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A Multi-Criteria Decision Making (MCDM) for Renewable Energy Plants Location Selection in Vietnam under a Fuzzy Environment

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Abstract: In the context of increasing energy demands in Vietnam, and as a result of the limited supply of domestic energy (oil/gas/coal reserves are exhausted), the potential for renewable energy sources in Vietnam is significant. Thus, building wind power plants in Vietnam is necessary. Access to this type of renewable energy not only contributes to society's energy supply but also helps to save energy and reduce environmental pollution. Although some works have reviewed applications of the Multi-Criteria Decision Making (MCDM) model in wind power plant site selection, little research has focused on this problem in a fuzzy environment. This is the reason why a hybrid Fuzzy Analytic Hierarchy Process (FAHP) and The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are developed for wind power plant site selection in Vietnam. In the first stages of this research, an FAHP model is proposed for determining the weight of each potential location for building a wind power plant, based on qualitative and quantitative factors. A TOPSIS is applied for ranking all potential alternatives in the final stage. The authors collected data from seven locations, which have good conditions for investment in a wind power plant. The results indicate that Binh Thuan (Binh Thuan Province is located on coast of South Central Vietnam) is the best place for building a wind power plant in Vietnam. The contributions of this work proposed an MCDM approach under fuzzy environments for wind power plant location selection in Vietnam. This paper also resides in the evolution of a new approach that is flexible and practical for a decision-maker. This work also provides a useful guideline for wind power plant location selection in others countries.

Keywords: renewable energy; location selection; wind power plant; MCDM; TOPSIS; FAHP; fuzzy environments

1. Introduction

Wind power is the use of air flow through wind turbines to provide the mechanical power to turn electric generators. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land [1].

Nowadays, at least 90 other countries are using wind power to supply their electric power grids [2]. Annual wind power capacity additions in 2018 is 539.581 MW [3]. Yearly wind energy production is also growing rapidly and has reached around 10.8% of worldwide electric power usage [4].

Existing coal and gas fields in the near future will be exhausted, so many countries are now focused on developing wind resources. Wind energy is the latest and most powerful source of energy in the world today. The development of wind energy in Vietnam toward the objective of mitigating the impacts of climate change is among the solutions that are considered feasible today. Currently, the first 100 MW wind farm has been operating and is conducting research into phases up to 2025, for up to 1000 MW.

In this work, the author considered seven Decision Making Units (DMUs) including Quang Ninh, Binh Thuan, Quang Tri, Ninh Thuan, Ninh Thuan, Tra Vinh and Hai Van for building wind power plants in Vietnam. This is because these provinces have the greatest potential for harnessing wind energy. Wind power could reach 800 MW. In addition to high average speed, local wind tends to be steady due to the small number of storms. During the monsoon period, winds reach speeds of six to seven meters per second. Wind power plant site selection is identified as a critical issue that could affect economic, environmental, technological, and social factors. Further, location selection is complicated, in that decision-makers must have broad perspectives concerning qualitative and quantitative criteria. Furthermore, there is no work that applies these models for wind power plant location selection in Vietnam Thus, the authors propose a Multi-Criteria Decision Making (MCDM) model, including Fuzzy Analytic Hierarchy Process (FAHP) and The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), to select the optimal location for construction of wind power plants in Vietnam. FAHP is proposed for defining the weight of each potential location in the first stages of this work. The FAHP embeds the fuzzy theory to basic analytic hierarchy process (AHP), which was developed by Saaty [5]. FAHP is a widely used decision-making technique in many MCDM problems. In a general AHP model, the objective is in the first level, and the criteria and subcriteria are in the second and third levels, respectively. Finally, the options are found in the fourth level. A general MCDM process model is shown in Figure 1.

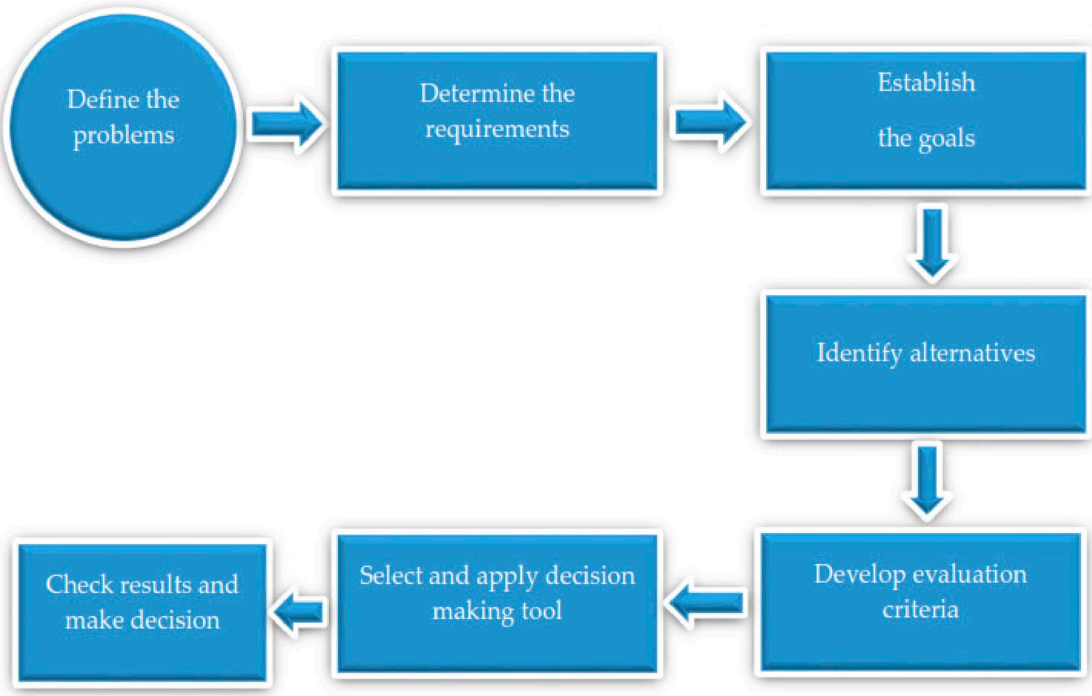

Figure 1. General Multi-Criteria Decision Making (MCDM) process [6,7].

The FAHP can be used for ranking alternatives, but the disadvantage of the FAHP model is that input data, expressed in linguistic terms, depends on the experience of experts. Thus, the authors proposed TOPSIS models for ranking potential locations in the final stages. TOPSIS is a multi-criteria decision analysis method. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS).

The remainder of the article provides background materials to assist in developing the MCDM model. Then, hybrid FAHP–TOPSIS approaches are presented to select the best location for wind power plant construction from seven potential locations in Vietnam. The results and contributions will be discussed at the end of this paper.

2. Literature Review

Much research has been conducted on MCDM approaches, applying them to various fields of science and engineering. This research has been increasing, including works from G. C. Biswal, S. P. Shukla [8], who applied Geographic Information System (GIS) integrated with MCDM for effective site selection for large wind turbine. Dragan Pamucar et al. [9] combined use of GIS with multi-criteria techniques of Best-Worst method (BWM) and Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) for Wind farms location selection. Geovanna Villacreses et al. [10] was to implement a geographical information system with multi-criteria decision making methods, to select the most feasible location for installing wind power plants in continental Ecuador. Ali Azizi et al. [11] used analytic network process (ANP) and decision making trial and evaluation laboratory (DEMATEL) in a GIS environment for Land suitability assessment for wind power plant site selection. This study assessed the possibility of establishing wind farms in Ardabil province in northwestern Iran by using a combination of ANP and DEMATEL methods in a GIS environment. DEMATEL was used to determine the criteria relationships. The weights of the criteria were determined using ANP and the overlaying process was done on GIS [11]. Patrict Scherhaufer [12] analyzed two main challenges in the assessment: (i) the integration of various relevant stakeholders into the research process, (ii) the integration of different research methods into one conceptionally and methodologically reliable assessment investigating the social acceptance of wind energy

Ahmet Aktasa and Mehmet Kabak [13] proposed a MCDM approach based on hesitant fuzzy linguistic terms set to solve the wind turbine site selection problem. Shafiqur Rehman and Salman A. Khan [14] presented a Multi-Criteria Wind Turbine Selection using Weighted Sum Approach. E. Chamanehpour et al. [15] proposed MCDM methods in GIS for Site selection of wind power plants. Chia-Nan Wang et al. [16] proposed a MCDM approach for Solid Waste to Energy Plant Location Selection in Vietnam. The research also provides a special, useful guideline for solid waste to energy plant location selection in many countries, as well as provides a guideline for location selection in other industries [16]. Chia-Nan Wang et al. [17] presented a MCDM model for Solar Power Plant Location Selection. Supplier selection has been defined as an important problem which could affect the efficiency of an organization. Solar panel supplier selection is complicated in that decision-makers must have a wide range of insight and perspectives about the qualitative and quantitative factors [17].

V. Mytilinou1 and A. J. Kolios [18] proposed a multi-objective optimization approach applied to offshore wind farm location selection in United Kingdom (UK). Varvara Mytilinou et al. [19] presented a Framework for the Selection of Optimum Offshore Wind Farm Locations for Deployment in UK.

Yousaf Ali et al. [20] used AHP for selection of suitable sites in Pakistan for wind power plant installation. Abdel Rahman Al-Shabeeb et al. [21] presented AHP with GIS for a Preliminary Site Selection of Wind Turbines in the North West of Jordan. Yasir Ahmed Solangi [22] used A Factor Analysis, AHP, and Fuzzy-TOPSIS for The Selection of Wind Power Project Location in the Southeastern Corridor of Pakistan. Dragan Pamucar et al. [9] proposed a GIS Multi-Criteria Hybrid Model for Location Selection for Wind Farms. Lütfü ŞağbanşuaandFigenBalo [23] used the MCDM model for 1.5 MW wind turbine selection. James Gaede and Ian H. Rowlands [24] studied a bibliometric review of the social acceptance literature for energy technology and fuels. Tufan Demirel and Ugur Yalcin [25] applied FAHP for selecting the best location for the power station. Chia-Nan Wang et al. [26] proposed a hybrid fuzzy analysis network process (FANP) and Data Envelopment Analysis (DEA) approach for supplier evaluation and selection. Babak Daneshvar Rouyendegh et al. [27] used Intuitionistic

Fuzzy TOPSIS in site selection of Wind Power Plants in Turkey. Dimitra G. Vagiona and Manos Kamilakis [28] applied GIS–AHP–TOPSIS for Site Selection for Offshore Wind Farms in the South Aegean—Greece. Mostafa Rezaei-Shouroki [29] proposed a MCDM model for the location optimization of wind turbine sites. Kajal CHATTERJEE and Samarjit KAR [30] proposed Complex Proportional Assessment (COPRAS) -Z methodology, and Z-number model fuzzy numbers with a reliable degree to represent imprecise judgment of decision makers' in evaluating the weights of criteria and selection of renewable energy alternatives. Baban, S. and Parry, T. [31] developed and applied a GIS-based approach to locating wind farms in the UK.

Pedro G. Lind et al. [32] compared the resulting data reconstruction with that of a model based on a neural network, which has been previously reported as a data-mining algorithm suitable for reconstructing this signal. The results present evidence that the stochastic approach outperforms the neural network in the high frequency domain (1 Hz). Through a Simple Stochastic Model, Pedro G. Lind et al. [33] proposed a procedure to estimate the fatigue loads on wind turbines, based on a recent framework used for reconstructing data series of stochastic properties measured at wind turbines. Ana Russo et al. [34] presented a simple neural network and data pre-selection framework, discriminating the most essential input data for accurately forecasting the concentrations of PM10, based on observations for the years between 2002 and 2006 in the metropolitan region of Lisbon, Portugal. Robert Gennaro Sposatoa and Nina Hampla [35] presented worldviews as predictors of wind and solar energy support in Austria. Ana Russo, Frank Raischel and Pedro G. Lind [36] applied recent methods in stochastic data analysis for discovering a set of a few stochastic variables that represent the relevant information on a multivariate stochastic system, used as input for artificial neural network models for air quality forecast.

3. Material and Methodology

3.1. Research Development

In this work, the authors proposed an MCDM model, including fuzzy AHP and TOPSIS approaches, for selecting the optimal location for wind power plant construction in Vietnam. There are three stages in this research, as shown in Figure 2.

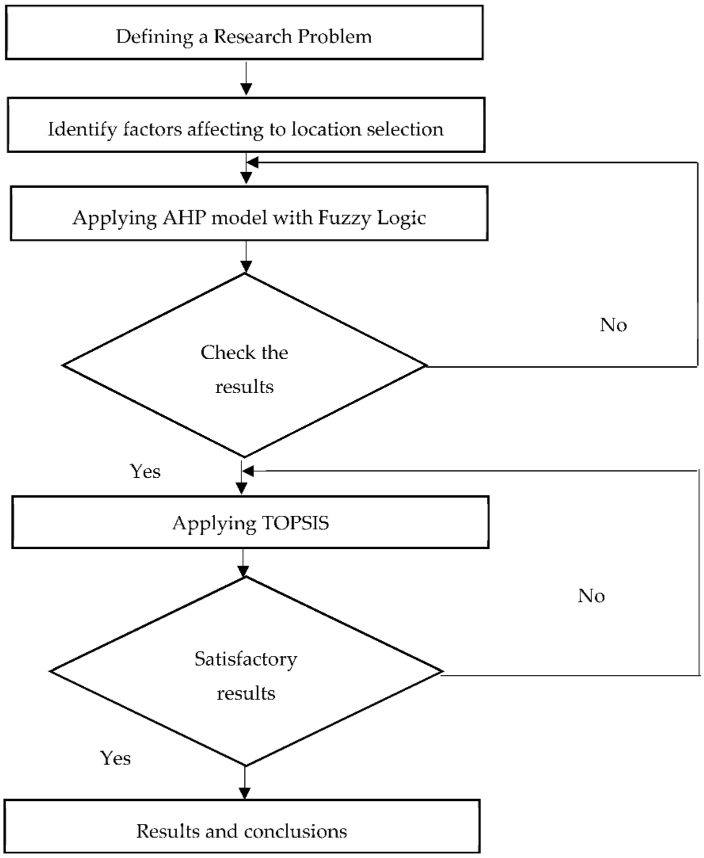

Figure 2. Research methodology.

Stage 1: Defining goal and criteria. In this step, the criteria for selecting the optimal location will be identified. All the criteria have been built through expert interviews and literature reviews.

Stage 2: Applying the FAHP model. There are seven alternatives that can be highly effective for building wind power plants in Vietnam. In this stage, an FAHP is proposed to determine the weight of all criteria and subcriteria.

Stage 3: TOPSIS model is one of the best techniques for addressing complex problems of decision-making, which has a connection with various qualitative and quantitative factors. Thus, the TOPSIS model is applied in this stage. The ranking list will also be defined in this stage.

3.2. Methodology

A brief introduction about fuzzy sets and fuzzy numbers, AHP and TOPSIS models are shown in Sections 3.2.1–3.2.3 of this paper.

3.2.1. Fuzzy Sets and Fuzzy Number

Zadeh (1965) [37] proposed a theory to deal with uncertainty environment conditions. The triangular fuzzy number (TFN) can be defined as (l, m, u). The value l, m and u $(l \leq m \leq u)$, indicate the smallest, the promising and the largest value. A TFN is shown in Figure 3.

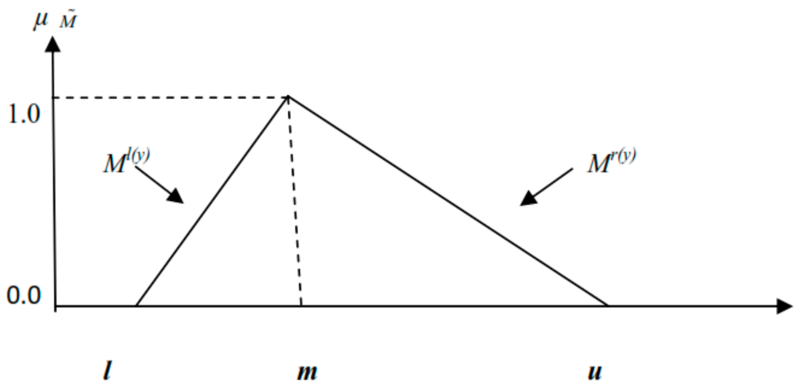

Figure 3. Triangular Fuzzy Number (TFN).

A triangular fuzzy number can be described as:

$$\mu\left(\frac{x}{\widetilde{F}}\right) = \begin{cases} 0, & x < l, \\ \frac{x-l}{m-l} & l \le x \le m, \\ \frac{u-x}{u-m} & m \le x \le u, \\ 0, & x > u, \end{cases} \tag{1}$$

A fuzzy number (FN) is given by the representatives of each level of membership function as follows:

$$\widetilde{M} = (M^{l(y)}, M^{r(y)}) = [l + (m-l)y,\ u + (m-u)y], y\ \in [0,1] \tag{2}$$

where $l(y)$ and $r(y)$ denote the left-side representation and the right-side representation of a fuzzy number, respectively. Two positive TFN (l_{11}, m_{11}, u_{11}) and $(l_{12},\ m_{12}, u_{12})$ are presented as following:

$$\begin{array}{c} (l_{11},\ m_{11},\ u_{11}) + (l_{12},\ m_{12},\ u_{12}) = (l_{11} + l_{12},\ m_{11} + m_{12}, u_{11} + u_{12}) \\ (l_{11},\ m_{11},\ u_{11}) - (l_{12},\ m_{12},\ u_{12}) = (l_{11} - l_{12},\ m_{11} - m_{12}, u_{11} - u_{12}) \\ (l_{11},\ m_{11},\ u_{11}) \times (l_{12},\ m_{12},\ u_{12}) = (l_{11} \times l_{12},\ m_{11} \times m_{12}, u_{11} \times u_{12}) \\ \frac{(l_{11},\ m_{11},\ u_{11})}{(l_{12},\ m_{12},\ u_{12})} = (l_{11}/u_{12},\ m_{11}/m_{12}, u_{11}/l_{12}) \end{array} \tag{3}$$

3.2.2. Fuzzy Analytical Hierarchy Process (AHP)

FAHP was developed by Saaty [5]. There are seven stages of the procedure as follows:

Step 1: Decision maker compares the criteria via linguistic terms as shown in Table 1.

Table 1. Linguistic terms and the corresponding TFN.

Saaty Scale	Definition	FTN Scale
1	Equally important	(1,1,1)
3	Weakly important	(2,3,4)
5	Fairly important	(4,5,6)
7	Strongly important	(6,7,8)
9	Absolutely important	(9,9,9)
2	The intermittent values between two adjacent scales	(1,2,3)
4		(3,4,5)
6		(5,6,7)
8		(7,8,9)

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

A pairwise comparison and relative scores is completed as follows:

$$\widetilde{K_1} = (l_A, m_A, u_A) \tag{4}$$

$$l_A = (l_{A1} \otimes l_{A2} \otimes \ldots \otimes l_{Ai})^{\frac{1}{i}},\ A = 1,\ 2,\ \ldots i \tag{5}$$

$$m_A = (m_{A1} \otimes m_{A2} \otimes \ldots \otimes m_{Ai})^{\frac{1}{i}},\ A = 1,\ 2,\ \ldots i \tag{6}$$

$$u_A = (u_{A1} \otimes u_{A2} \otimes \ldots \otimes u_{Ai})^{\frac{1}{i}},\ A = 1,\ 2,\ \ldots i \tag{7}$$

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

The geometric fuzzy mean is established by (28):

$$\widetilde{K}_Y = \left(\sum_{A=1}^{i} l_A, \sum_{A=1}^{i} m_A, \sum_{A=1}^{i} u_A \right) \tag{8}$$

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

The fuzzy geometric mean is determined as:

$$\widetilde{F} = \frac{\widetilde{K}_A}{\widetilde{Q}_Y} = \frac{(l_A, m_A, u_A)}{\sum_{A=1}^{i} l_A, \sum_{A=1}^{i} m_A, \sum_{A=1}^{i} u_A} = \left[\frac{l_A}{\sum_{A=1}^{i} u_A}, \frac{m_A}{\sum_{A=1}^{i} m_A}, \frac{u_A}{\sum_{A=1}^{i} l_A} \right] \tag{9}$$

Step 5: Calculation of PA_{ul}

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

$$PA_{ul} = (PAl_{ul}, PAu_{ul});\ A = 1,\ 2,\ \ldots i;\ l = 1,\ 2,\ \ldots L \tag{10}$$

Step 6: Calculation of P_{Al}, P_{Au}

Values of P_{Al}, P_{Au} are calculated by combining the lower and the upper values, and dividing them by the total μ values:

$$P_{Al} = \frac{\sum_{A=1}^{i} u(P_{Al})_l}{\sum_{l=1}^{L} u_A};\ A = 1,\ 2,\ \ldots i;\ l = 1,\ 2,\ \ldots L \tag{11}$$

$$P_{Au} = \frac{\sum_{A=1}^{i} u(P_{Au})_l}{\sum_{l=1}^{L} u_A};\ A = 1,\ 2,\ \ldots i;\ l = 1,\ 2,\ \ldots L \tag{12}$$

Step 7: Calculation of X_{bd}

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

$$P_{Ad} = \alpha \times P_{Au} + (1 - \alpha) \times P_{Al};\ \alpha\ \in [0,1];\ A = 1,\ 2, \ldots i \tag{13}$$

Step 8: Calculation of P_{Az}

$$P_{Az} = \frac{P_{Ad}}{\sum_{A=1}^{i} P_{Ad}};\ A = 1, 2, \ldots i \tag{14}$$

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

TOPSIS approach is presented by Hwang and Yoon [38]. The main concept of TOSIS is that optimal alternatives must have the shortest geometric distance from the PIS and NIS [39].

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

$$h_{cd} = \frac{y_{cd}}{\sqrt{\sum_{c}^{g} y_{ab}^{2}}},\ c = 1, \ldots g; d = 1, \ldots h. \tag{15}$$

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

$$l_{cd} = P_{cd} h_{cd},\ c = 1, \ldots ., g; d = 1, \ldots, h. \tag{16}$$

where Pj is the weight of the cth criterion and $\sum\limits_{c=1}^{h} p_p = 1$.

Step 3: Calculate the PIS (F^{+}) and PIS (F^{-}), where l_c^{+} indicate the maximum values of l_{cd} and l_c^{-} indicates the minimum value l_{cd} .

$$F^{+} = \{l_1^{+}, \ldots, l_h^{+}\} = \{(\max_d l_{cd} | c \in C), (\min_d l_{cd} | d \in D)\}, \tag{17}$$

$$F^{-} = \{l_1^{-}, \ldots, l_n^{-}\} = \{(\min_d l_{cd} | c \in C), (\max_d l_{cd} | d \in D)\}, \tag{18}$$

where A is related to profit criteria, and F is related to cost criteria.

Step 4: Determine a distance of the PIS (Q_c^{+}) separately by:

$$Q_c^{+} = \left\{ \sum_{d=1}^{h} (l_{cd} - l_d^{+})^2 \right\}^{\frac{1}{2}},\ c = 1,\ \ldots.,\ g \tag{19}$$

Similarly, the separation from the NIS (Q_c^{-}) is given as:

$$Q_c^{-} = \left\{ \sum_{d=1}^{h} (l_{cd} - l_d^{-})^2 \right\}^{\frac{1}{2}},\ c = 1,\ \ldots.,\ g \tag{20}$$

Step 5: Determine the relationship proximal to the problem-solving approaches, proximal relationship from option F_c to option F^{+}

$$C_c = \frac{Q_c^{-}}{Q_c^{+} + Q_c^{-}},\ c = 1, \ldots, g. \tag{21}$$

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

4. Case Study

Located in the monsoon subtropical area with a long coastline, Vietnam has fundamental advantages for developing wind energy. When comparing the average wind speed in the East Sea of Vietnam and the surrounding sea areas, the result shows that wind in the East Sea of Vietnam is fairly strong and seasonally changes. A wind speed map of Vietnam is shown in Figure 4.

For this research, the authors collected data from seven potential locations that are viable for wind power plants, as shown in Table 2.

Table 2. Seven potential locations for building wind power plants in Vietnam.

No	Locations	Symbol
1	Quang Ninh	DMU1
2	Binh Thuan	DMU2
3	Quang Tri	DMU3
4	Ninh Thuan	DMU4
5	Tra Vinh	DMU5
6	Hai Van	DMU6
7	Bac Lieu	DMU7

The AHP model with fuzzy logic is applied in the first stage of this work. A hierarchical structure to select the best location is built with four main criteria (including 12 sub-criteria). Completion of a questionnaire for analyzing the FAHP model is done by interviewing experts, and preferences from other research. The weight of each criteria is defined by the comparison matrix. The Hierarchical Structures for the FAHP approach are shown in Figure 5.

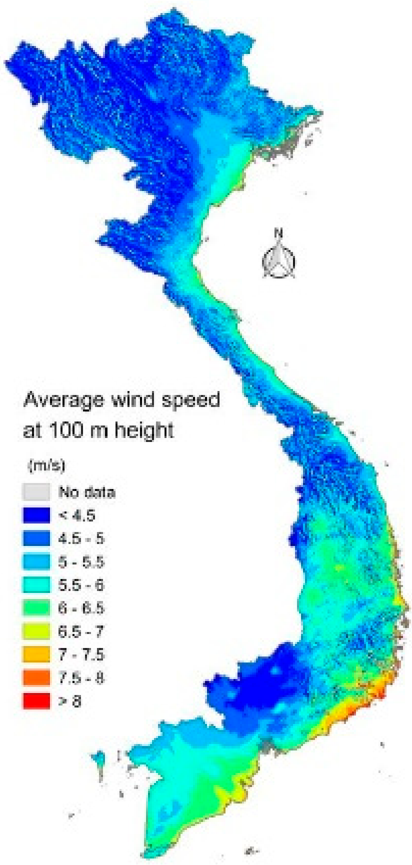

Figure 4. Wind speed map of Vietnam [40].

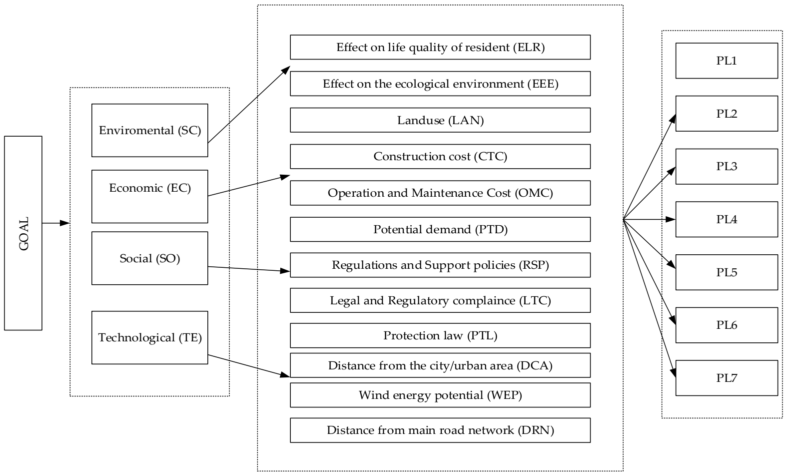

Figure 5. Hierarchical structures of the Fuzzy Analytic Hierarchy Process (FAHP) model.

A fuzzy comparison matrix for GOAL from the FAHP model is shown in Table 3.

Table 3. Fuzzy comparison matrices for GOAL.

Criteria	Economic (EC)	Environmental (SC)	Social (SO)	Technological (TE)
Economic (EC)	(1,1,1)	(2,3,4)	(3,4,5)	(2,3,4)
Environmental (SC)	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(4,5,6)
Social (SO)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)	(1,2,3)
Technological (TE)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1,1,1)

The fuzzy numbers were converted to real numbers by using the TFN. During the defuzzification, the authors obtain the coefficients α = 0.5 and β = 0.5 (Tang and Beynon) [41]. In it, α represents the uncertain environment conditions, and β represents the attitude of the evaluator is fair.

$$g_{0.5,0.5}(\overline{a_{EC,SC}}) = [(0.5 \times 2.5) + (1 - 0.5) \times 3.5] = 3$$

$$f_{0.5}(L_{EC,SC}) = (3 - 2) \times 0.5 + 2 = 2.5$$

$$f_{0.5}(U_{EC,SC}) = 4 - (4 - 3) \times 0.5 = 3.5$$

$$g_{0.5,0.5}(\overline{a_{SC,EC}}) = 1/3$$

The remaining calculations for others criteria are similar to the above calculation. The real number priority when comparing the main criteria pairs are shown in Table 4.

Table 4. Real number priority.

Criteria	Economic (EC)	Environmental (SC)	Social (SO)	Technological (TE)
Economic (EC)	1	3	4	3
Environmental (SC)	1/3	1	2	5
Social (SO)	$\frac{1}{4}$	1/2	1	2
Technological (TE)	1/3	1/5	1/2	1

For calculating the maximum individual value as following:

$$OA1 = (1 \times 3 \times 4 \times 3)^{1/4} = 2.44$$

$$OA2 = (1/3 \times 1 \times 2 \times 5)^{1/4} = 1.35$$

$$OA3 = (1/4 \times 1/2 \times 1 \times 2)^{1/4} = 0.71$$

$$OA4 = (1/3 \times 1/5 \times 1/2 \times 1)^{1/4} = 0.43$$

$$\sum OA = \text{OA1} + \text{OA2} + \text{OA3} + \text{OA4} = 4.9$$

$$\omega_1 = \frac{2.44}{4.93} = 0.49$$

$$\omega_2 = \frac{1.35}{4.93} = 0.27$$

$$\omega_3 = \frac{0.71}{4.93} = 0.14$$

$$\omega_4 = \frac{0.43}{4.93} = 0.09$$

$$\begin{bmatrix} 1 & 3 & 4 & 2 \\ 1/3 & 1 & 2 & 5 \\ 1/4 & 1/2 & 1 & 2 \\ 1/3 & 1/5 & 1/2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.49 \\ 0.27 \\ 0.14 \\ 0.09 \end{bmatrix} = \begin{bmatrix} 2.04 \\ 1.16 \\ 0.58 \\ 0.38 \end{bmatrix}$$

$$\begin{bmatrix} 2.04 \\ 1.16 \\ 0.58 \\ 0.38 \end{bmatrix} / \begin{bmatrix} 0.49 \\ 0.27 \\ 0.14 \\ 0.09 \end{bmatrix} = \begin{bmatrix} 4.16 \\ 4.30 \\ 4.14 \\ 4.22 \end{bmatrix}$$

Based on the number of main criteria, the authors get $n = 4$, λ_{max} and CI is calculated as follows:

$$\lambda_{max} = \frac{4.16 + 4.30 + 4.14 + 4.22}{4} = 4.21$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.21 - 4}{4 - 1} = 0.07$$

To calculate CR value, we get $RI = 0.9$ with $n = 4$.

$$CR = \frac{CI}{RI} = \frac{0.04}{0.9} = 0.08$$

Because $CR = 0.08 \leq 0.1$, so we need not to be re-evaluated. A fuzzy comparison matrix for all sub-criteria are shown in Appendix A.

After evaluating the interaction between all the criteria in the FAHP model, the results from Microsoft Excel are shown in Table 5.

Table 5. Results of the FAHP model.

No.	Sub-Criteria	Weight
1	Land use (LAN)	0.02858
2	Construction cost (CTC)	0.26503
3	Distance from main road network (DRN)	0.01089
4	Wind energy potential (WEP)	0.04987
5	Effect on the ecological environment (EEE)	0.07047
6	Effect on life quality of resident (ELR)	0.17379
7	Legal and Regulatory compliance (LTC)	0.07166
8	Potential demand (PTD)	0.07012
9	Operation and Maintenance Cost (OMC)	0.16696
10	Distance from the city/urban area (DCA)	0.02854
11	Protection law (PTL)	0.01896
12	Regulations and support policies (RSP)	0.04514

Based on the weight of all criteria as defined by the FAHP model, all the potential locations will be ranked by the TOPSIS model in this stage. The normalized weight matrix is shown in Table 6.

Table 6. Normalized Weight Matrix from The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) model.

DMU	LAN	CTC	DRN	WEP	EEE	ELR	LTC	PTD	OMC	DCA	PTL	RSP
DMU1	0.0034	0.0644	0.0052	0.0186	0.0262	0.0548	0.0273	0.0331	0.0402	0.0115	0.0081	0.0171
DMU2	0.0050	0.0322	0.0040	0.0186	0.0262	0.0731	0.0273	0.0294	0.0402	0.0086	0.0081	0.0171
DMU3	0.0067	0.0805	0.0035	0.0186	0.0262	0.0639	0.0182	0.0294	0.0402	0.0115	0.0060	0.0196
DMU4	0.0118	0.1127	0.0046	0.0186	0.0262	0.0731	0.0364	0.0294	0.0804	0.0101	0.0060	0.0220
DMU5	0.0118	0.1127	0.0029	0.0247	0.0262	0.0731	0.0182	0.0258	0.0603	0.0130	0.0070	0.0147
DMU6	0.0151	0.1288	0.0046	0.0124	0.0350	0.0548	0.0364	0.0184	0.0804	0.0101	0.0050	0.0147
DMU7	0.0151	0.1288	0.0035	0.0186	0.0175	0.0639	0.0182	0.0147	0.0804	0.0101	0.0091	0.0122

5. Results and Discussion

Wind power plant site selection is identified as a critical issue that could affect economic, environmental, technological, and social factors. Further, location selection is complicated, in that decision-makers must have broad perspectives concerning qualitative and quantitative criteria.

In this research, seven potential locations in Vietnam are considered. In this stage, the identification of key criteria and sub-criteria is based on a review of the literature and scientific reports related to the content of the research to determine the necessary criteria. A hierarchical structure to select the optimal place was built with four main criteria. The FAHP was used to define a priority of each potential sites. Then, the TOPSIS model is proposed for ranking potential location. The distance of the PIS Q_c^+ and the separation from the NIS Q_c^- are shown in Table 7.

Table 7. Q_c^+ and Q_c^- value from TOPSIS model.

DMUs	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7
Q(+,c)	0.0400	0.0155	0.0508	0.0929	0.0856	0.1111	0.1079
Q(−,c)	0.0805	0.1089	0.0694	0.0323	0.0393	0.0136	0.0280

Results of the TOPSIS model are summarized in Figures 6 and 7; based on the final performance score C_c in Table 8, the final location ranking list is DMU2, DMU1, DMU3, DMU5, DMU4, DMU6, and DMU7, respectively. The results show that Binh Thuan (DMU2) is the best location for building a wind power plant in Vietnam.

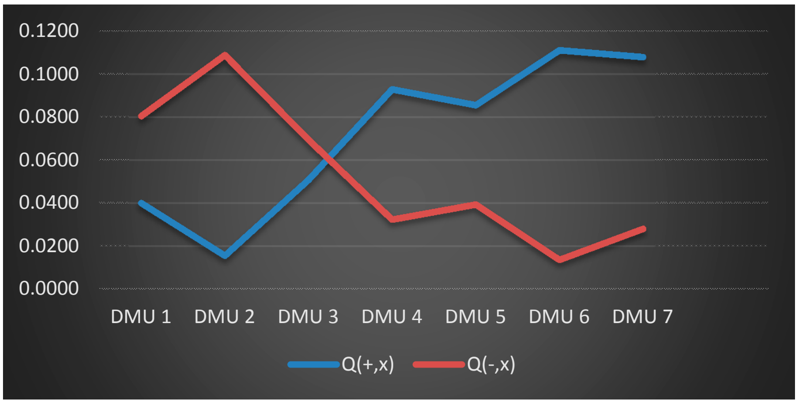

Figure 6. Geometric distance from positive ideal solution (PIS) and negative ideal solution (NIS).

Table 8. Ranking list of TOPSIS model.

DMUs	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7
C(c)	0.6679	0.8754	0.5775	0.2580	0.3150	0.1088	0.2059
Rank	2	1	3	5	4	7	6

In Figure 6, DMU2 has the shortest geometric distance from the PIS and the longest geometric distance from the NIS.

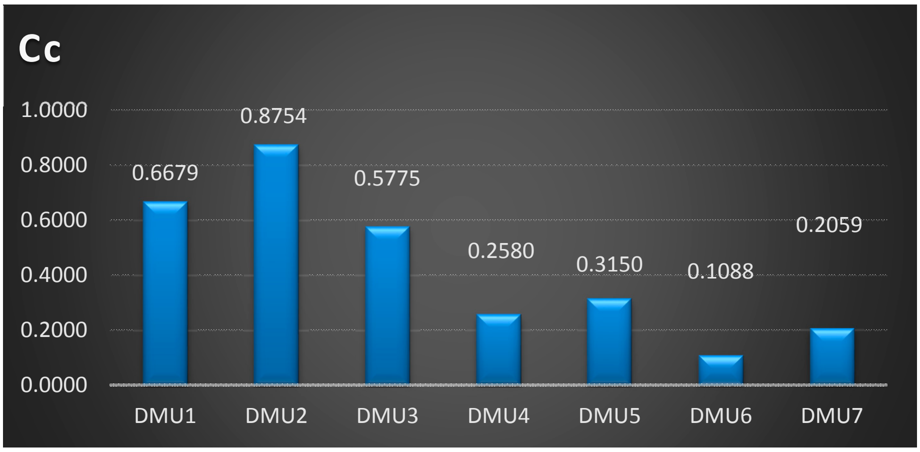

Figure 7. Results from TOPSIS model.

This research can be used for ranking potential locations for building wind power plants in many countries, but the number of locations selection is practically limited because of the number of pairwise comparisons that need to be made and a disadvantage of the FAHP approach is that input data, expressed in linguistic terms, depends on experience of decision makers and thus involves subjectivity. Thus, the authors propose to extend these using the MCDM model by combining different methodologies in future research.

6. Conclusions

Location is among the most important decisions that management faces. Thus, wind power plant location decision-making is a highly complex process. The purpose of a location study is to determine an area and site at which the projected operation and investment can be carried out under optimal conditions, with the best monetary return, and with the least number of problems.

Although researchers have applied the FAHP and TOPSIS models in location selection, very few have considered wind power plant location selection under fuzzy environment conditions. Furthermore, there is no work that applies these models for wind power plant location selection in Vietnam. This is a reason why the authors proposed a hybrid AHP model with fuzzy logic and TOPSIS approach for wind power plant location selection. The results in Table 8 show that DMU2 (Binh Thuan) is an optimal place for building a wind power plant in Vietnam.

The contributions of this work proposed a MCDM approach under fuzzy environments for wind power plant location selection in Vietnam. This paper also resides in the evolution of a new fuzzy MCDM model that is flexible and practical for the decision-maker. This research also provides a useful guideline for wind power plant location selection in others countries.

For improving these MCDM models, it is suggested that applications be increased through development of new factors, subfactors, or different methodologies, e.g., fuzzy analysis network process (FANP), etc., which can also be combined for different scenarios regarding energy issues.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Input data of GOAL.

Criteria	Priority																	Criteria
	(9,9,9)	**(7,8,9)**	**(6,7,8)**	**(5,6,7)**	**(4,5,6)**	**(3,4,5)**	**(2,3,4)**	**(1,2,3)**	**(1)**	**(1,2,3)**	**(2,3,4)**	**(3,4,5)**	**(4,5,6)**	**(5,6,7)**	**(6,7,8)**	**(7,8,9)**	**(9,9,9)**	
EC							X											SC
EC						X												SO
EC							X											TE
SC								X										SO
SC					X													TE
SO								X										TE

Table A2. Input data of Economic (EC).

Criteria	Priority																	Criteria
	(9,9,9)	**(7,8,9)**	**(6,7,8)**	**(5,6,7)**	**(4,5,6)**	**(3,4,5)**	**(2,3,4)**	**(1,2,3)**	**(1,1,1)**	**(1,2,3)**	**(2,3,4)**	**(3,4,5)**	**(4,5,6)**	**(5,6,7)**	**(6,7,8)**	**(7,8,9)**	**(9,9,9)**	
CTC								X										OMC
CTC							X											PTD
OMC							X											PTD

Table A3. Input data of Environmental (SC).

Criteria	Priority																	Criteria
	(9,9,9)	**(7,8,9)**	**(6,7,8)**	**(5,6,7)**	**(4,5,6)**	**(3,4,5)**	**(2,3,4)**	**(1,2,3)**	**(1,1,1)**	**(1,2,3)**	**(2,3,4)**	**(3,4,5)**	**(4,5,6)**	**(5,6,7)**	**(6,7,8)**	**(7,8,9)**	**(9,9,9)**	
CTC											X							OMC
CTC							X											PTD
OMC					X													PTD

Table A4. Input data of Social (SO).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
DCA							X											DRN
DCA										X								WEP
DRN												X						WEP

Table A5. Input data of Technological (TE).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
LRC							X											DRN
LRC								X										WEP
PTL											X							WEP

Table A6. Input data of Construction cost (CTC).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1									X									PL2
PL1						X												PL3
PL1							X											PL4
PL1					X													PL5
PL1							X											PL6
PL1				X														PL7
PL1						X												PL3
PL2								X										PL4
PL2									X									PL5
PL2					X													PL6
PL2							X											PL7
PL3											X							PL4
PL3												X						PL5
PL3										X								PL6
PL3								X										PL7
PL4												X						PL5
PL4							X											PL6
PL4					X													PL7
PL5								X										PL6
PL5								X										PL7
PL6								X										PL7

Table A7. Input data of Distance from the city/urban area (DCA).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1								X										PL2
PL1						X												PL3
PL1								X										PL4
PL1				X														PL5
PL1								X										PL6
PL1							X											PL7
PL1							X											PL3
PL2						X												PL4
PL2								X										PL5
PL2							X											PL6
PL2								X										PL7
PL3										X								PL4
PL3												X						PL5
PL3											X							PL6
PL3										X								PL7
PL4								X										PL5
PL4									X									PL6
PL4												X						PL7
PL5										X								PL6
PL5													X					PL7
PL6											X							PL7

Table A8. Input data of Distance from main road network (DRN).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1							X											PL2
PL1								X										PL3
PL1							X											PL4
PL1			X															PL5
PL1							X											PL6
PL1								X										PL7
PL1								X										PL3

Table A8. *Cont.*

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL2					X													PL4
PL2							X											PL5
PL2								X										PL6
PL2						X												PL7
PL3							X											PL4
PL3								X										PL5
PL3									X									PL6
PL3							X											PL7
PL4												X						PL5
PL4										X								PL6
PL4											X							PL7
PL5										X								PL6
PL5										X								PL7
PL6									X									PL7

Table A9. Input data of Effect on the ecological environment (EEE).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1										X								PL2
PL1							X											PL3
PL1						X												PL4
PL1										X								PL5
PL1								X										PL6
PL1							X											PL7
PL1								X										PL3
PL2							X											PL4
PL2										X								PL5
PL2								X										PL6
PL2							X											PL7
PL3								X										PL4
PL3								X										PL5
PL3							X											PL6

Table A9. *Cont.*

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL3						X												PL7
PL4										X								PL5
PL4											X							PL6
PL4									X									PL7
PL5								X										PL6
PL5							X											PL7
PL6							X											PL7

Table A10. Input data of Effect on life quality of resident (ELR).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1								X										PL2
PL1				X														PL3
PL1							X											PL4
PL1						X												PL5
PL1								X										PL6
PL1							X											PL7
PL1								X										PL3
PL2						X												PL4
PL2								X										PL5
PL2										X								PL6
PL2							X											PL7
PL3										X								PL4
PL3									X									PL5
PL3													X					PL6
PL3										X								PL7
PL4						X												PL5
PL4										X								PL6
PL4							X											PL7
PL5												X						PL6
PL5							X											PL7
PL6								X										PL7

Table A11. Input data of Land use (LAN).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1								X										PL2
PL1								X										PL3
PL1					X													PL4
PL1						X												PL5
PL1			X															PL6
PL1								X										PL7
PL1											X							PL3
PL2							X											PL4
PL2								X										PL5
PL2						X												PL6
PL2										X								PL7
PL3					X													PL4
PL3								X										PL5
PL3					X													PL6
PL3								X										PL7
PL4							X											PL5
PL4								X										PL6
PL4											X							PL7
PL5								X										PL6
PL5												X						PL7
PL6								X										PL7

Table A12. Input data of Legal and Regulatory compliance (LTC).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1								X										PL2
PL1							X											PL3
PL1					X													PL4
PL1						X												PL5
PL1								X										PL6
PL1							X											PL7
PL1											X							PL3

Table A12. *Cont.*

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL2										X								PL4
PL2						X												PL5
PL2								X										PL6
PL2						X												PL7
PL3								X										PL4
PL3							X											PL5
PL3								X										PL6
PL3				X														PL7
PL4							X											PL5
PL4								X										PL6
PL4						X												PL7
PL5								X										PL6
PL5								X										PL7
PL6							X											PL7

Table A13. Input data of Operation and Maintenance Cost (OMC).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1								X										PL2
PL1						X												PL3
PL1								X										PL4
PL1							X											PL5
PL1							X											PL6
PL1						X												PL7
PL1								X										PL3
PL2								X										PL4
PL2									X									PL5
PL2											X							PL6
PL2											X							PL7
PL3										X								PL4
PL3													X					PL5
PL3										X								PL6

Table A13. *Cont.*

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL3										X								PL7
PL4												X						PL5
PL4											X							PL6
PL4										X								PL7
PL5									X									PL6
PL5							X											PL7
PL6								X										PL7

Table A14. Input data of Potential demand (PTD).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1										X								PL2
PL1					X													PL3
PL1							X											PL4
PL1			X															PL5
PL1					X													PL6
PL1								X										PL7
PL1						X												PL3
PL2					X													PL4
PL2							X											PL5
PL2						X												PL6
PL2								X										PL7
PL3												X						PL4
PL3							X											PL5
PL3											X							PL6
PL3										X								PL7
PL4							X											PL5
PL4								X										PL6
PL4						X												PL7
PL5											X							PL6
PL5										X								PL7
PL6								X										PL7

Table A15. Input data of Protection law (PTL).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1						X												PL2
PL1							X											PL3
PL1								X										PL4
PL1						X												PL5
PL1					X													PL6
PL1				X														PL7
PL1							X											PL3
PL2								X										PL4
PL2						X												PL5
PL2							X											PL6
PL2							X											PL7
PL3												X						PL4
PL3											X							PL5
PL3								X										PL6
PL3											X							PL7
PL4							X											PL5
PL4					X													PL6
PL4							X											PL7
PL5								X										PL6
PL5							X											PL7
PL6											X							PL7

Table A16. Input data of Regulations and support policies (RSP).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL1								X										PL2
PL1					X													PL3
PL1					X													PL4
PL1						X												PL5
PL1					X													PL6
PL1								X										PL7
PL1							X											PL3

Table A16. *Cont.*

Criteria	**Priority**																	**Criteria**
	(9,9,9)	**(7,8,9)**	**(6,7,8)**	**(5,6,7)**	**(4,5,6)**	**(3,4,5)**	**(2,3,4)**	**(1,2,3)**	**(1,1,1)**	**(1,2,3)**	**(2,3,4)**	**(3,4,5)**	**(4,5,6)**	**(5,6,7)**	**(6,7,8)**	**(7,8,9)**	**(9,9,9)**	
PL2					X													PL4
PL2						X												PL5
PL2							X											PL6
PL2				X														PL7
PL3										X								PL4
PL3											X							PL5
PL3												X						PL6
PL3												X						PL7
PL4										X								PL5
PL4												X						PL6
PL4											X							PL7
PL5										X								PL6
PL5								X										PL7
PL6										X								PL7

Table A17. Input data of Wind energy potential (WEP).

Criteria	**Priority**																	**Criteria**
	(9,9,9)	**(7,8,9)**	**(6,7,8)**	**(5,6,7)**	**(4,5,6)**	**(3,4,5)**	**(2,3,4)**	**(1,2,3)**	**(1,1,1)**	**(1,2,3)**	**(2,3,4)**	**(3,4,5)**	**(4,5,6)**	**(5,6,7)**	**(6,7,8)**	**(7,8,9)**	**(9,9,9)**	
PL1									X									PL2
PL1							X											PL3
PL1						X												PL4
PL1								X										PL5
PL1					X													PL6
PL1							X											PL7
PL1						X												PL3
PL2						X												PL4
PL2								X										PL5
PL2					X													PL6
PL2				X														PL7
PL3						X												PL4
PL3								X										PL5
PL3								X										PL6

Table A17. Input data of Wind energy potential (WEP).

Criteria	Priority																	Criteria
	(9,9,9)	(7,8,9)	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)	(7,8,9)	(9,9,9)	
PL3							X											PL7
PL4											X							PL5
PL4							X											PL6
PL4								X										PL7
PL5										X								PL6
PL5							X											PL7
PL6								X										PL7

Table A18. Comparison matrix for SC.

Sub-Criteria	EEE	ELR	LAN	Weight
EEE	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	0.258284876
ELR	(2,3,4)	(1,1,1)	(4,5,6)	0.636985704
LAN	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1,1,1)	0.104729421
Total				1
CR = 0.03703				

Table A19. Comparison matrix for SO.

Sub-Criteria	LRC	PTL	RSP	Weight
LRC	(1,1,1)	(2,3,4)	(1,2,3)	0.527836099
PTL	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	0.139647883
RSP	(1/3,1/2,1)	(2,3,4)	(1,1,1)	0.332516017
Total				1
CR = 0.05156				

Table A20. Comparison matrix for SC.

Sub-Criteria	EEE	ELR	LAN	Weight
EEE	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	0.258284876
ELR	(2,3,4)	(1,1,1)	(4,5,6)	0.636985704
LAN	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1,1,1)	0.104729421
Total				1
CR = 0.03703				

Table A21. Comparison matrix for SO.

Sub-Criteria	LRC	PTL	RSP	Weight
LRC	(1,1,1)	(2,3,4)	(1,2,3)	0.527836099
PTL	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	0.139647883
RSP	(1/3,1/2,1)	(2,3,4)	(1,1,1)	0.332516017
Total				1
CR = 0.05156				

Table A22. Comparison matrix for TE.

Sub-Criteria	DCA	DRN	WEP	Weight
DCA	(1,1,1)	(2,3,4)	(1/3,1/2,1)	0.319618264
DRN	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	0.121957193
WEP	(1,2,3)	(3,4,5)	(1,1,1)	0.558424543
Total				1
CR = 0.01759				

Table A23. Comparison matrix for CTC.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,1,1)	(3,4,5)	(2,3,4)	(4,5,6)	(2,3,4)	(5,6,7)	0.319782
DMU2	(1,1,1)	(1,1,1)	(3,4,5)	(1,2,3)	(1,1,1)	(4,5,6)	(2,3,4)	0.212268
DMU3	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,2,3)	0.050783

Table A23. *Cont.*

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU4	(1/4,1/3,1/2)	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(1/5,1/4,1/3)	(2,3,4)	(4,5,6)	0.124539
DMU5	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)	(3,4,5)	(1,1,1)	(1,2,3)	(1,2,3)	0.178695
DMU6	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1,2,3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	0.069675
DMU7	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	0.044258
Total								1
CR = 0.09203								

Table A24. Comparison matrix for DCA.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,2,3)	(3,4,5)	(1,2,3)	(5,6,7)	(1,2,3)	(2,3,4)	0.292825713
DMU2	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(3,4,5)	(1,2,3)	(2,3,4)	(1,2,3)	0.213869561
DMU3	(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)	0.049046169
DMU4	(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)	0.086112465
DMU5	(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)	0.070959901
DMU6	(1/3,1/2,1)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	0.096740938
DMU7	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(3,4,5)	(4,5,6)	(2,3,4)	(1,1,1)	0.190445253
Total								1
CR = 0.09687								

Table A25. Comparison matrix for DRN.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(2,3,4)	(1,2,3)	(2,3,4)	(6,7,8)	(2,3,4)	(1,2,3)	0.317502421
DMU2	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(4,5,6)	(2,3,4)	(1,2,3)	(3,4,5)	0.218285913
DMU3	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1,2,3)	(1,1,1)	(2,3,4)	0.143736516
DMU4	(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)	0.04558615
DMU5	(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)	0.071874529
DMU6	(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)	0.104924547
DMU7	(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)	0.098089925
Total								1
CR = 0.07316								

Table A26. Comparison matrix for EEE.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1/3,1/2,1)	(2,3,4)	(3,4,5)	(1/3,1/2,1)	(1,2,3)	(2,3,4)	0.198261784
DMU2	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	(1/3,1/2,1)	(1,2,3)	(2,3,4)	0.206508609
DMU3	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1,2,3)	(2,3,4)	(3,4,5)	0.179097455
DMU4	(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)	(1/4,1/3,1/2)	(1,1,1)	0.058657984
DMU5	(1,2,3)	(1,2,3)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)	0.20408295
DMU6	(1/3,1/2,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(2,3,4)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	0.102786784
DMU7	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	0.050604434
				Total				1
				CR = 0.09031				

Table A27. Comparison matrix for DLR.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,2,3)	(5,6,7)	(2,3,4)	(3,4,5)	(1,2,3)	(2,3,4)	0.292051312
DMU2	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(3,4,5)	(1,2,3)	(1/3,1/2,1)	(2,3,4)	0.178575121
DMU3	(1/7,1/6,1/5)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(1,1,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	0.052008315
DMU4	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,2,3)	(1,1,1)	(3,4,5)	(1/3,1/2,1)	(2,3,4)	0.125238171
DMU5	(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)	0.073449212
DMU6	(1/3,1/2,1)	(1,2,3)	(4,5,6)	(1,2,3)	(3,4,5)	(1,1,1)	(1,2,3)	0.21401434
DMU7	(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)	0.064663529
				Total				1
				CR = 0.08811				

Table A28. Comparison matrix for LAN.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,2,3)	(1,2,3)	(4,5,6)	(3,4,5)	(6,7,8)	(1,2,3)	0.297109615
DMU2	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1,2,3)	(3,4,5)	(1/3,1/2,1)	0.124532089
DMU3	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(4,5,6)	(1,2,3)	(4,5,6)	(1,2,3)	0.234956786
DMU4	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1,1,1)	(2,3,4)	(1,2,3)	(1/4,1/3,1/2)	0.073137012
DMU5	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1/5,1/4,1/3)	0.066573111

Table A28. *Cont.*

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU6	(1/8,1/7,1/6)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	0.039680622
DMU7	(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)	0.164010765
				Total				1
				CR = 0.07234				

Table A29. Comparison matrix for LRC.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,2,3)	(2,3,4)	(4,5,6)	(3,4,5)	(1,2,3)	(2,3,4)	0.320996701
DMU2	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(3,4,5)	(1,2,3)	(3,4,5)	0.134004031
DMU3	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(1,2,3)	(2,3,4)	(1,2,3)	(5,6,7)	0.208398594
DMU4	(1/6,1/5,1/4)	(1,2,3)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1,2,3)	(3,4,5)	0.143500136
DMU5	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)	(1,2,3)	(1,2,3)	0.070266308
DMU6	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	0.08248656
DMU7	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	0.040347668
				Total				1
				CR = 0.09685				

Table A30. Comparison matrix for OMC.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,2,3)	(3,4,5)	(1,2,3)	(2,3,4)	(2,3,4)	(3,4,5)	0.308665923
DMU2	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(1,2,3)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	0.100914216
DMU3	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	0.050939728
DMU4	(1/3,1/2,1)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/3,1/2,1)	0.06964802
DMU5	(1/4,1/3,1/2)	(1,1,1)	(4,5,6)	(3,4,5)	(1,1,1)	(1,1,1)	(2,3,4)	0.186425117
DMU6	(1/4,1/3,1/2)	(2,3,4)	(1,2,3)	(2,3,4)	(1,1,1)	(1,1,1)	(1,2,3)	0.168877067
DMU7	(1/5,1/4,1/3)	(2,3,4)	(1,2,3)	(1,2,3)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,1,1)	0.11452993
				Total				1
				CR = 0.08676				

Table A31. Comparison matrix for PTD.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,2,3)	(4,5,6)	(2,3,4)	(6,7,8)	(4,5,6)	(1,2,3)	0.317733136
DMU2	(1/3,1/2,1)	(1,1,1)	(3,4,5)	(4,5,6)	(2,3,4)	(3,4,5)	(1,2,3)	0.262261449
DMU3	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(1/5,1/4,1/3)	(2,3,4)	(1/4,1/3,1/2)	(1/3,1/2,1)	0.052969386
DMU4	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(3,4,5)	(1,1,1)	(2,3,4)	(1,2,3)	(3,4,5)	0.148887171
DMU5	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	0.040194693
DMU6	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(2,3,4)	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(1,2,3)	0.095375409
DMU7	(1/3,1/2,1)	(1/3,1/2,1)	(1,2,3)	(1/5,1/4,1/3)	(1,2,3)	(1/3,1/2,1)	(1,1,1)	0.082578756
				Total				1
				CR = 0.09832				

Table A32. Comparison matrix for PTL.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(3,4,5)	(2,3,4)	(1,2,3)	(3,4,5)	(4,5,6)	(5,6,7)	0.351089881
DMU2	(1/5,1/4,1/3)	(1,1,1)	(2,3,4)	(1,2,3)	(3,4,5)	(2,3,4)	(2,3,4)	0.200265621
DMU3	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,2,3)	(1/4,1/3,1/2)	0.054487897
DMU4	(1/3,1/2,1)	(1/3,1/2,1)	(3,4,5)	(1,1,1)	(2,3,4)	(4,5,6)	(2,3,4)	0.180208506
DMU5	(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)	0.098704044
DMU6	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)	0.040650718
DMU7	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	0.074593332
				Total				1
				CR = 0.09284				

Table A33. Comparison matrix for RSP.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,2,3)	(4,5,6)	(4,5,6)	(3,4,5)	(4,5,6)	(1,2,3)	0.316504491
DMU2	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(4,5,6)	(3,4,5)	(2,3,4)	(5,6,7)	0.280026948
DMU3	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	0.039448039
DMU4	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	0.045923993
DMU5	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(2,3,4)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	(1,2,3)	0.094718777

Table A33. *Cont.*

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU6	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(3,4,5)	(3,4,5)	(1,2,3)	(1,1,1)	(1/3,1/2,1)	0.10995477
DMU7	(1/3,1/2,1)	(1/7,1/6,1/5)	(3,4,5)	(2,3,4)	(1/3,1/2,1)	(1,2,3)	(1,1,1)	0.113422982
Total								1
CR = 0.09493								

Table A34. Comparison matrix for WEP.

Alternatives	DMU1	DMU2	DMU3	DMU4	DMU5	DMU6	DMU7	Weight
DMU1	(1,1,1)	(1,1,1)	(2,3,4)	(3,4,5)	(1,2,3)	(4,5,6)	(2,3,4)	0.258369063
DMU2	(1,1,1)	(1,1,1)	(3,4,5)	(3,4,5)	(1,2,3)	(4,5,6)	(5,6,7)	0.293351061
DMU3	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1,1,1)	(3,4,5)	(1,2,3)	(1,2,3)	(2,3,4)	0.142468303
DMU4	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1,2,3)	0.07703134
DMU5	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(1/3,1/2,1)	(2,3,4)	0.109773315
DMU6	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,2,3)	(1,1,1)	(1,2,3)	0.075558663
DMU7	(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)	0.043448255
Total								1
CR = 0.0986								

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