1/9)

Step 2: Calculation of $\widetilde{P}_1$

A pairwise comparison and relative scores as (24):

$$\widetilde{P}_a = (l_a, m_a, u_a) \tag{24}$$

$$l_a = (l_{a1} \otimes l_{a2} \otimes \ldots \otimes l_{ai})^{\frac{1}{i}},\ a = 1,\ 2,\ \ldots i \tag{25}$$

$$m_a = (m_{a1} \otimes m_{a2} \otimes \ldots \otimes m_{ai})^{\frac{1}{i}},\ a = 1,\ 2,\ \ldots i \tag{26}$$

$$u_a = (u_{a1} \otimes u_{a2} \otimes \ldots \otimes u_{ai})^{\frac{1}{i}},\ i = 1,\ 2,\ \ldots i \tag{27}$$

Step 3: Calculation of $\widetilde{P}_Y$

The geometric fuzzy mean was established by (28):

$$\widetilde{P}_Y = \left(\sum_{a=1}^{i} l_a, \sum_{a=1}^{i} m_a, \sum_{a=1}^{i} u_a\right) \tag{28}$$

Step 4: Calculation of $\widetilde{R}$

The fuzzy geometric mean was determined as:

$$\widetilde{R} = \frac{\widetilde{P}_a}{\widetilde{P}_Y} = \frac{(l_a, m_a, u_a)}{\sum_{a=1}^{i} l_a, \sum_{a=1}^{i} m_a, \sum_{a=1}^{i} u_i} = \left[\frac{l_a}{\sum_{a=1}^{i} u_a}, \frac{m_a}{\sum_{a=1}^{i} m_a}, \frac{u_a}{\sum_{a=1}^{i} l_a}\right] \tag{29}$$

Step 5: Calculation of $Wa_{\beta l}$

The criteria depending on β cut values are defined for the calculated β. The fuzzy priorities will apply for lower and upper bounds for each β value:

$$Wa_{\beta l} = \left(Wal_{\beta l}, Wau_{\beta l}\right); a = 1,\ 2,\ \ldots i; l = 1,\ 2,\ \ldots L \tag{30}$$

Step 6: Calculation of W_{al}, W_{au}

Values of W_{al}, W_{au} are calculated by combining the lower and the upper values, and dividing them by the total β values:

$$W_{al} = \frac{\sum_{a=1}^{i} \beta(W_{al})_l}{\sum_{l=1}^{L} \beta_l}; a = 1,\ 2,\ \ldots i; l = 1,\ 2,\ \ldots L \tag{31}$$

$$W_{au} = \frac{\sum_{a=1}^{i} \beta(W_{au})_l}{\sum_{l=1}^{L} \beta_l}; a = 1,\ 2,\ \ldots i; l = 1,\ 2,\ \ldots L \tag{32}$$

Step 7: Calculation of X_{ad}

Combining the upper and the lower bounds values by using the optimism index (γ) to order to defuzzify:

$$W_{ad} = \gamma \times W_{au} + (1-\gamma) \times W_{al}; \gamma\ \in [0,1]; a = 1,\ 2, \ldots i \tag{33}$$

Step 8: Calculation of W_{az}

The defuzzification values priorities are normalization by:

$$W_{az} = \frac{W_{ad}}{\sum_{a=1}^{i} W_{ad}}; a = 1, 2, ..i \tag{34}$$

2.2.3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

Hwang and Yoon [40] is presented the TOPSIS approach in 1981. The main concept of TOPSIS is that the best options should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS) [41]. There are m alternatives and n criteria and the result of TOPSIS model shows the score of each option [42]. The method is illustrated below:

Step 1: Determine the normalized decision matrix, raw values (x_{ij}) are converted to normalized values (n_{ij}) by:

$$h_{ab} = \frac{y_{ab}}{\sqrt{\sum_{a}^{g} y_{ab}^2}},\ a = 1, \ldots g; b = 1, ..h. \tag{35}$$

Step 2: Calculate the weight normalized value (v_{ij}), by:

$$l_{ab} = P_{ab} h_{ab},\ a = 1, \ldots, g; b = 1, \ldots, h. \tag{36}$$

where Pj is the weight of the a^{th} criterion and $\sum_{b=1}^{h} p_p = 1$.
Step 3: Calculate the PIS (B^+) and PIS (B^-), where l_a^+ indicate the maximum values of l_{ab} and l_a^- indicates the minimum value l_{ab}:

$$B^+ = \{l_1^+, \ldots, l_h^+\} = \left\{ \left(\max_b l_{ab} \middle| a \in A \right), \left(\min_b l_{ab} \middle| a \in A \right) \right\}, \tag{37}$$

$$B^- = \{l_1^-, \ldots, l_n^-\} = \left\{ \left(\min_b l_{ab} \middle| a \in A \right), \left(\max_b l_{ab} \middle| b \in B \right) \right\}, \tag{38}$$

where A is related with profit criteria, and B is related with cost criteria.

Step 4: Determine a distance of the PIS (S_a^+) separately by:

$$S_a^+ = \left\{ \sum_{b=1}^{h} (l_{ab} - l_b^+)^2 \right\}^{\frac{1}{2}},\ a = 1,\ \ldots,\ g \tag{39}$$

Similarly, the separation from the NIS $\left(S_i^-\right)$ is given as:

$$S_a^- = \left\{ \sum_{b=1}^{h} \left(l_{ab} - l_b^-\right)^2 \right\}^{\frac{1}{2}}, \ a = 1, \ \ldots, \ g \tag{40}$$

Step 5: Determine the relationship proximal to the problem solving approaches, proximal relationship from option B_a to option B^+:

$$C_a = \frac{S_a^-}{S_a^+ + S_a^-}, \ a = 1, \ldots, g. \tag{41}$$

Step 6: Rank alternatives to determine the best option with the maximum value of C_a

3. Case Study

According to the research results of many scientists, Viet Nam is the best place with natural conditions and favorable terrain to develop renewable energy. Viet Nam is located in the tropical monsoon region, the average number of sunshine hours in the year ranges from 2500 to 3000 h and the average temperature of over 21 °C. In addition, Viet Nam has abundant solar radiation sources. Viet Nam's solar map is shown in Figure 5.

Figure 5. Viet Nam's solar resources map. (*Source*: The World Bank).

The authors collected data from 46 potential sites, which are able to invest in solar power plants as shown in Table 3.

Table 3. List of the 46 locations identified in Viet Nam.

No.	Sites	DMUs	No.	Sites	DMUs
1	Bac Giang	DMU 1	24	My Tho	DMU 24
2	Binh Thuan	DMU 2	25	Nam Dinh	DMU 25
3	Buon Ma Thuoc	DMU 3	26	Nha Trang	DMU 26
4	Ca Mau	DMU 4	27	Ninh Binh	DMU 27
5	Cam Ranh	DMU 5	28	Phu Lien	DMU 28
6	Can Tho	DMU 6	29	Phu Quoc	DMU 29
7	Cang Long	DMU 7	30	Phuoc Long	DMU 30
8	Chau Doc	DMU 8	31	Pleiku	DMU 31
9	Con Son	DMU 9	32	Quang Ngai	DMU 32
10	Da Nang	DMU 10	33	Quy Nhon	DMU 33
11	Dien Bien	DMU 11	34	Rach Gia	DMU 34
12	Dong Ha	DMU 12	35	Soc Trang	DMU 35
13	Dong Hoi	DMU 13	36	Son La	DMU 36
14	Ha Tinh	DMU 14	37	Tan Son Nhat	DMU 37
15	Hai Duong	DMU 15	38	Tay Ninh	DMU 38
16	Hoa Binh	DMU 16	39	Thai Binh	DMU 39
17	Hoang Sa	DMU 17	40	Thanh Hoa	DMU 40
18	Hong Gai	DMU 18	41	Tuy Hoa	DMU 41
19	Hue	DMU 19	42	Uong Bi	DMU 42
20	Hung Yen	DMU 20	43	Viet Tri	DMU 43
21	Kon Tum	DMU 21	44	Vinh	DMU 44
22	Lai Chau	DMU 22	45	Vinh Yen	DMU 45
23	Moc Hoa	DMU 23	46	Vung Tau	DMU 46

DEA is a mathematical programming technique that determines the relative effectiveness of multiple input and output decision makers (DMUs) [43]. There are two inputs, two outputs in including Temperature, Wind Speed, Sunshine hours, Elevation [14]. Inputs and Outputs of DMUs are shown in Figure 6.

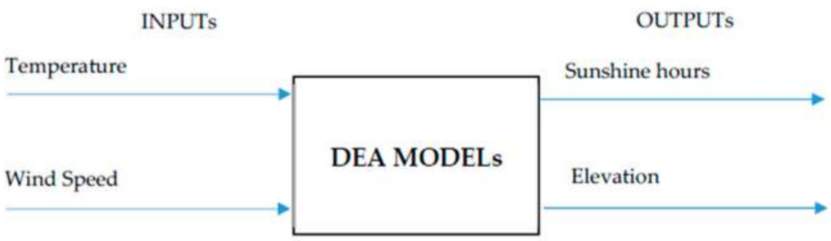

Figure 6. Inputs and Output of DEA Models.

Some additional data about the 46 locations are shown in Table 4.

Table 4. Data set of the 46 DMUs.

DMUs	Temperature	Wind Speed	Sunshine Hours	Elevation
DMU 1	23.40	1.80	1695.00	29.00
DMU 2	26.80	2.20	2878.00	10.00
DMU 3	23.60	2.80	2460.00	467.00
DMU 4	26.80	1.30	2300.00	1.00
DMU 5	26.90	2.80	2672.00	20.00
DMU 6	26.60	1.50	2561.00	1.00
DMU 7	26.80	1.80	2621.00	1.00
DMU 8	27.20	1.70	2589.00	2.00
DMU 9	27.00	2.60	2351.00	120.00
DMU 10	25.80	1.50	2182.00	5.00

Table 4. *Cont.*

DMUs	Temperature	Wind Speed	Sunshine Hours	Elevation
DMU 11	22.00	0.90	2034.00	490.00
DMU 12	25.10	2.60	1910.00	10.00
DMU 13	24.50	2.50	1857.00	13.00
DMU 14	23.90	1.50	1664.00	7.00
DMU 15	23.40	2.40	1658.00	1.00
DMU 16	23.40	1.00	1641.00	23.00
DMU 17	26.80	4.80	2788.00	38.00
DMU 18	23.10	2.70	1690.00	3.00
DMU 19	25.20	1.50	1970.00	3.00
DMU 20	23.30	1.70	1625.00	4.00
DMU 21	23.50	1.40	2374.00	530.00
DMU 22	23.00	0.80	1824.00	213.21
DMU 23	27.30	2.00	2686.00	1.00
DMU 24	27.00	1.70	2645.00	1.00
DMU 25	23.50	2.20	1619.00	1.00
DMU 26	26.60	2.40	2540.00	3.00
DMU 27	23.60	1.90	1611.00	12.00
DMU 28	23.10	3.00	1693.00	8.00
DMU 29	27.10	3.00	2364.00	53.00
DMU 30	25.50	1.60	2521.00	192.00
DMU 31	21.70	2.70	2412.00	756.00
DMU 32	25.70	1.30	2248.00	14.00
DMU 33	26.90	1.90	2470.00	8.00
DMU 34	27.40	2.80	2470.00	1.00
DMU 35	26.80	1.70	2423.00	1.00
DMU 36	21.10	1.10	2000.00	673.00
DMU 37	27.40	2.80	2489.00	4.00
DMU 38	26.90	1.50	2672.00	20.00
DMU 39	23.30	2.10	1639.00	3.00
DMU 40	23.60	1.70	1690.00	18.00
DMU 41	26.50	2.20	2467.00	2.00
DMU 42	23.50	1.90	1920.00	37.00
DMU 43	23.50	1.50	1601.00	20.00
DMU 44	23.90	1.80	1677.00	10.00
DMU 45	23.80	1.60	1670.00	18.00
DMU 46	26.70	3.00	2728.00	1.00

For selecting the best potential location, several DEA models including CCR-I; CCR-O; BCC-I; BCC-O and SBM-I-C are applied in this step. The results of the DEA models are shown in Table 5.

Table 5. The results of the DEA models.

DMUs	DEA MODEL				
	CCR-I	CCR-O	BCC-I	BCC-O	SBM-I-C
DMU 1	0.68383	0.68383	0.90171	0.69605	0.60007
DMU 2	1	1	1	1	1
DMU 3	0.94215	0.94215	0.94243	0.95405	0.82069
DMU 4	0.89423	0.89423	0.89427	0.93521	0.85555
DMU 5	0.90842	0.90842	0.91247	0.93074	0.76786
DMU 6	0.96655	0.96655	0.96663	0.967	0.93596
DMU 7	0.94796	0.94796	0.94929	0.95109	0.89048
DMU 8	0.93456	0.93456	0.93693	0.94805	0.87444
DMU 9	0.80141	0.80141	0.82014	0.84111	0.67095
DMU 10	0.84249	0.84249	0.86032	0.84395	0.77921

Table 5. *Cont.*

DMUs	DEA MODEL				
	CCR-I	CCR-O	BCC-I	BCC-O	SBM-I-C
DMU 11	1	1	1	1	1
DMU 12	0.69621	0.69621	0.84064	0.70152	0.57406
DMU 13	0.69434	0.69434	0.86122	0.69607	0.57425
DMU 14	0.6831	0.6831	0.88285	0.68319	0.62196
DMU 15	0.6488	0.6488	0.90171	0.65191	0.53603
DMU 16	0.75164	0.75164	0.93369	0.7667	0.74231
DMU 17	0.93592	0.93592	0.96325	0.97486	0.69601
DMU 18	0.66219	0.66219	0.91342	0.66537	0.53413
DMU 19	0.77402	0.77402	0.8373	0.77612	0.71333
DMU 20	0.66544	0.66544	0.90558	0.67532	0.58865
DMU 21	1	1	1	1	1
DMU 22	1	1	1	1	1
DMU 23	0.938	0.938	0.93829	0.95277	0.86668
DMU 24	0.96061	0.96061	0.96369	0.96856	0.91935
DMU 25	0.63547	0.63547	0.89787	0.64293	0.53539
DMU 26	0.88324	0.88324	0.89432	0.8882	0.76302
DMU 27	0.63832	0.63832	0.89407	0.65091	0.55676
DMU 28	0.65937	0.65937	0.91342	0.66656	0.52121
DMU 29	0.79351	0.79351	0.80416	0.8311	0.64609
DMU 30	0.97002	0.97002	0.97137	0.97245	0.93655
DMU 31	1	1	1	1	1
DMU 32	0.90238	0.90238	0.90266	0.91407	0.85562
DMU 33	0.88164	0.88164	0.88862	0.8854	0.78419
DMU 34	0.8257	0.8257	0.83348	0.85823	0.68268
DMU 35	0.8854	0.8854	0.88698	0.8891	0.80428
DMU 36	1	1	1	1	1
DMU 37	0.83205	0.83205	0.83892	0.86484	0.68793
DMU 38	1	1	1	1	1
DMU 39	0.65071	0.65071	0.90558	0.66133	0.55309
DMU 40	0.68497	0.68497	0.89407	0.69292	0.60721
DMU 41	0.86623	0.86623	0.88488	0.86705	0.75471
DMU 42	0.76366	0.76366	0.89787	0.77919	0.66542
DMU 43	0.66645	0.66645	0.89787	0.66931	0.60457
DMU 44	0.66527	0.66527	0.88285	0.67358	0.58559
DMU 45	0.68002	0.68002	0.88655	0.68365	0.61039
DMU 46	0.92817	0.92817	0.94226	0.9509	0.78322

As the results in Table 5 show, there are seven DMUs that are potential locations, including DMU 2, DMU 11, DMU 21, DMU 22, DMU 31, DMU 36 and DMU 38. These DMUs will be evaluated in next step of this research. The FAHP model is applied in this stage. The weight of criteria are defined by the comparison matrix. Criteria structures are built based on qualitative and quantitative factors. The Hierarchical structures for the FAHP approach are shown in Figure 7.

A fuzzy comparison matrix for all criteria are shown in Tables 6–25:

Table 6. Fuzzy comparison matrix for criteria.

Criteria	EC	EN	SC	SO	TE
EC	(1, 1, 1)	(1/4, 1/3, 1/2)	(1, 2, 3)	(1, 2, 3)	(1/3, 1/2, 1)
EN	(2, 3, 4)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)
SC	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(1, 1, 1)
SO	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/3, 1/2, 1)
TE	(1, 2, 3)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)

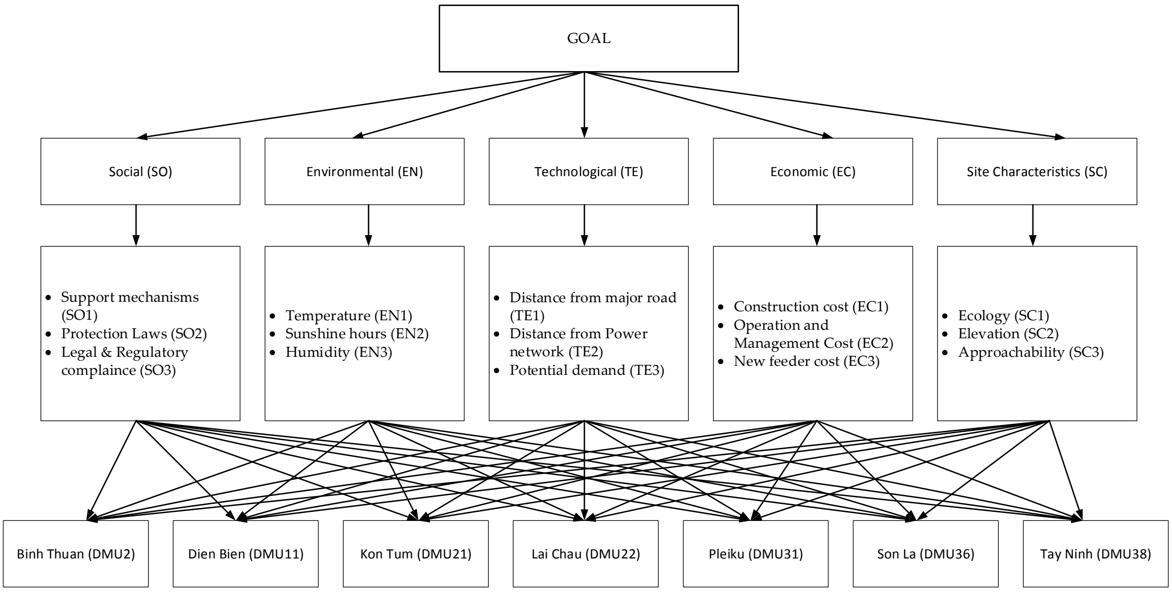

Figure 7. The Hierarchical structures for the FAHP approach.

To convert the fuzzy numbers to real numbers we proceed to solve the fuzzy clusters using the triangular fuzzy method. During the defuzzification we obtain the coefficients $\alpha = 0.5$ and $\beta = 0.5$ (Tang and Beynon) [44]. In it, α represents the uncertain environment, β represents the attitude of the evaluator is fair:

$$g_{0.5,0.5}(\overline{a_{EN,EC}}) = [(0.5 \times 2.5) + (1 - 0.5) \times 3.5] = 3$$
$$f_{0.5}(L_{EN,EC}) = (3 - 2) \times 0.5 + 2 = 2.5$$
$$f_{0.5}(U_{EN,EC}) = 4 - (4 - 3) \times 0.5 = 3.5$$
$$g_{0.5,0.5}(\overline{a_{EC,EN}}) = 1/3$$

The remaining calculations are similar to the above, as well as the fuzzy number priority points. The real number priorities when comparing the main criteria pairs are presented in Table 7.

Table 7. Real number priority.

Criteria	EC	EN	SC	SO	TE
EC	1	1/3	2	2	1/2
EN	3	1	3	2	1
SC	1/2	1/3	1	3	1
SO	1/2	1/2	1/3	1	1/2
TE	2	1	1	2	1

To calculate the maximum individual values as follows:

$$GM1 = (1 \times 1/3 \times 2 \times 2 \times 1/2)^{1/5} = 0.92$$

$$GM2 = (3 \times 1 \times 3 \times 2 \times 1)^{1/5} = 1.78$$

$$GM3 = (1/2 \times 1/3 \times 1 \times 3 \times 1)^{1/5} = 0.87$$

$$GM4 = (1/2 \times 1/2 \times 1/3 \times 1 \times 1/2)^{1/5} = 0.53$$

$$GM5 = (2 \times 1 \times 1 \times 2 \times 1)^{1/5} = 1.32$$

$$\sum GM = GM1 + GM2 + GM3 + GM4 + GM5 = 5.42$$

$$\omega_1 = \frac{0.92}{5.42} = 0.17$$
$$\omega_2 = \frac{1.78}{5.42} = 0.33$$
$$\omega_3 = \frac{0.87}{5.42} = 0.16$$
$$\omega_4 = \frac{0.53}{5.42} = 0.1$$
$$\omega_4 = \frac{1.32}{5.42} = 0.24$$

$$\begin{bmatrix} 1 & 1/3 & 2 & 2 & 1/2 \\ 3 & 1 & 3 & 2 & 1 \\ 1/2 & 1/3 & 1 & 3 & 1 \\ 1/2 & 1/2 & 1/2 & 1 & 1/2 \\ 2 & 1 & 1 & 2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.17 \\ 0.33 \\ 0.16 \\ 0.1 \\ 0.24 \end{bmatrix} = \begin{bmatrix} 0.92 \\ 1.76 \\ 0.9 \\ 0.55 \\ 1.27 \end{bmatrix}$$

$$\begin{bmatrix} 0.92 \\ 1.76 \\ 0.9 \\ 0.55 \\ 1.27 \end{bmatrix} / \begin{bmatrix} 0.17 \\ 0.33 \\ 0.16 \\ 0.1 \\ 0.24 \end{bmatrix} = \begin{bmatrix} 5.41 \\ 5.33 \\ 5.63 \\ 5.5 \\ 5.29 \end{bmatrix}$$

With the number of criteria is 5, we get $n = 5$, λ_{max} and CI are calculated as follows:

$$\lambda_{max} = \frac{5.41 + 5.33 + 5.63 + 5.5 + 5.29}{5} = 5.432$$

$$CI = \frac{5.43 - 5}{5 - 1} = 0.1075$$

For CR, with n = 5 we get $RI = 1.12$:

$$CR = \frac{0.1075}{1.12} = 0.09598$$

We have $CR = 0.09598 \leq 0.1$, so the pairwise comparison data is consistent and does not need to be re-evaluated. The results of the pair comparison between the main criteria are presented in Table 8.

Table 8. Fuzzy comparison matrices for criteria.

Criteria	EC	EN	SC	SO	TE	Weight
EC	(1, 1, 1)	(1/4, 1/3, 1/2)	(1, 2, 3)	(1, 2, 3)	(1/3, 1/2, 1)	0.17201
EN	(2, 3, 4)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	0.32965
SC	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(1, 1, 1)	0.16526
SO	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/3, 1/2, 1)	0.09694
TE	(1, 2, 3)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	0.23614
Total						1
$CR = 0.09598$						

Table 9. Comparison matrix for environmental criteria.

Criteria	EN 3	EN 2	EN 1	Weight
EN3	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	0.19580
EN2	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	0.49339
EN1	(1, 2, 3)	(1/3, 1/2, 1)	(1, 1, 1)	0.31081
Total				1
$CR = 0.05156$				

Table 10. Comparison matrix for site characteristics criteria.

Criteria	SC 3	SC 2	SC 1	Weight
SC 3	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	0.52784
SC 2	(1/3, 1/2, 1)	(1, 1, 1)	(2, 3, 4)	0.33251
SC 1	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	0.13965
Total				1
CR = 0.05156				

Table 11. Comparison matrix for social criteria.

Criteria	SO 3	SO 2	SO 1	Weight
SO 3	(1, 1, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	0.15706
SO 2	(1, 2, 3)	(1, 1, 1)	(1/4, 1/3, 1/2)	0.24931
SO 1	(2, 3, 4)	(2, 3, 4)	(1, 1, 1)	0.59363
Total				1
CR = 0.05156				

Table 12. Comparison matrix for economic criteria.

Criteria	EC 1	EC 3	EC 2	Weight
EC 1	(1, 1, 1)	(1/3, 1/2, 1)	(1, 2, 3)	0.31081
EC 3	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	0.49339
EC 2	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 1, 1)	0.19580
Total				1
CR = 0.05156				

Table 13. Comparison matrix for technological criteria.

Criteria	TE 1	TE 2	TE 3	Weight
TE 1	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	0.19580
TE 2	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	0.31081
TE 3	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	0.49339
Total				1
CR = 0.05156				

The comparison matrix of sub-criteria based on the alternatives is shown below:

Table 14. Comparison matrix for TE1 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(2, 3, 4)	(6, 7, 8)	(2, 3, 4)	(1, 2, 3)	0.354451
DMU 11	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 2, 3)	(4, 5, 6)	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	0.208178
DMU 21	(1/6, 1/5, 1/4)	(1/3, 1/2, 1)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	(2, 3, 4)	0.125652
DMU 22	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/5, 1/4, 1/3)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	0.045139
DMU 31	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(3, 4, 5)	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	0.069171
DMU 36	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	(1, 1, 1)	0.100762
DMU 38	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	(1, 1, 1)	0.096648
Total								1
CR = 0.08404								

Table 15. Comparison matrix for TE2 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	(2, 3, 4)	(5, 6, 7)	(4, 5, 6)	(2, 3, 4)	0.333294
DMU 11	(1/3, 1/2, 1)	(1, 1, 1)	(3, 4, 5)	(1, 2, 3)	(2, 3, 4)	(2, 3, 4)	(5, 6, 7)	0.233267
DMU 21	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	0.109613
DMU 22	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 1, 1)	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	0.13301
DMU 31	(1/7, 1/6, 1/5)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/5, 1/4, 1/3)	(1, 1, 1)	(3, 4, 5)	(2, 3, 4)	0.092202
DMU 36	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1, 1, 1)	(1, 2, 3)	0.052846
DMU 38	(1/4, 1/3, 1/2)	(1/7, 1/6, 1/5)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1, 1, 1)	0.045768
Total								1
CR = 0.09594								

Table 16. Comparison matrix for TE3 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	(1/3, 1/2, 1)	(5, 6, 7)	(3, 4, 5)	(1, 2, 3)	0.293807
DMU 11	(1/3, 1/2, 1)	(1, 1, 1)	(2, 3, 4)	(1/5, 1/4, 1/3)	(1, 2, 3)	(2, 3, 4)	(1, 2, 3)	0.214438
DMU 21	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	0.049645
DMU 22	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	(1/5, 1/4, 1/3)	0.086324
DMU 31	(1/7, 1/6, 1/5)	(1/3, 1/2, 1)	(3, 4, 5)	(1/3, 1/2, 1)	(1, 1, 1)	(1/3, 1/2, 1)	(1/6, 1/5, 1/4)	0.071619
DMU 36	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	(1/4, 1/3, 1/2)	0.087677
DMU 38	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 2, 3)	(3, 4, 5)	(4, 5, 6)	(2, 3, 4)	(1, 1, 1)	0.196491
Total								1
CR = 0.08852								

Table 17. Comparison matrix for SC1 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(1/3, 1/2, 1)	(2, 3, 4)	(1, 1, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(2, 3, 4)	0.13004
DMU 11	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(1/3, 1/2, 1)	(1, 2, 3)	(2, 3, 4)	0.197223
DMU 21	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1, 1, 1)	(1, 2, 3)	(1/6, 1/5, 1/4)	(1, 2, 3)	(1, 2, 3)	0.113704
DMU 22	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 1, 1)	0.077497
DMU 31	(1, 2, 3)	(1, 2, 3)	(4, 5, 6)	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	0.274544
DMU 36	(2, 3, 4)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 2, 3)	(1/3, 1/2, 1)	(1, 1, 1)	(2, 3, 4)	0.149847
DMU 38	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	0.057146
Total								1
CR = 0.09079								

Table 18. Comparison matrix for SC2 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(2, 3, 4)	(3, 4, 5)	(1, 2, 3)	(2, 3, 4)	0.3033
DMU 11	(1/4, 1/3, 1/2)	(1, 1, 1)	(4, 5, 6)	(3, 4, 5)	(1, 2, 3)	(1/3, 1/2, 1)	(2, 3, 4)	0.189088
DMU 21	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/5, 1/4, 1/3)	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	0.044302
DMU 22	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(3, 4, 5)	(1, 1, 1)	(3, 4, 5)	(1/3, 1/2, 1)	(2, 3, 4)	0.132378
DMU 31	(1/5, 1/4, 1/3)	(1/3, 1/2, 1)	(1, 1, 1)	(1/5, 1/4, 1/3)	(1, 1, 1)	(1/5, 1/4, 1/3)	(2, 3, 4)	0.071387
DMU 36	(1/3, 1/2, 1)	(1, 2, 3)	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	(1, 1, 1)	(1, 2, 3)	0.197566
DMU 38	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 2, 3)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1, 1, 1)	0.06198
Total								1
CR = 0.09473								

Table 19. Comparison matrix for SC3 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	(6, 7, 8)	(1, 2, 3)	0.314672
DMU 11	(1/5, 1/4, 1/3)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	(3, 4,5)	(2, 3, 4)	(1/3, 1/2, 1)	0.144856
DMU 21	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	(4, 5, 6)	(1, 2, 3)	0.176472
DMU 22	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1, 1, 1)	(2, 3, 4)	(5, 6, 7)	(1/4, 1/3, 1/2)	0.107392
DMU 31	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(1/5, 1/4, 1/3)	0.051436
DMU 36	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1/7, 1/6, 1/5)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/3, 1/2, 1)	0.036723
DMU 38	(1/3, 1/2, 1)	(1, 2, 3)	(1/3, 1/2, 1)	(2, 3, 4)	(3, 4, 5)	(1, 2, 3)	(1, 1, 1)	0.168449
Total								1
CR = 0.09232								

Table 20. Comparison matrix for SO1 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(4, 5, 6)	(3, 4, 5)	(1, 2, 3)	(2, 3, 4)	(4, 5, 6)	(3, 4, 5)	0.369784
DMU 11	(1/6, 1/5, 1/4)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	0.183518
DMU 21	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	0.044326
DMU 22	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(2, 3, 4)	(1, 1, 1)	(1/3, 1/2, 1)	(1, 2, 3)	(1/4, 1/3, 1/2)	0.095751
DMU 31	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	0.079245
DMU 36	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 2, 3)	(1/3, 1/2, 1)	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	0.07467
DMU 38	(1/5, 1/4, 1/3)	(1/3, 1/2, 1)	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	0.152707
				Total				1
				CR = 0.09669				

Table 21. Comparison matrix for SO2 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(1, 2, 3)	(5, 6, 7)	(1, 2, 3)	(3, 4, 5)	(4, 5, 6)	(2, 3, 4)	0.305459
DMU 11	(1/3, 1/2, 1)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	(5, 6, 7)	(2, 3, 4)	0.243481
DMU 21	(1/7, 1/6, 1/5)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	0.03918
DMU 22	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(4, 5, 6)	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(2, 3, 4)	0.191699
DMU 31	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(2, 3, 4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	0.098135
DMU 36	(1/6, 1/5, 1/4)	(1/7, 1/6, 1/5)	(1, 2, 3)	(1/6, 1/5, 1/4)	(1/3, 1/2, 1)	(1, 1, 1)	(1, 1, 1)	0.052314
DMU 38	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 1, 1)	0.069733
				Total				1
				CR = 0.05496				

Table 22. Comparison matrix for SO3 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(4, 5, 6)	(3, 4, 5)	(1, 2, 3)	(2, 3, 4)	0.307084
DMU 11	(1/3, 1/2, 1)	(1, 1, 1)	(1, 1, 1)	(4, 5, 6)	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	0.218813
DMU 21	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	0.165351
DMU 22	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1/3, 1/2, 1)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	0.112322
DMU 31	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	0.064014
DMU 36	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 1, 1)	(1, 2, 3)	0.075672
DMU 38	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1, 1, 1)	(1/3, 1/2, 1)	(1, 1, 1)	0.056743
				Total				1
				CR = 0.09264				

Table 23. Comparison matrix for EN1 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(4, 5, 6)	(3, 4, 5)	(2, 3, 4)	0.379402
DMU 11	(1/4, 1/3, 1/2)	(1, 1, 1)	(4, 5, 6)	(1, 2, 3)	(1, 2, 3)	(2, 3, 4)	(3, 4, 5)	0.216035
DMU 21	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1, 1, 1)	(2, 3, 4)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	0.107386
DMU 22	(1/8, 1/7, 1/6)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	0.042011
DMU 31	(1/6, 1/5, 1/4)	(1/3, 1/2, 1)	(1, 1, 1)	(3, 4, 5)	(1, 1, 1)	(1, 1, 1)	(3, 4, 5)	0.114659
DMU 36	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	0.082888
DMU 38	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/3, 1/2, 1)	(1, 2, 3)	(1/5, 1/4, 1/3)	(1/3, 1/2, 1)	(1, 1, 1)	0.057619
				Total				1
				CR = 0.09124				

Table 24. Comparison matrix for EN2 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(2, 3, 4)	(3, 4, 5)	(1, 2, 3)	(4, 5, 6)	(2, 3, 4)	(3, 4, 5)	0.330479
DMU 11	(1/4, 1/3, 1/2)	(1, 1, 1)	(5, 6, 7)	(3, 4, 5)	(3, 4, 5)	(1, 2, 3)	(2, 3, 4)	0.233849
DMU 21	(1/5, 1/4, 1/3)	(1/8, 1/7, 1/6)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	0.058942
DMU 22	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	0.068136
DMU 31	(1/6, 1/5, 1/4)	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1, 1, 1)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	0.041927
DMU 36	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(2, 3, 4)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	0.14113
DMU 38	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(3, 4, 5)	(2, 3, 4)	(3, 4, 5)	(1/3, 1/2, 1)	(1, 1, 1)	0.125536
				Total				1
				CR = 0.08438				

Table 25. Comparison matrix for EN3 based on the alternatives.

DMUs	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38	Weight
DMU 2	(1, 1, 1)	(4, 5, 6)	(2, 3, 4)	(3, 4, 5)	(1, 2, 3)	(5, 6, 7)	(4, 5, 6)	0.3751
DMU 11	(1/6, 1/5, 1/4)	(1, 1, 1)	(2, 3, 4)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(1, 2, 3)	0.15814
DMU 21	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1, 2, 3)	(1/4, 1/3, 1/2)	0.055333
DMU 22	(1/5, 1/4, 1/3)	(1, 1, 1)	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)	0.135332
DMU 31	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(3, 4, 5)	(1/3, 1/2, 1)	(1, 1, 1)	(3, 4, 5)	(1, 2, 3)	0.133423
DMU 36	(1/7, 1/6, 1/5)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1, 1, 1)	(1/5, 1/4, 1/3)	0.040685
DMU 38	(1/6, 1/5, 1/4)	(1/3, 1/2, 1)	(2, 3, 4)	(1, 1, 1)	(1/3, 1/2, 1)	(3, 4, 5)	(1, 1, 1)	0.101987
Total								1
CR = 0.08831								

The final weight of the criteria are shown in Table 26.

Table 26. The weight of criteria.

Symbol	Criteria	Weight
SO 1	Support mechanisms (SO 1)	0.05755
SO 2	Protection law (SO 2)	0.02417
SO 3	Legal and Regulatory compliance (SO 3)	0.01522
EN 1	Temperature (EN 1)	0.10246
EN 2	Sunshine hours (EN 2)	0.16264
EN 3	Humidity (EN 3)	0.06454
TE 1	Distance from major road (TE 1)	0.04624
TE 2	Distance from power network (TE 2)	0.07339
TE 3	Potential demand (TE 3)	0.1165
EC 1	Constructions cost (EC 1)	0.05346
EC 2	Operations and Maintenances Cost (EC 2)	0.03368
EC 3	New feeder cost (EC 3)	0.08487
SC 1	Ecology (SC 1)	0.05495
SC 2	Elevation (SC 2)	0.02308
SC 3	Approachability (SC 3)	0.08723

The weights of alternative locations with respect to all sub criteria and the Normalized Decision Matrix of sub criteria are shown in Tables 27–29.

Table 27. The weights of alternative locations with respect to sub criteria.

Sub-Criteria	DMUs						
	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38
EN 1	0.31978	0.21227	0.05078	0.12454	0.17870	0.06968	0.04426
EN 2	0.33048	0.23385	0.05894	0.06814	0.04193	0.14113	0.12554
EN 3	0.37510	0.15814	0.05533	0.13533	0.13342	0.04069	0.10199
SC 1	0.13004	0.19722	0.11370	0.07750	0.27454	0.14985	0.05715
SC 2	0.30310	0.18909	0.044301	0.13238	0.07139	0.19757	0.06198
SC 3	0.31467	0.14486	0.17647	0.10739	0.05143	0.03672	0.16845
SO 1	0.36978	0.18352	0.04432	0.09575	0.07924	0.07467	0.15271
SO 2	0.30546	0.243482	0.03918	0.19170	0.09813	0.05231	0.06973
SO 3	0.30708	0.218812	0.16535	0.11232	0.06401	0.07567	0.05674
EC 1	0.31978	0.21227	0.05078	0.12454	0.17870	0.06968	0.04426
EC 2	0.32801	0.10282	0.04674	0.06451	0.19437	0.16046	0.10306
EC 3	0.37679	0.21522	0.06511	0.12752	0.03546	0.05819	0.12170
TE 1	0.35445	0.20818	0.12565	0.04514	0.06917	0.10076	0.09665
TE 2	0.33329	0.23327	0.10961	0.13301	0.09220	0.05285	0.04577
TE 3	0.29782	0.21270	0.04960	0.07731	0.07713	0.08854	0.19689

Table 28. Normalized Decision Matrix.

Sub-Criteria	DMUs						
	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38
EN 1	0.31978	0.21227	0.05078	0.12454	0.17870	0.06968	0.04426
EN 2	0.33048	0.23385	0.05894	0.06814	0.04193	0.14113	0.12554
EN 3	0.375010	0.15814	0.05533	0.13533	0.13342	0.04069	0.10199
SC 1	0.13004	0.19722	0.11370	0.07710	0.27454	0.14985	0.05715
SC 2	0.30310	0.18909	0.04430	0.13238	0.07139	0.19757	0.06198
SC 3	0.31467	0.14486	0.17647	0.10739	0.05144	0.03672	0.16845
SO 1	0.36978	0.18352	0.04432	0.09575	0.07924	0.07467	0.15271
SO 2	0.30546	0.24348	0.03918	0.19170	0.09813	0.05231	0.06973
SO 3	0.30708	0.21881	0.16535	0.11232	0.06401	0.07567	0.05674
EC 1	0.31978	0.21227	0.05078	0.12454	0.17870	0.06966	0.04426
EC 2	0.32801	0.10282	0.04674	0.06451	0.19437	0.16048	0.10306
EC 3	0.37679	0.21522	0.06511	0.12752	0.03545	0.05819	0.12170
TE 1	0.35445	0.20818	0.12565	0.04514	0.06917	0.10076	0.09665
TE 2	0.33329	0.23327	0.10961	0.13301	0.09220	0.05285	0.04577
TE 3	0.29783	0.21270	0.04910	0.07731	0.07713	0.08854	0.19689

Table 29. The weighted Normalized Decision Matrix.

DMUs	Main-Criteria				
	EN (0.0992)	SC (0.0536)	SO (0.0916)	EC (0.0929)	TE (0.0907)
DMU 2	0.31999	0.23524	0.37084	0.12591	0.26166
DMU 11	0.07651	0.11556	0.06848	0.21590	0.07157
DMU 21	0.02816	0.03464	0.10010	0.06539	0.04642
DMU 22	0.09199	0.14394	0.09065	0.02859	0.07826
DMU 31	0.03971	0.04045	0.05607	0.03332	0.04939
DMU 36	0.14022	0.37121	0.04745	0.09761	0.10414
DMU 38	0.30343	0.05896	0.26641	0.43327	0.38857

In the final stage, all the potential locations will be ranked by the TOPSIS model. The weight of sub-criteria can be used from the result of the fuzzy AHP approach. The normalized weight matrix values are shown in Table 30.

Table 30. Normalized Weight Matrix.

Criteria	DMUs						
	DMU 2	DMU 11	DMU 21	DMU 22	DMU 31	DMU 36	DMU 38
SO 1	0.02210	0.01580	0.01580	0.01580	0.02210	0.02210	0.02840
SO 2	0.01070	0.00840	0.00600	0.00600	0.00840	0.00950	0.01070
SO 3	0.04040	0.03030	0.03530	0.02520	0.02520	0.04040	0.03030
EN 1	0.04550	0.03540	0.04040	0.04040	0.03030	0.03030	0.04550
EN 2	0.07940	0.05290	0.06170	0.04410	0.06170	0.05290	0.07060
EN 3	0.01350	0.03360	0.01350	0.02690	0.03360	0.02020	0.02020
TE 1	0.01350	0.01350	0.02020	0.00670	0.02020	0.02700	0.01350
TE 2	0.02610	0.02610	0.03480	0.01740	0.01740	0.04350	0.01740
TE 3	0.03870	0.04510	0.05150	0.03870	0.05800	0.03220	0.03870
EC 1	0.01540	0.02310	0.02310	0.02310	0.01540	0.01540	0.02310
EC 2	0.00930	0.00930	0.01390	0.01390	0.01390	0.01390	0.01390
EC 3	0.02400	0.03600	0.02400	0.03600	0.04800	0.02400	0.02400
SC 1	0.02440	0.02170	0.02440	0.01900	0.02170	0.01630	0.01630
SC 2	0.01190	0.00950	0.00950	0.00240	0.00480	0.00950	0.00950
SC 3	0.03390	0.04360	0.02420	0.04360	0.01940	0.02910	0.02910

In Figure 8, DMU 2 has shortest geometric distance from the PIS and the longest geometric distance from the NIS.

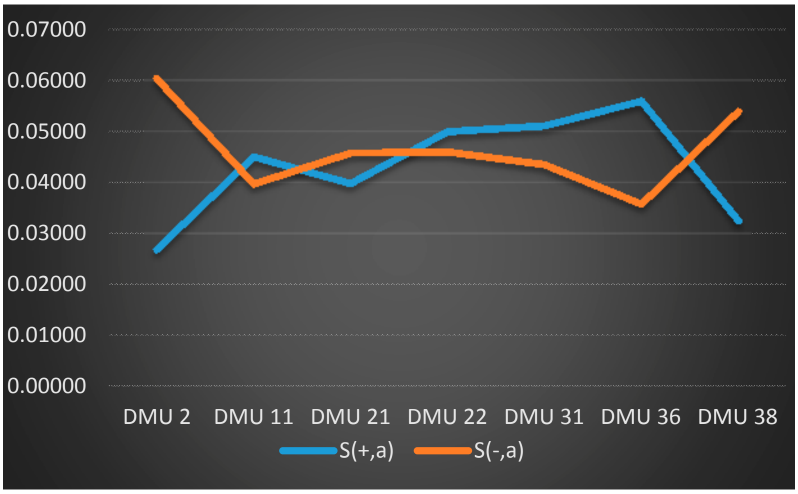

Figure 8. Geometric distance from PIS and NIS.

The results of TOPSIS model are shown in Figure 9, based on the final performance score C_a, the final location ranking list are DMU 2, DMU 38, DMU 21, DMU 22, DMU 11, DMU 31 and DMU 36. The results show that DMU 2 (Binh Thuan) is the most optimal location for building a solar plant in Viet Nam.

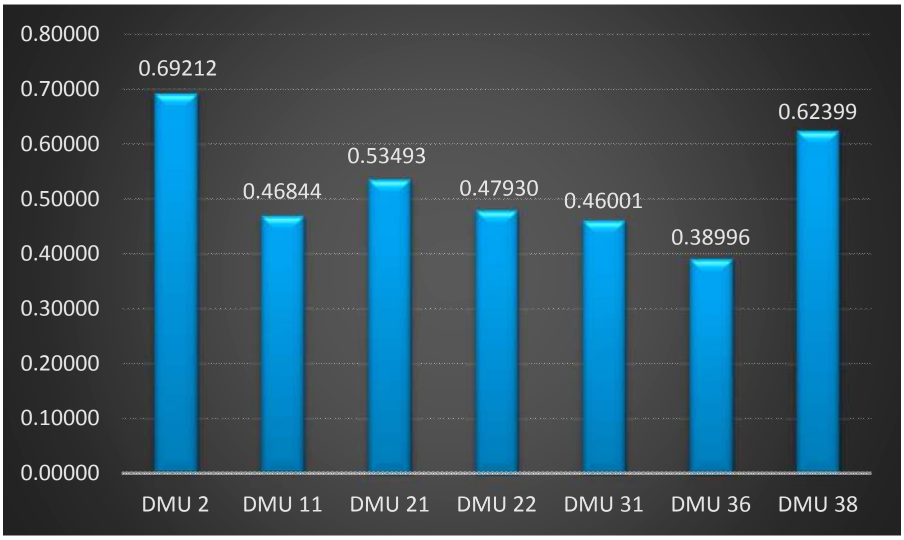

Figure 9. The result from TOPSIS model.

4. Conclusions

Studies applying the MCDM approach to various fields of science and engineering have been increasing in number over the past years. One of the fields where the MCDM model has been employed ii in location selection problems. Especially in the renewable energy sector, decision makers have to evaluate both qualitative and quantitative factors. Although some studies have reviewed applications of MCDM approaches in solar power plant location selection, very few works has focused on this problem in a fuzzy environment. This is a reason why in this work MCDM model including AHP with fuzzy logic, DEA and TOPSIS is proposed for solar power plant location selection in Viet Nam. The goal of this study was to design a MCDM approach for building solar power plants based on natural and social factors. In the first step of the research, proper areas are defined by using several DEA models, then a fuzzy analytical hierarchy process is proposed for evaluating the weight of criteria.

The FAHP can be applied for ranking alternatives but the number of sites selected is practically limited because of the number of pairwise comparisons that need to be made, and a disadvantage of the FAHP approach is that the input data, expressed in linguistic terms, depend on the experience of decision makers and thus involves subjectivity. This is a reason why we proposed the TOPSIS model for ranking alternatives in the final stage. Also, TOPSIS is presented to reaffirm it as a systematic method and solve the disadvantages of the FAHP model as mentioned above. As a results, the site with the best potential DMU 2 (Binh Thuan) because it has the highest ranking score in the final stage.

The contribution of this study is the presentation of a multi-criteria decision making model (MCDM) for solar plant site selection in Viet Nam under fuzzy environment conditions. This paper also represents the evolution of a new approach that is flexible and practical for the decision maker. This research also provides a useful guideline for solar power plant location selection in other countries as well as a guideline for location selection in other industries.

In future research, this MCDM model also can be applied to many different countries. In addition, different methods, such as FANP or PROMETHEE, etc., could also be combined for different scenarios.

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