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Analysis on sustainable performance of wind power by using MCDM method

Wind power can be an efficient way to alleviate energy shortage and environmental pollution, and to realize sustainable development in terms of energy generation. The sustainability assessment of a wind power project among its alternatives is a complex task that cannot be solely simplified to environmental or economic feasibility and requires the consideration of its technological and social aspects as well as other circumstances. This paper proposes a novel method for selecting the most sustainable wind power projects. The method is based on multi-criteria decision-making (MCDM) techniques; the analytic hierarchy process and entropy weight method combined with determining the weights of evaluation indexes, and an innovative index-weight optimization method based on the Lagrange conditioned extreme value. The TOPSIS is applied to rank wind project alternatives considering the system functionality and proportionality. The results indicated that the calculated wind power's sustainable level can provide a reference point for the planning and operation of the wind project; the results thus have a certain value with regard to both their theoretical significance and practical application in engineering.

Keywords: Analytic hierarchy process, comprehensive evaluation index system, entropy method, TOPSIS, wind power sustainability level.

1. Introduction

The rapid development of the world economy brings potential energy and environmental problems such as global environmental deterioration, a shortage of traditional energy resources, and climate change. The growing demand and use of coal, oil, natural gas, and other traditional energy sources, which are unsustainable energies, have generated concerns regarding serious potential environmental pollution. Given the negative externalities of traditional energy generation activities, the sustainability of renewables has increasingly gained importance. The construction and operation of wind energy represents a strategic method to realize sustainable development, which has significant impacts on technologies, the environment, economy, and society. Furthermore, wind power is arguably an important platform for energy supply and plays a leading role in decarburizations in the near future[1].

It is clear that the construction and operation of wind energy represent a strategic method to realize sustainable development not only in China but also all over the word, which has significant impacts on the technology, environment, economy and society. Furthermore, it can be argued that wind power will be an important platform for energy supply and play a leading role in de-carbonization in the near future. However, generating power on a mainstream basis assumes new responsibilities such as the insurance of a reliable and cost-effective functioning of the overall energy system and its contribution to energy security. This becomes problematic given that wind power, by nature, is characterized by stochastic fluctuation, which affects the stability of the original power grid and restricts this renewable's sustainable development. Thus, advanced technologies must be examined to improve the stability level of wind generators. Moreover, power grid construction is lagging the increasing power loads observed in some areas of urban China and may result in wind curtailment. This phenomenon has worsened since 2016, during which the total wind curtailment rate was 38.4%. Other challenges have been linked to the feed-in tariff (FIT), which has become an increasing burden on the Chinese government due to the rapid development of wind power. As a result, the development of funding solutions to finance the FIT has increased, thereby resulting in pressure on the renewable industry to lower its costs. A combination of all these challenges may result in a waste of wind resources, an economic deficit on wind projects, and may hinder the sustainable development of wind energy.

Identifying the most sustainable wind project can minimize the use of resources, alleviate environmental burdens, and simultaneously contribute to the local economy and increase employment. Currently, some studies related to the sustainability of renewable energy resources (RES)

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to evaluate the power grid have been conducted. Authors in[2] examined the sustainable technologies for electricity generation in Greece using multi-criteria decision-making (MCDM) method. Authors in[3] proposed a hybrid MCDM method to evaluate the external benefits of China's renewable energy power based on three kinds of indexes, specifically economic, social, and environmental factors, with the concept of sustainability. The results indicated that solar photovoltaics (PV) power has the maximum sustainable benefit, followed by wind power and biomass power. Authors in[4] assessed central Southern England for wind and solar energy sustainability, wherein the sustainability of wind energy was generally low and solar exhibited the highest overall sustainability. Authors in[5] applied the MCDM approach with analytic hierarchy process-ordered weighted averaging (AHP-OWA) weights calculation method to derive the wind farm land suitability index and classification under a geographical information system (GIS) environment. Authors in[6] employed the country-specific values (New Zealand) for the indicators to assess the sustainability of the electricity system in detail from its economic, social, and environmental aspects. The aforementioned studies examined the sustainability of different kinds of renewables, or the partial sustainable characters of wind energy. The comprehensive evaluation of sustainable wind energy levels has not been reported. The present study performed well-rounded research to measure the sustainability of wind projects in consideration of multiple aspects to serve as an important topic for the sustainable development of wind power projects and to fulfill the current research gap.

This paper examined the sustainable performance of wind generation projects as a multi-criteria decision-making (MCDM) problem. The primary MCDM analysis step is the calculation of weights for the various indicators, which includes two main approaches. The first involves subjective weighting methods such as the analytic hierarchy process (AHP), the Delphi analysis, and the fuzzy comprehensive evaluation method (FCEM). The second approach involves objective weighting methods such as the grey comprehensive evaluation method (GCEM) and entropy method. Objective weighting methods emphasize the differences between indices, whereas subjective weighting methods can provide an absolute measure of importance. It is noted, however, that most studies only employ either subjective or objective methods to determine the weights. For example, a comprehensive assessment method that considers voltage and power losses was presented, wherein the weights were determined only by objective judgment[7]. In another case[8], only a subjective methodology that combined the AHP method and expert feedback was employed to evaluate different renewable energy options. Moreover, the proportions of subjective and objective evaluation methods in these studies are usually defined as fifty-fifty. However, a fifty-fifty proportion cannot always provide an accurate result. In response to the limitations of subjective and objective weighting methods, both methods are ideally employed in proportion to their designated importance.

Under these circumstances, this paper aims at proposing a sustainable level evaluation model for wind generation projects as a decision support tool for scholars and investors with the intention of integrating different sustainable wind project indexes in a multi-index system using the MCDM method. To address the limitations of subjective and objective weighting methods, this paper presents an index weighting optimization method that combines both subjective and objective weighting methods in proportion to their designated importance. Herein, the entropy weighting (EW) method is employed as an objective weighting method to obtain an objective evaluation on the differences between the indices, and the AHP method based on the expert opinion is employed to revise the objective weighting results to obtain a comprehensive weighting of the indices. Finally, the Lagrange conditioned extreme value (LCEV) is employed to optimize the proportion of each index weight assigned by the objective and subjective methods. Lastly, the technique in the order of preference by similarity to the ideal solution[9] is employed to provide a reasonable ranking of the results. This method fully employed existing information to enhance the objectivity of the ranking results. The originality of the paper is derived from its integration of the EW-AHP based on the LCEV and TOPSIS for wind project selection by distinguishing the most sustainable wind generation projects from the generic wind projects, which has never been reported in literature. The paper also differentiates itself by presenting a case study in China of a real power grid with abundant wind energy to analyze the proposed method rather than technologies. The present study aims to guide researchers and other investors to easily forecast wind projects' sustainable performance and decide accordingly.

2. Materials and methods

2.1. Identification of evaluation indexes and their hierarchy

The selection of the most suitable assessment indexes and their scoring plays a vital role. Thus, the first step in the proposed method is to determine the indexes for the sustainable assessment of wind power projects. The proposed model offered in the present study generates sixteen sub-criteria in a three-layer structure that is subjected to expert validation, of which the hierarchical structure rationality of the selection criteria is validated as proposed by the authors. The model's structure is presented in Fig. 1, and the definitions of all criteria are shown in Fig. 1. As shown in the figure, the overall target is situated at the first level of the proposed hierarchy A. In the second level, the sub-target criteria are denoted as P_1, P_2, P_3, P_4 and P_5. The indexes in the third level are listed as X_1, X_2, X_3 ... X_{16}, where $P_1 = \{X_1, X_2, X_3, X_4\}$, $P_2 = \{X_5, X_6, X_7, X_8\}$, $P_3 = \{X_9, X_{10}\}$,

$P_4 = \{X_{11}, X_{12}, X_{13}\}$ and $P_5 = \{X_{14}, X_{15}, X_{16}\}$. Thereafter, the model was applied on a case study with three real wind projects to allow experts to provide their opinions on the pair-wise comparison of every index and calculate the scores of their weights.

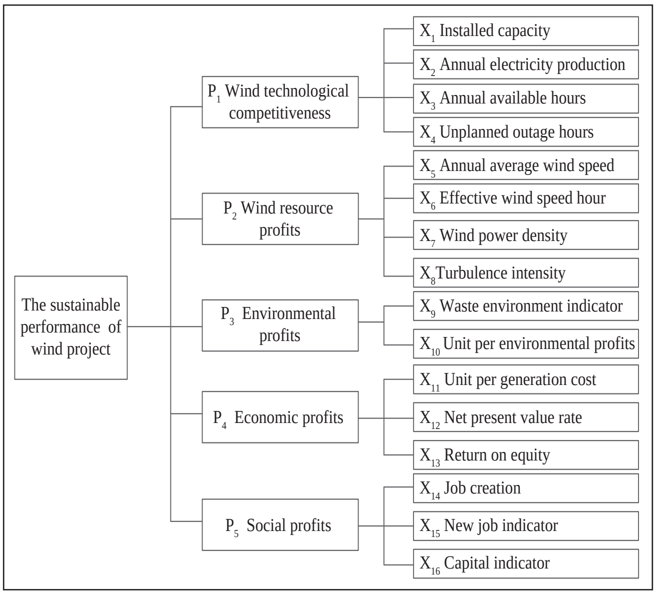

Fig 1. The original image hierarchy of the proposed assessment indexes

2.2. Comprehensive weights calculation

MCDM provides a comprehensive and reasonable evaluation of the wind power system based on multiple parameters that have a variety of attributes or have overall characteristics that are influenced by many factors[10]. As discussed, the core step of the MCDM analysis is the appropriate calculation of weights for the selected indicators. Therefore, the present study combined AHP for the calculation of the subjective weights and the EW method for the calculation of the objective weights. Firstly, the EW method was applied to render an objective weighting value for each index. Secondly, AHP was employed to revise the objective weighting and fulfill a comprehensive weighting evaluation. The application of AHP can mitigate the interference caused by the objective factors in the assessment process. An index weight optimization method based on the LCEV was then proposed to calculate the reasonable proportions of the weighting provided by AHP and EW, which then provides a comprehensive weighting value for each index.

Step one: Calculate the probability of the indices for the preparation of the EW method

Define a sequence $x_{ij} = \{x_{1j}, x_{2j}, \ldots x_{nj}\}$, $x_{ij} \geq 0$, which means the observed value of the j^{th} alternative for the i^{th} index, the probability of x_{ij} is defined as

$$\mathrm{Pro}(x_{ij}) = x_{ij} \Big/ \sum_{i=1}^{n} x_{ij} \tag{1}$$

Where i = 1, 2, 3, ... n and j = 1, 2, 3, ... m.

Step two: Calculation of the entropy value

Based on the first step, the entropy value of j^{th} alternative defined as

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n}\mathrm{Pro}(x_{ij})\ln\mathrm{Pro}(x_{ij}) \tag{2}$$

Step three: Calculate the discrimination factor

The discrimination factor of j^{th} alternative is defined as

$$g_j = 1 - e_j \tag{3}$$

Step four: Calculate the objective weight based on EW method

The objective weight of j^{th} alternative of the system is defined as:

$$q_{(objective)\,j} = g_j \Big/ \sum_{j=1}^{m} g_j \tag{4}$$

Here, we note that the amount of information that can be provided by an index increases with decreasing entropy. Thus, the index has greater importance and a correspondingly greater objective weight.

Step five: Structure a decision problem and articulate preferences over indices for the preparation of AHP.

AHP is based on three principles: first, the structure of a model is established; a comparative judgment of the alternatives and indices is then generated; and third, synthesis of the priorities is calculated. For the subjective weighting operation, the power grid experts selected options from the fundamental ranking criteria remain established in[11], which is employed to simplify the representation of the degree of expert-chosen preferences to rank the indices.

Step six: Construct an evaluation matrix:

Establish the comparison matrix A:

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \tag{5}$$

Wherein, every element aij represents the individual preference of the experts according to the relative importance of the two indices. Here, $a_{ij} > 0$, $a_{ii} = 1$, and $a_{ji} = 1/a_{ij}$

Step seven: Derive subjective weights

This step aims to transform the pair-wise matrix A into a vector of subjective weights that can be attached to multiple outcomes. The vector of the subjective weights $P_{(subject)\,j}$ belonging to index i can be obtained from A by the eigenvector method.

$$AP_{(subject)\,j} = \lambda_{max} P_{(subject)\,j} \tag{6}$$

where $P_{(subject)\,j}$ is the eigenvector corresponding to the maximal eigenvalue λ_{max} of A.

Step eight: Check the consistency

The final consistency ratio CR is defined as

$$C_R = \frac{\lambda_{max} - k}{\gamma\,(m-1)} \tag{7}$$

The consistency is defined by the relation among the entries of A: $a_{ij} \times a_{jk} = a_{ik}$; and γ_m is the random consistency index. The values of γ_m are shown in[12], for different values of k. If $C_R < 0.1$, A is deemed acceptable. Otherwise, A is considered inconsistent, and matrix A must be reviewed and improved until $C_R < 0.1$.

Step nine: comprehensive weight calculation

Although a combination of subjective and objective evaluation methods can be expected to provide more accurate results, the relative importance that should be placed on the subjectively and objectively determined weights of the indices remains uncertain. As a result, the present study proposed a Lagrange conditioned extreme value (LCEV). As noted before, P(subjective)j and q(objective)j are the subjective and objective weights, respectively, thereby defining the comprehensive weight as

$$\omega_{com} = k_i^{(1)} P_{(subjective)\,j} + k_i^{(2)} P_{(objective)\,j} \tag{8}$$

where $k_i^{(1)}$ and $k_i^{(2)}$ are constants that satisfy the conditions $k_i^{(1)} > 0$, $k_i^{(2)} > 0$ and $\left(k_i^{(1)}\right)^2 + \left(k_i^{(2)}\right)^2 = 1$. The comprehensive values y_i in Equation 9 are defined by applying additive method

$$y_i = \sum_{j=1}^{m} \omega_{com}\, x_{ij} = \sum_{j=1}^{m} \left(k_i^{(1)} p_{(subjective)\,j} + k_i^{(2)} q_{(objective)\,j}\right) x_{ij} \tag{9}$$

Here, when the sum of the comprehensive values, $\sum_{i=1}^{n} y_i$, is at its maximum, then $k_i^{(1)}$ and $k_i^{(2)}$ is determined. According to the above stated conditions for $k_i^{(1)}$ and $k_i^{(2)}$, the LCEV is defined as follow.

$$L\left(k_i^{(1)}, k_i^{(2)}, \lambda\right) = \sum_{i=1}^{n} y_i + \lambda\left(\left(k_i^{(1)}\right)^2 + \left(k_i^{(2)}\right)^2 - 1\right) =$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\left(k_i^{(1)} p_{(subjective)\,j} + k_i^{(2)} q_{(objective)\,j}\right) x_{ij} + \lambda\left(\left(k_i^{(1)}\right)^2 + \left(k_i^{(2)}\right)^2 - 1\right) \tag{10}$$

If the partial derivatives of the LCEV with respect to $k_i^{(1)}$, $k_i^{(2)}$ and λ are set to zero, then we can obtain comprehensive weights ω_{com} from Equation 11.

$$\omega_{com} = \sum_{j=1}^{m}\left(\left(\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} p_{(subjective)\,j}\, x_{ij}}{\sqrt{\left(\sum_{i=1}^{n}\sum_{j=1}^{m} p_{(subjective)\,j}\, x_{ij}\right)^2 + \left(\sum_{i=1}^{n}\sum_{j=1}^{m} q_{(objective)\,j}\, x_{ij}\right)^2}}\right) p_j + \left(\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} q_{(objective)\,j}\, x_{ij}}{\sqrt{\left(\sum_{i=1}^{n}\sum_{j=1}^{m} p_{(subjective)\,j}\, x_{ij}\right)^2 + \left(\sum_{i=1}^{n}\sum_{j=1}^{m} q_{(objective)\,j}\, x_{ij}\right)^2}}\right) q_j\right) \tag{11}$$

2.3. Comprehensive evaluation of the TOPSIS algorithm

Once the indexes weights are calculated, the wind project assessment can be used to compare wind projects and identify the most sustainable wind project with the help of TOPSIS. The TOPSIS algorithm is proposed to evaluate alternatives by calculating the geometric distances from the benefit and cost ideal solutions. The specific steps of TOPSIS are presented as follows:

Step one: Normalize the initial index system

Generally, the attributes of the different indexes may be different. Some indexes hold benefit-type contributions, namely the larger the better, such as in installed capacity and annual electricity production. On the contrary, some indexes are costly and require smaller values, such as for unplanned outage hours and turbulence intensity. The vector norm method was employed to implement the dimensionless quantity of different kinds of indicators with the same magnitude and dimension. The data matrix was configured as $X = [x_{ij}]_{n*m}$ where x_{ij} is the observed value of the j^{th} alternative for the i^{th} index assuming there are n samples and m indexes in each sample. Therefore, the dimensionless value of x_{ij} is defined as

$$x_{ij}^{*} = \begin{cases} x_{ij} \Big/ \sqrt{\sum_{i=1}^{n} x_{ij}^2} & \text{(a)} \\ \sqrt{\sum_{i=1}^{n} x_{ij}^2} \Big/ x_{ij} & \text{(b)} \end{cases} \tag{12}$$

where i = 1, 2, 3, ... n, while j = 1, 2, 3, ...m, $x_{ij} \geq 0$, $x_{ij} \in (0,1)$ and $\sum_{i}^{n}\left(x_{ij}^{*}\right)^2 = 1$. For the benefit-type index, Equation 12(a) was employed to normalize the initial index, whereas Equation 12(b) was employed to normalize the cost-type index.

Step two: Determine the two types of ideal solutions

All criteria must be divided into two kinds, specifically the benefit ideal solution Y^+ and the cost ideal solution Y^-, which can be computed by Equations 13 and 14, respectively:

$$Y^+ = \{(y_{ij}^{max} \mid j \in J), (y_{ij}^{min} \mid j \in J') \; i = 1, 2, \dots m\}$$
$$= \{y_1^+, y_1^+, \cdots y_j^+ \cdots y_n^+\} \tag{13}$$

$$Y^- = \{(y_{ij}^{min} \mid j \in J), (y_{ij}^{max} \mid j \in J') \; i = 1, 2, \dots m\}$$
$$= \{y_1^-, y_1^-, \cdots y_j^- \cdots y_n^-\} \tag{14}$$

Step three: Calculate the distances of each alternative from the two types of ideal solutions

The geometric distance is the common method to calculate the distance between two triangular values. Recently, the Euclid distance has demonstrated its own advantages in terms of discrimination and evaluation. Therefore, the distance D_i^+ and D_i^- of each alternative form Y^+ and Y^- can be obtained based on Equations 15 and 16:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(y_j^+ - y_{ij}\right)^2} \tag{15}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(y_j^- - y_{ij}\right)^2} \tag{16}$$

Step four: Calculate the closeness coefficients of all alternatives

The closeness coefficient C_i can be employed to reflect the distance closest to D_i^+ as well as D_i^-, which can be computed by Equation 17:

$$C_i = \frac{D_i^+}{D_i^- + D_i^+} \tag{17}$$

where $0 \leq C_i \leq 1$ and higher values of C_i result in a better design performance. The values of C_i can be ranked to obtain the final results.

3. Experimental applications analysis

3.1. Experimental set up

The proposed method was designed and tested in line with the actual operation of a power grid in Hami City, China. Hami, which is a mainland city, not only has an abundance of wind energy resources but also exhibits multi-level voltage and high penetration wind power, thereby rendering it ideal for demonstrating the proposed method. To promote the sustainable development and management of the wind power projects and make the utmost use of the wind resource, the sustainability of different regional wind projects of the Hami grid must first be assessed and ranked. The tested power system structure exhibited a total wind capacity of 4885.2 MW, and used 220 kV lines to connect to 750 kV transformer substations, as shown in Fig. 2. For the purposes of the current paper, the Hami grid was divided into three main regions according to the geographical location of wind power groups, i.e., regions A, B, and C. The wind groups of three regions are thereby named as wind project A, wind project B, and wind project C for simplicity for reading in this paper.

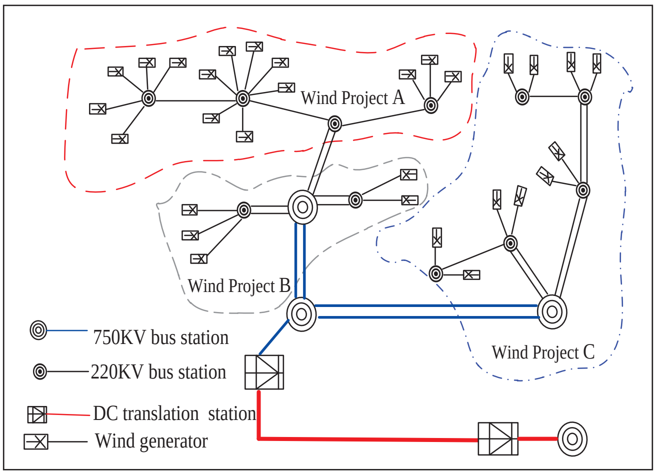

Fig. 2: Simple structure of the main Hami grid employed in this study

The main parameters, according to the evaluation index system obtained from the Hami Statistics Bureau and verified by wind experts, are shown in Table 1. The total active power capacity of wind projects A, B, and C were 2641.1 MW, 440.9 MW, and 1803.2 MW, respectively. According to Table 1, wind project A exhibited the largest installation capacity, annual electricity production, and the highest environmental profits, whereas wind project B exhibited the most favorable wind recourses despite being the smallest installation. However, all the parameters of wind project C appeared to be average.

Table 1. Parameters of the test system

Index	A	B	C	Unite
X_1	2641.1	440.9	1803.2	kW
X_2	127,235.2	74,511.6	176,430.4	kWh
X_3	6230	6486	5763	h
X_4	197	172	185	h
X_5	5.2	6.1	4.7	m/s
X_6	6250	7556	4021	h
X_7	918.54	923.6	873.22	kW/m2
X_8	0.1	0.07	0.09	/
X_9	24,000	19,000	35,000	t/kWh
X_{10}	98.4	17.6	72.1	RMB/kW
X_{11}	0.25	0.21	0.23	%
X_{12}	0.77	0.71	0.69	%
X_{13}	0.98	0.93	0.91	%
X_{14}	59	34	41	Number/kWh
X_{15}	0.22	0.18	0.2	%
X_{16}	110	70	160	RMB/kWh

3.2. Data preprocessing and calculation

The above indexes of wind projects A, B, and C are reprocessed based on Equation 12. We obtained the normalized and non-dimensional data. At the same time, we can obtain the standardization matrix X^T, as presented in Equation 18. Equation 18 demonstrates the differences of some indexes' values, such as in X_1, X_2, X_{10} and X_{14} of the three wind projects. On the contrary, other indexes' values, such as X_3, X_4, X_7, X_{14} and X_{15} are similar. The sustainability of each region cannot be defined by a single index only; that is to say, the sustainability of a wind power system cannot be accurately determined using only parts of its indexes. Therefore, a comprehensive evaluation of the sustainability of the wind power project must be performed using a comprehensive index system, as is the case here.

$$X = \begin{bmatrix} 0.81813 & 0.55336 & 0.58325 & 0.53871 & 0.55963 & 0.58972 & 0.58573 & 0.48363 & 0.57112 & 0.79837 & 0.51681 & 0.63298 & 0.55347 \\ 0.13658 & 0.32406 & 0.60722 & 0.61701 & 0.65648 & 0.71294 & 0.58895 & 0.69090 & 0.72142 & 0.14280 & 0.64602 & 0.51789 & 0.35221 \\ 0.55858 & 0.76732 & 0.53953 & 0.57366 & 0.50582 & 0.37940 & 0.55683 & 0.53737 & 0.39163 & 0.58499 & 0.56175 & 0.57544 & 0.75473 \end{bmatrix} \quad (18)$$

3.3. Calculation of the comprehensive weights

The objective of the weight indexes can be calculated by the EW method, specifically by Equations 1-4, as shown in Table 2. The EW method emphasizes the difference between the indexes. Therefore, the present study also applied the AHP method as directed by the experts to revise the calculated results of the objective weights calculation and generate comprehensive evaluation results.

For subjective weighting, experts were invited to provide scores on the basis of the pairwise comparison of indices to represent the relative importance of the various indicators. Here, it is assumed that the subjective weighting of each index is equivalent in all wind farms, which is to say $P_{(subjective)(1)} = P_{(subjective)(2)} = P_{(subjective)(3)}$. The final subjective weights are shown in Table 2.

Table 2. Objective weights calculation results of three wind projects

	$q_{objective}$			$p_{objective}$
No.	A	B	C	A = B = C
1	0.075332	0.025102	0.062952	0.0188
2	0.058995	0.047023	0.076564	0.0334
3	0.061041	0.071037	0.061567	0.0579
4	0.057970	0.071741	0.064029	0.1029
5	0.059428	0.074507	0.059048	0.0073
6	0.061476	0.078281	0.048730	0.0137
7	0.061208	0.069706	0.062826	0.0192
8	0.053982	0.076833	0.061408	0.0250
9	0.060217	0.078830	0.049795	0.0237
10	0.074238	0.025961	0.064829	0.0710
11	0.056411	0.073784	0.063180	0.0352
12	0.063081	0.068003	0.062341	0.0839
13	0.062270	0.068367	0.062957	0.1331
14	0.071031	0.056752	0.059804	0.0733
15	0.064320	0.064277	0.064155	0.1164
16	0.059002	0.049794	0.075816	0.1848

Moreover, the proportions of the objective and subjective weights can be calculated by Equations 8-10. Finally, the comprehensive weight indexes matrixes $[\omega_{(1)}, \omega_{(2)}, \omega_{(3)}]T$ are defined by Equation 11 and are calculated in Equation 19.

3.4. Calculation of the final results by the TOPSIS method

The TOPSIS method was employed to calculate the final comprehensive evaluation results considering the system functionality and proportionality, thereby disposing the information loss caused by the comprehensive weights. The non-dimensionalized fuzzy decision matrix Y is constructed (Table 3). Secondly, the positive ideal solution Y+ and negative ideal solution Y- are calculated using the weighted normalized matrix by Equations 13-14. The closeness degree between the weighted decision matrixes is then calculated by Equations 15-16, the calculation results of which are presented in Table 3.

Finally, the closeness coefficient Ci is obtained by Equation 17, as presented in Table 4. The following conclusions are generated according to the obtained values of Ci in the wind project C were relatively the most sustainable parts of the established power grid. On the contrary, the minimal value of wind project B characterized the region as the least sustainable wind project.

Table 3. Calculation results of TOPSIS

No.	A	B	C
1	0.080304	0.009253	0.049718
2	0.07007	0.039377	0.104128
3	0.118676	0.125507	0.109866
4	0.188279	0.217216	0.201097
5	0.036405	0.051906	0.032729
6	0.04659	0.066079	0.026387
7	0.05431	0.058035	0.05223
8	0.051024	0.082097	0.058835
9	0.047922	0.07079	0.030066
10	0.152002	0.025308	0.109347
11	0.06274	0.084229	0.070044
12	0.161861	0.149939	0.144947
13	0.247359	0.235291	0.229749
14	0.180578	0.102445	0.123919
15	0.237324	0.194171	0.215733
16	0.326158	0.207255	0.44621
Y^+	0.32616	0.23529	0.44620
Y^-	0.03640	0.00925	0.02638
D^+	0.85977	0.58342	1.35007
D^-	0.50306	0.48274	0.575913

$$\omega_i = \begin{bmatrix} 0.09816 & 0.12663 & 0.20347 & 0.34950 & 0.06505 & 0.07900 & 0.09272 & 0.10550 & 0.08391 & 0.19039 & 0.12140 & 0.37493 & 0.58930 \\ 0.06775 & 0.12151 & 0.20669 & 0.35204 & 0.07907 & 0.09268 & 0.09854 & 0.11883 & 0.09813 & 0.17723 & 0.13038 & 0.37493 & 0.58845 \\ 0.08901 & 0.13570 & 0.20363 & 0.35055 & 0.06471 & 0.06955 & 0.09380 & 0.10949 & 0.07677 & 0.18692 & 0.12469 & 0.37490 & 0.59122 \end{bmatrix} \quad (19)$$

The case study suggests that the proposed model can provide a new and feasible way for seeking the most sustainable wind project from a list of available options. To validate the plausibility of the final results, the ranking procedure is repeated with the ordered weighted averaging (OWA), the results of which are shown in Table 4. As a weighted average method, the OWA operator is used widely in various application studies. OWA is considered a convenient modelling approach and is readily understood in terms of the measures it generates. The comparisons of the results reveal identical TOPSIS and OWA ranking results, thereby implying the dependability of the approach.

Table 4. Calculation results of TOPSIS and OWA

Wind project	TOPSIS	Rank
A	0.63087221	2
B	0.547217201	3
C	0.700978119	1
Wind project	OWA	Rank
A	0.633242233	2
B	0.611914944	3
C	0.665330432	1

According to Table 4, wind project C remains in the first place, followed by wind project A, and wind project B as the least preferred option. In general, the range of values for the TOPSIS method provides a larger difference between wind projects A, B, and C, thereby suggesting the applicability of the TOPSIS method in addressing the greater discrimination between the alternatives. The ranking index formed by the TOPSIS method both considers the benefit of the ideal solution and cost ideal solution of each index, thereby enabling researchers to approach the selection problem of the sustainable level of the wind projects from multiple perspectives rather than simply selecting the highest OWA score. Therefore, the TOPSIS method incorporates the concept of contradiction into the ranking of the compromise solutions, which can improve the quality of ranking results.

4. Conclusions

The present study proposed a combined MCDM framework for the sustainable level of the wind energy project selection model. A hierarchical wind project evaluation criteria framework was proposed and validated by experts. Two MCDM weights decision methods, specifically EW and AHP, were combined by the LCEV method to calculate this set of multilevel criteria, which consists of five main dimensions and sixteen sub-criteria. An empirical case study containing three Hami City wind projects in China was used to exemplify the approach and rank the sustainable level of each wind project by the TOPSIS method. The results of the case study were robust with regards to the OWA method. The model can thus not only be compatible with different index systems but can also identify a wind power project’s greater or weaker level of sustainability.

The present article aims at aiding in study project-based evaluations and acts a supporting decision tool for investors. This study presents its originality in its comprehensive criteria structure, which is balanced on the five dimensions of sustainability of the wind power project. In addition, the combination of its proposed comprehensive weights calculation method (AHP and EW, optimized by LCEV) with the TPOSIS method in the selection problem of the sustainable level of the wind project has not been previously published in literature to authors' knowledge. Distinguishing wind projects from general wind technologies can reduce the oversimplification of decision problems and aid in the evaluation of alternatives in the light of more specific data. The next stage of this research will focus on the design of an application software based on the proposed method to quickly calculate and analyze the sustainability level of wind power projects.

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