Research Article

Risk Assessment of Low-Speed Wind Power Projects Based on an Aggregated Cloud Method: A Case in China

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Due to the aggravating wind curtailment phenomenon, low-speed wind power project (LSWPP) with the superiority of its generation being absorbed locally is rapidly developing in China. As the risk and opportunity coexist, a comprehensive risk assessment should be implemented to evaluate the risk level of a LSWPP. This paper firstly identified 38 risk factors based on a questionnaire survey and then sorted out 17 critical risk factors and divided them into 4 criteria to form the evaluation index system. In order to overcome the deficiencies of not considering randomness of linguistic variables and neglecting the interrelationship between factors, we proposed an aggregated method which combined ANP, the cloud theory, and the technique for order preference by similarity to ideal solution (TOPSIS) for LSWPPs risk assessment. After a case in China was studied and the sensitivity was tested, the effectiveness and application of this framework are demonstrated. Through the calculation of membership of each project, it indicated that the overall risk level of LSWPPs is relatively high. Finally, some recommendations of each critical risk factor were given for government, investors, and decision-makers to help them make more appropriate decisions and distribute the limited resources more rationally.

1. Introduction

In recent years, the LSWPPs [1] have become an investment direction that is closely watched by investors and government as well as a focus in the renewable energy field [1]. There are several reasons leading to this situation which mainly focus on the following factors: (1) renewable energy has been a key component in development plans of Chinese government [2]. As the atmospheric contamination has been a severe problem to solve in today's China, developing renewable energy industry is the most resultful approach to alleviate environmental pressure and achieve the commitment made by Chinese government at the Copenhagen Conference [3]. (2) Unbalanced power demand and load relationship: ever since the 12th five-year plans, wind power industry has experienced an explosive growth which mainly concentrates upon the 3-N regions (which refers to the north, northeast, and northwest areas) and areas rich in wind resources. But the absorption ability of these regions has been put to the test

because the load center is far away from the grid. Therefore, the wind that cannot be absorbed will be curtailed. (3) The goal of 13th five-year wind power plans: due to the high wind curtailment rate in 3-N regions, new wind power projects in these areas are postponed and disapproved by Chinese government. In order to accomplish the installed capacity target, other than general wind power projects, the investors and private sectors should concentrate on LSWPP which takes up the highest proportion of china as the category IV of wind resource areas.

LSWPP, with the characteristic of lacking quality wind resources, has its own superiority compared to general wind power projects. Firstly, the scale of LSWPP is usually limited to a certain extent partly so that the generating equipment availability hour, the total investment cost, and cost per kilowatt will effectively influence the revenue which means the investment cost could be controlled. Secondly, low-speed wind sets are generally placed near power center so that electricity demand can be forecasted instead of wind curtailment

phenomenon. Although LSWPP has its own advantages, we should not neglect the uncertainty and risk that will directly or indirectly affect its smooth implementation in the whole life cycle of a LSWPP considering the long payback period, multiple policies influence, and high requirement of design and construction, for instance, (1) technical risk including technology progressiveness[4], site selection risk [5], and design/construction deficiencies [6]; (2) operating and political risk including change of supporting laws [7] and operation and maintenance risk [8]; and (3) economic risk including construction cost risk [9] and feed-in tariff risk [10]. Inadequate or inappropriate risk management may lead to decision-making mistakes, difficulties in financing, failure to get completion on time as well as low operation efficiency, and other unpredictable issues. Therefore, a reliable risk assessment and analysis is essential to the success of a LSWPP. The general wind power projects risk factors have been identified by many scholars [7, 8, 11], which include ecological balance risk, earning risk, and natural environmental risk. However, in consideration of the specific characteristics of LSWPPs, the ordinary risk factors cannot describe the particularity of these projects so the risk factors for risk assessment of LSWPPs will not be limited to the above ones. Currently, academic circles lack a comprehensive and integrated risk assessment framework for LSWPPs; therefore this paper aimed at this field.

This paper has three main objectives: (1) Identify the critical risk factors for LSWPPs in China. (2) Establish an evaluation index system specific for LSWPPs risk assessment and then prove the applicability and feasibility toward LSWPPs. (3) Analyze the critical risk factors and give the investors advice to avoid the failure of a project. We employed an aggregated method which combined ANP, cloud theory, and TOPSIS to build up the evaluation system with a view to the applicability of cloud theory in dealing with randomness and fuzziness in linguistic information, the fitness of ANP toward complicated interrelationship between risk factors, and the visibility of TOPSIS in comparing projects. As the risk assessment for LSWPPs has not been fully studied and paid enough attention to, this study can fill in literature gaps and contribute to this field. In addition to this, the established evaluation system for LSWPPs can provide a reference for policy makers and investors so that they can make appropriate decisions and distribute limited resources rationally. Furthermore, the countermeasures and advice for critical risk factors are proposed to give the industry participants more inspirations.

This paper is organized as follows. Section 2 reviews the relative literature on risk assessment on wind power and method. Then the critical risk factors are identified and summarized in Section 3. Section 4 mainly introduces the method and builds up the risk assessment framework. In Section 5, we study a case in China in order to demonstrate the applicability of proposed framework and test the sensibility. The countermeasures for investors about the critical risk factors are given in Section 6. And finally, the final conclusions are provided in Section 7.

2. Literature Review

2.1. Risk Assessment of Wind Power Project. Wind power project's risk assessment is a kind of investment evaluation which takes an important role in project construction and effectively influences the construction procedure through its quality. There are already literatures from different angles to evaluate the investment of wind power projects; Alishahi pointed out that investors will face certain risks during the investment decision stage due to the intermittency and uncertainty of wind power, and in order to reduce the risk level, he proposed a modified wind power investment incentive mechanism to recover part of the cost and further inspired the investment toward wind power project [12]. Gillenwater analyzed the effect that green power market implements on investment of wind power industry. Through simulating project financial analysis model by means of Monte Carlo method, the result indicated that green power market has not exerted much influence on wind power investors on account of not offering reliable risk assurance measures by green power market in the United States [13]. Göransson investigated the influence that geographical distribution of wind power projects exerted on large-scale wind power investment on the basis of considering factors like wind resource conditions and load distance and via establishing two wind power construction scene models and found the investment was greatly affected by generation scheduling and transmission capacity [14]. V. Gass used Measure-Correlate-Predict Method within the Variance Ratio Method to integrate the risk of wind energy uncertainty into profitability assessment and used Conditional Value at Risk approach to derive probability levels for certain internal rate of returns [15]. Shi built the wind power utilization level evaluation index system which consisted of wind resource characteristics, equipment type, output, curtailment, grid technology, and operation management and took a project to evaluate as an example [16]. Jia thought there were a number of factors influencing decision of wind power project which mainly contains four critical factors, economy, technology, policy, and environment, and further established a multiattribute decision model on the basis of this [17]. Wu performed a comparative analysis of different methods for different projects and pointed out that Chinese enterprises used the income method and the market method most frequently to evaluate wind power projects [18]. From the literatures we have studied above, we can indicate that scholars no longer study this task from the single economic perspective but are gradually shifting to national policies, social preferences, and green mechanism views.

In recent years, the decision environment of wind power project is getting more and more complicated, so the identification of the risk factors influencing the implementation of project is necessary. Bilski analyzed opinions of the public through perspectives of economy, social, health, and environment toward wind power project investment, where the noise emissions of wind turbines prejudice the health of local residents and further result in negative social impact [19]. Vagiona analyzed the factors that affect decision of offshore wind power site selection and proposed to use GIS to

exclude the sites that dissatisfied the basic standard and then established an objective site selection model which includes mean wind speed, distance to conservation area, distance to lanes, and distance to grid that is available [20]. Jia divided wind power project into four phases including feasibility study, investment and financing, building construction, and operations and maintenance and built a relatively complete risk assessment system and then evaluated the practical project with analytic hierarchy process (AHP) method [8]. Serhat converted different external risks into a common scale and these expressed the level of risk factors of which change in laws and regulations, environmental issues, local community, grid connection, land use and permits, and erroneous wind resource assessment are the key risk factors [7]. Li pointed out the main risk factors influencing the wind power industry by using a quantitative analysis model from feed-in tariff and grid electricity. He noticed that factors like high generation cost, mismatch between capacity and generation, power grid construction lag, deficient policy, and so on are becoming increasingly prominent [21]. These literatures with respect to risk identification are conducted with evaluation approach, but they are either not considering the uncertainty of linguistic fuzziness or not constructing an overall risk assessment index system which means the risk factors influencing the wind power projects are not analyzed systematically. Most important of all, there are few studies concerning the evaluation of LSWPP, not to mention the risk assessment of LSWPP. So it is of great importance to identify the specific factors for LSWPP in order to evaluate the risk level more rationally and effectively.

2.2. Fuzzy Synthetic Evaluation Method. Fuzzy synthetic evaluation method is a comprehensive evaluation approach based on fuzzy mathematics. Different from the researches that use the crisp value which may induce the information loss to express the comments given by experts, the fuzzy set we use in fuzzy synthetic evaluation has the ability to overcome this tackle. On the issues of converting assessment information into linguistic variables, there are diverse approaches such as triangular fuzzy number used by Kabir G in power substation location selection [33], intuitionistic fuzzy sets adopted by Devi K in plant location selection [34], rough set that Liu S used in distribution center location selection [35], and interval valued fuzzy set which Mokhtarian M N employed in suitable location for digging some pits for municipal wet waste landfill [36]. But all these approaches only consider the fuzziness while the randomness has not been described. Cloud model, the method that can conduct comprehensive analysis contraposing fuzziness and randomness in linguistic environment, was firstly proposed by Li [37] and can greatly reduce the loss of valid information in uncertain languages. It has also been employed in risk assessment studies as Zhang had used to assess the tunnel-induced damage to existing pipelines [38].

Methods researchers used in determining the index weight are also multitudinous. The ones mostly used are AHP [8], sequential relation analysis method which had been employed in wind/solar hybrid power station macrosite selection by Wu [39], fuzzy theory which had been used

under site selection of electric vehicle charging station by Guo [40], and λ -fuzzy measurement used by Wu for thermal power plant [41]. But all the methods mentioned above lack reasonable measurement of interaction effects between factors and reflected in neglect of interaction effect relationship and are inappropriate in application. To solve this issue, analytic network process (ANP) is proposed to calculate the index weight for risk assessment index factors. Due to the interactional relationship between risk factors, ANP was meant to be the most suitable model for index weight calculation.

In summary, this paper will use an integrated approach which combines ANP and cloud model to assess the risk level of LSWPPs so that the fuzziness and randomness of linguistic variables and interactional relationship between factors can be described without valid information loss.

3. Evaluation Index System of LSWPPs Risk Assessment

As for the LSWPPs, there are kinds of different uncertain risks that may bring uncertainty to projects; in order to control the risks of LSWPPs, the identification of relative risk factors is of the essence. In this section, we adopt a three-phase approach which combines the checklist method and Delphi technique to pick out related risk factors so that the critical factors for assessing risk of LSWPPs can be identified and further classified.

3.1. Identifying Risk Factors of General Wind Power Projects by Literature Review. Many scholars have conducted risk assessment for wind power projects from different aspects of view such as investment risk [8, 32], policy risk [24], and ecological risk [29, 42]. Scholars and experts have collected lots of lessons to learn during the design and construction of existing LSWPPs; thus a list of risk factors have been summed up in this phase. Because of the wind curtailment phenomenon aggravated in recent years, the development of wind power industry has shifted to LSWPPs so that these projects have become ever-increasingly concerned by governments and private sectors in China as a financing or technology analysis model for the construction. Experts and employees in related industries have certain experience and insights toward LSWPPs. With the regard of this, the list of risk factors that we have obtained above is submitted to relevant experts and employees in related industries to confirm the validity. In this phase we analyzed 18 literatures concerning risk assessment of wind power projects from 2010 to 2018 and further a table of 38 risk factors for LSWPPs is sorted out and summarized. The factors identified are shown in Table 1 and the explanation of these factors is listed in Appendix A.

3.2. Estimating Risk Factors of LSWPPs by Experts through Questionnaire Survey. As a resultful approach in gathering experts' opinions, questionnaire survey method has always been adopted in risk assessment studies. Song employed interviews to collect the relative data of PPP waste-to-energy incineration projects [43]. To evaluate 44 risk factors in PPP

TABLE 1: Rank of risk factors through questionnaires.

Risk factors	Rank	PO	ED	CRG	Normalization	Reference
Wind resource condition risk	1	5.21	5.61	5.41	1	1,4,9,11,12,13,14,15,16
Wind turbine selection risk	2	5.00	5.39	5.19	0.9101	8,9,13,17
Technology maturity	3	4.96	5.11	5.04	0.8441	2,3,5
Change of supporting laws	4	4.25	5.43	4.80	0.7470	1,2,4,7,8
Feed-in tariff risk	5	4.46	5.14	4.79	0.7420	1,2,3,4
Electricity consumption demand	6	4.61	4.96	4.78	0.7382	1,9,11,13
Topographic condition	7	4.61	4.93	4.77	0.7310	1,2,5,7
Design/construction deficiencies	8	4.43	5.07	4.74	0.7201	2,5,
Technology progressiveness	9	4.39	5.11	4.74	0.7190	1,3,5,9,10,11
Construction cost risk	10	4.43	5.00	4.71	0.7060	1,4,9,10,11,12,14,16,17,18
Profitability risk	11	4.21	5.14	4.66	0.6850	1,2,5,7
Insolvency risk	12	4.21	5.04	4.61	0.6646	1,2,3,5,12
Construction period	13	4.32	4.89	4.60	0.6610	2,5,12
Site selection risk	14	4.25	4.79	4.51	0.6240	4,9,11,12,13,14,15,16
Operation & maintenance risk	15	4.14	4.71	4.42	0.5861	2,5,12,13,14
Lack of commercialization operation mechanism	16	4.00	4.61	4.29	0.5331	11
Delay in project approvals and permits	17	4.00	4.57	4.28	0.5261	2,5,6,9,14
Operation cost risk	18	4.00	4.43	4.21	0.4979	1,2,5,10,12,14,19
Financial subsidy risk	19	3.86	4.57	4.20	0.4938	1,2,3,4
Tax privilege risk	20	4.04	4.32	4.18	0.4841	1,5,6
Climate conditions	21	3.79	4.50	4.13	0.4637	1,2,5,7,12
Wind resources assessment risk	22	3.82	4.39	4.10	0.4511	1,4,9,11,12,13,14,15,16
Wind farm set placement risk	23	3.82	4.36	4.08	0.4441	1,17
Independence R&D capacity	24	3.79	4.32	4.04	0.4291	3,7,8,9,10,11
Land acquisition risk	25	3.79	4.04	3.91	0.3721	2,4,5,7,9
Lack of coordination of the supply chain of wind power industry	26	3.64	4.14	3.88	0.3621	4,8,10,11
Market growth potential	27	3.89	3.86	3.87	0.3579	2,3,9,10
Public acceptance of risk	28	4.11	3.61	3.85	0.3471	1,5,7,11
Related standards support	29	3.57	4.14	3.85	0.3460	4,8,9,10,11,12,13
Consulting risk	30	3.89	3.68	3.78	0.3199	8
Construction safety risk	31	3.68	3.71	3.70	0.2831	3
Competitiveness of other renewable energy	32	3.64	3.75	3.70	0.2830	11,18
Ecological balance risk	33	3.57	3.54	3.55	0.2233	17,16
Wind curtailment	34	3.43	3.50	3.46	0.1858	8,9
Connection to power grid risk	35	3.14	3.75	3.43	0.1728	1,3,8,9,11,18
Green power certificates risk	36	3.29	3.46	3.37	0.1479	1
Insurance risk	37	3.32	3.32	3.32	0.1260	8
Inflation	38	2.61	3.50	3.02	0	2,3,5

Reference: 1=[22]; 2=[23]; 3=[10]; 4=[24]; 5=[6]; 6=[25]; 7=[7]; 8=[11]; 9=[26]; 10=[4]; 11=[5]; 12=[27]; 13=[28]; 14=[8]; 15=[29]; 16=[30]; 17=[31]; 18=[9]; 19=[32].

straw-based power generation projects in China, Wu used a questionnaire survey so that the evaluation by experts can be collected [23]. Surveys have been an effective way for Serhat Kucukali to identify the potential risks of wind power projects and he conducted relative literature reviews as well [7]. In our research, in order to estimate the importance and the objective of risk factors selected through the above phase, we implement a questionnaire survey to respondents to let them estimate 38 risk factors in low-speed wind power projects by taking probability of occurrence (PO) and effect degree (ED) into account. We use a 7-point system for experts to

evaluate the PO and ED of each factor (1= very low, 2= low, 3= relatively low, 4= medium, 5= relatively high, 6= high, and 7= very high). Compared to Serhat Kucukali's study [7], we use two indicators to estimate the degree of risk factors and further evaluate the importance of factors, so that the information is more complete and the 7-point system allows experts to rank the factors in a wider range. The questionnaire we conducted included two main contents: (1) the definition of each factor. Although the experts and employees in relative industries we invited are all familiar to these risk factors, the description we narrated may not be comprehensible to all the

TABLE 2: Information of respondents.

Organization of respondents	Relevant scholars	LSWPP practitioners	Government
Percentage	53.6%	32.1%	21.4%
Number of LSWPPs participated in or studied	2 or less	3-4	5 or more
Percentage	64.3%	25%	5.2%

respondents. So, a description for the definition of each factor is necessary. (2) The whole set of risk factors. 38 factors are listed for experts to rank the PO and ED from 1 to 7. As the importance of these risk factors cannot be evaluated merely through comparing PO or ED, it is necessary to put forward a new factor to integrate these two factors. So, on the basis of PO and ED, we propose a new factor named comprehensive risk grade (CRG) to describe the integrated risk level of each factor, and CRG is defined as $\sqrt{PO \times ED}$ which represents the risk level for each factor. The rank results of PO, ED, and CRG for each factor are listed in Table 1.

The selecting criteria we used for experts and employees of related industries are mainly based on three aspects: (1) they all have rich experience in low-speed wind power projects construction as well as ample understanding about wind power risk assessment; (2) they all have been involved in at least one low-speed wind power project, which means they have the ability to sort out the critical risk factors from the list; (3) experts we selected have published at least one paper in international journal in related fields.

On the basis of the standard we proposed above, we selected 40 experts and employees of related industries who are qualified to conduct the questionnaire survey. The survey lasted for 3 months and we finally acquired the result with 28 effective responds and the information about these professionals is listed in Table 2.

3.3. Summarizing CRGs and Establishing the Evaluation Index System. Through previous phase, the PO and ED of each factor are given by experts, respectively, while CRGs have been calculated; we can rank the factors according to the CRG and after normalizing CRGs (normalized CRG = (average actual value – average minimum value) / (average maximum value – average minimum value)). We consider the factors whose normalized CRGs are equal to or greater than 0.5 as the critical risk factors. In this phase, we select 17 factors to conduct further assessment.

4. Methodology

4.1. Description of ANP. Analysis Network Process (ANP) is a method of decision-making that was firstly proposed by Professor T. L. Saaty in the United States in 1996 to adapt nonindependent hierarchy [44]. ANP uses the network structure of which elements may influence each other to show the complexity of the system. This feature is exactly the reasonable description of the mutual influence between the actual things. The method can be described in the following steps [45–47].

Suppose there are m elements in control level, denoted by $C_i (i = 1, 2, \dots, m)$ and N clusters in network level, denoted

by $P_i (i = 1, 2, \dots, N)$, and each cluster P_i has N elements, $P_{i1}, P_{i2}, \dots, P_{in_i} (i = 1, 2, \dots, N)$.

Step 1. Set C_i as the criteria and element $P_{jk} (k = 1, 2, \dots, n_j)$ in P_i as the subcriteria. Compare the elements in clusters P_i according to the their impact on P_{jk} and determine the weighting matrix T_{ij} .

$$T_{ij} = \begin{bmatrix} t_{i1}^{(j1)} & t_{i1}^{(j2)} & \dots & t_{i1}^{(jn_j)} \\ t_{i2}^{(j1)} & t_{i2}^{(j2)} & \dots & t_{i2}^{(jn_j)} \\ \vdots & \vdots & \dots & \vdots \\ t_{in_i}^{(j1)} & t_{in_i}^{(j2)} & \dots & t_{in_i}^{(jn_j)} \end{bmatrix}, \quad (1)$$

where the column vectors are the influence degree sorting vector of elements in P_i on elements in P_j .

Step 2. Aggregate the matrices to the super matrix T under C_i .

$$T = \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1N} \\ t_{21} & t_{22} & \dots & t_{2N} \\ \vdots & \vdots & \dots & \vdots \\ t_{N1} & t_{N2} & \dots & t_{NN} \end{bmatrix} \quad (2)$$

Step 3. Transform the resulting super matrices T to weighted supermatrix $T^* = (T^*_{ij})_{N \times N}$, in which $T^*_{ij} = \beta_{ij} T_{ij} (i, j = 1, 2, \dots, n)$.

Step 4. The limit matrix can be calculated as

$$T^\infty = \lim_{k \rightarrow \infty} T^k \quad (3)$$

In this limit matrix, the components in rows are the same.

Step 5. Determine overall weights of elements according to the limit matrix T^∞ , where ω_k is the elements of the k th row of matrix T^∞ .

4.2. Cloud Model. The decision-making problems in the real world are full of fuzziness and randomness; therefore human beings perceive things through natural language and thinking [48]. Natural language itself has the characteristic of uncertainty while words like “good” or “poor” cannot be described by exact figures. From this perspective, the usage of qualitative concepts to grasp quantitative uncertainty is more realistic and universal than mathematical expression [49]. The cloud model regards natural language as the pointcut and

FIGURE 1: The numerical characteristics of the cloud.

realizes the transformation of uncertainty between qualitative concepts and quantitative values which can simultaneously reflect the ambiguity of concept and randomness of assessment.

Definition 1 (see [6, 50]). Let $U = \{A\}$ be the universe of discourse and C a qualitative concept in U . If $x(x \in U)$ is a random instantiation of concept C satisfying $En' \sim N(En, He^2)$, $x \sim N(Ex, En'^2)$ and the certainty degree of x belonging to concept C meets

$$\mu = e^{-(x-Ex)^2/2(En')^2} \quad (4)$$

Then the distribution of x in the universe U is called a normal cloud. The cloud model describes the overall quantitative property by three numerical characteristics, which are as follows:

- (1) Expectation (Ex): it is the mathematical expectation of the cloud drops in the qualitative linguistic universe and is the most representative sample of the concept
- (2) Entropy (En): it represents the uncertainty of the qualitative concept and is determined by the ambiguity and randomness of the concept.
- (3) Hyper entropy (He): it is the measurement of uncertainty of entropy En , mainly reflecting the dispersion of the cloud drops

The numerical characteristics of the cloud can be shown in Figure 1.

The basic algorithm of clouds is defined as follows. Assuming that $C_1(Ex_1, En_1, He_1)$ and $C_2(Ex_2, En_2, He_2)$ are two clouds, then we have

$$C_1 + C_2 = \left(Ex_1 + Ex_2, \sqrt{En_1^2 + En_2^2}, \sqrt{He_1^2 + He_2^2} \right) \quad (5)$$

$$C_1 - C_2 = \left(Ex_1 - Ex_2, \sqrt{En_1^2 + En_2^2}, \sqrt{He_1^2 + He_2^2} \right) \quad (6)$$

$$C_1 \times C_2 = \left(Ex_1 Ex_2, \sqrt{(En_1 Ex_2)^2 + (Ex_1 En_2)^2}, \sqrt{(He_1 Ex_2)^2 + (Ex_1 He_2)^2} \right) \quad (7)$$

$$C_1 \div C_2 = \left(Ex_1 \div Ex_2, \sqrt{\left(\frac{En_1}{Ex_2}\right)^2 + \frac{(Ex_1 En_2)^2}{Ex_2^4}}, \sqrt{\left(\frac{He_1}{Ex_2}\right)^2 + \frac{(Ex_1 He_2)^2}{Ex_2^4}} \right) \quad (8)$$

$$\lambda C_1 = (\lambda Ex_1, \sqrt{\lambda} En_1, \sqrt{\lambda} He_1) \quad (9)$$

$$C_1^\lambda = (Ex_1^\lambda, \sqrt{\lambda} Ex_1^{\lambda-1} En_1, \sqrt{\lambda} Ex_1^{\lambda-1} He_1) \quad (10)$$

For the comparison between clouds, we can use Hamming distance to calculate the distance among them; then we can work out the probability of $P_1 \geq P_2$. As for the Hamming distance, the expression is

$$D(C_1, C_2) = \sqrt{\frac{\underline{d}^2(C_1, C_2) + \overline{d}^2(C_1, C_2)}{2}} \quad (11)$$

$$\underline{d}(C_1, C_2) = \left| \left(1 - \frac{3\sqrt{En_1^2 + He_1^2}}{Ex_1} \right) Ex_1 - \left(1 - \frac{3\sqrt{En_2^2 + He_2^2}}{Ex_2} \right) Ex_2 \right| \quad (12)$$

$$\overline{d}(C_1, C_2) = \left| \left(1 + \frac{3\sqrt{En_1^2 + He_1^2}}{Ex_1} \right) Ex_1 - \left(1 + \frac{3\sqrt{En_2^2 + He_2^2}}{Ex_2} \right) Ex_2 \right| \quad (13)$$

So, we can measure the probability of $C_1 \geq C_2$, assuming that the ideal cloud is $C^*(\min_i Ex_i, \min_i En_i, \min_i He_i)$, $i = 1, 2$.

$$P(C_1 \geq C_2) = \frac{D(C^*, C_1)}{D(C^*, C_1) + D(C^*, C_2)} \quad (14)$$

In this equation, $D(C^*, C_1)$ stands for Hamming distance between C^* and C_1 , and similarly, $D(C^*, C_2)$ stands for Hamming distance between C^* and C_2 . If $P(C_1 \geq C_2) \geq 0.5$, $C_1 \geq C_2$; otherwise $C_1 < C_2$.

4.3. Assessment Model for LSWPP Risk Based on ANP and Clouds Model. Reasonable risk evaluation is a crucial prerequisite for controlling project risks and achieving project success [51]. There are many ways to evaluate the investment

risks in previous literature while our study integrates the cloud model with ANP and to develop a framework for LSWPP risk assessment in China considering its better expression of assessment results.

The entropy (En) and hyper entropy (He) of a cloud are determined by the linguistic terms expressed by experts. Usage of golden ratio which originates from Fibonacci series is more objective and convenient to operate

The procedure of how to transform linguistic term into clouds can be summarized in the following steps.

Step 1. Determine the projects and risk factors. There are K experts to evaluate risk factors of given LSWPPs and initial assessment language values are given.

Step 2 (see [52]). Transformation between linguistic variables and clouds: the decision-makers express their ratings linguistically; then the linguistic variables should be transformed into a series of clouds.

First of all, let the linguistic term set we use in evaluating the projects be $S = \{s_{-3} : \text{very low}, s_{-2} : \text{low}, s_{-1} : \text{relative low}, s_0 : \text{medium}, s_1 : \text{relative high}, s_2 : \text{high}, s_3 : \text{very high}\}$, where the universe is $U = [X_{\min}, X_{\max}] = [0, 100]$. Seven clouds can be generated with their numerical characteristics utilizing the golden ratio, and then the relation between linguistic variables and their corresponding clouds can be obtained.

Calculation of expectation of cloud Ex :

$$Ex_0 = \frac{(X_{\min} + X_{\max})}{2}, \quad (15)$$

$$Ex_{(n-1)/2} = X_{\max},$$

$$Ex_{-(n-1)/2} = X_{\min}$$

$$Ex_j = Ex_0 + \frac{0.382j(X_{\min} + X_{\max})/2}{(n-3)/2} \quad (16)$$

$$Ex_{-j} = Ex_0 - \frac{0.382j(X_{\min} + X_{\max})/2}{(n-3)/2}, \quad (17)$$

$$\left(1 \leq j \leq \frac{n-3}{2}\right)$$

Calculation of entropy of cloud En :

$$En_{-1} = En_1 = \frac{0.382(X_{\max} - X_{\min})}{6} \quad (18)$$

$$En_0 = 0.618En_1,$$

$$En_{-j} = En_j = \frac{En_{j-1}}{0.618}, \quad (19)$$

$$\left(2 \leq j \leq \frac{n-1}{2}\right).$$

Calculation of hyper entropy of cloud He :

$$He_{-j} = He_j = \frac{He_{j-1}}{0.618}, \quad (20)$$

TABLE 3: Linguistic variables and corresponding clouds.

Rating of projects	Clouds
Very low (VL)	$S_0 (0, 16.671, 0.424)$
Low (L)	$S_1 (25, 10.301, 0.262)$
Relatively low (RL)	$S_2 (40.45, 6.367, 0.162)$
Medium (M)	$S_3 (50, 3.935, 0.1)$
Relatively high (RH)	$S_4 (59.55, 6.367, 0.162)$
High (H)	$S_5 (75, 10.301, 0.262)$
Very high (VH)	$S_6 (100, 16.671, 0.424)$

where He_0 is given by experts. Table 3 shows the linguistic scales and corresponding clouds for rating of projects, respectively.

Step 3. Aggregate the criterion values of each project. Use the cloud arithmetic average (CAA) operator to aggregate the opinion of each decision-maker and obtain the cloud $P_i(a_j)$ that represents the performance value of project p_j under the risk factor c_i :

$$C_i(a_j) = \frac{1}{t} \otimes (C_1 + C_2 + \dots + C_t) = \frac{1}{t} \otimes ((Ex_1, En_1, He_1) \oplus (Ex_2, En_2, He_2) \oplus \dots \oplus (Ex_t, En_t, He_t)) = \left(\frac{Ex_1 + Ex_2 + \dots + Ex_t}{t}, \right. \quad (21)$$

$$\left. \sqrt{\frac{En_1^2 + En_2^2 + \dots + En_t^2}{t}}, \sqrt{\frac{He_1^2 + He_2^2 + \dots + He_t^2}{t}} \right)$$

Step 4. Construct the ANP structure, determine the mutual influence relationship among each factor, establish the pairwise comparison matrix to obtain the weighted supermatrix and the limit supermatrix, and then use the Super-Decision software to complete the weight calculation process.

Step 5. Determine the degree of membership between the assessment and each risk level according to the membership function of the cloud:

$$N = \{(Ex_1 - 3En'_1, Ex_1 + 3En'_1)\} \cap \{(Ex_2 - 3En'_2, Ex_2 + 3En'_2)\} \quad (22)$$

$$M = \{(Ex_1 - 3En'_1, Ex_1 + 3En'_1)\} \cup \{(Ex_2 - 3En'_2, Ex_2 + 3En'_2)\} \quad (23)$$

$$\mu(x) = \frac{|N|}{|M|}, \quad (24)$$

where $\mu(x)$ is the membership, N and M represent the common and nonshared parts between two clouds, respectively, and En' refers to the normal random number gained by the cloud model.

Step 6 (see [6]). Aggregate the membership of each factor into one result to obtain the membership of the criterion, determine the risk level of each criterion, and then aggregate the membership of each criterion to get the ultimate membership of each project $\mu(N_k)$:

$$\mu(D_i) = W_n \cdot C_n = (w_1, w_2, \dots, w_n) \cdot \begin{bmatrix} \mu_1(x) \\ \mu_2(x) \\ \dots \\ \mu_n(x) \end{bmatrix} \quad (25)$$

$$\mu(N_k) = W_k \cdot C_k = (w_1, w_2, \dots, w_i) \cdot \begin{bmatrix} \mu_1(x) \\ \mu_2(x) \\ \dots \\ \mu_i(x) \end{bmatrix}, \quad (26)$$

where $\mu(D_i)$ and $\mu(N_k)$ refer to the membership of i th criterion and k th project, respectively, and W_n and W_k stand for the weight of n th factor and i th criterion, respectively.

Step 7. Use technique for order preference by TOPSIS method to compare the risk levels of projects and select the project with highest risk and lowest risk. The core idea of the TOPSIS method is to realize the risk assessment and rank of LSWPPs by calculating the weighted distance between the assessment index value and the ideal sampling point.

Calculate Euclidean distance y_i^+ between assessment index value and positive ideal sample point. In this formula, w_k refers to the weight of the k th risk factor calculated by ANP.

$$y_i^+ = \sum_{k=1}^m w_k (x_{ik} - x_k^+)^2 \quad (i = 1, 2, \dots, n) \quad (27)$$

Calculate Euclidean distance y_i^- between assessment index value and negative ideal sample point. In this formula, w_k refers to the weight of the k th risk factor calculated by ANP.

$$y_i^- = \sum_{k=1}^m w_k (x_{ik} - x_k^-)^2 \quad (i = 1, 2, \dots, n) \quad (28)$$

Calculate queue indication value Q_i which emphasizes the distance from negative ideal sample point, while the bigger the value of Q_i is, the higher the risk level a LSWPP will have.

$$Q_i = \frac{y_i^-}{y_i^+ + y_i^-} \quad (29)$$

The whole risk assessment process can be explained in Figure 2.

5. A Case Study

With the continuous development of the national economy and rising demand of green and low-carbon development in China, the developing trend of China's clean energy will

be overwhelming. In response to the requirements of the national energy-saving emission reduction policies, complying with the trend of new energy construction in China, a company intends to invest LSWPPs in Henan and Anhui provinces, which are the approved LSWPPs in company's project library. Considering the wind resource condition and economic benefit compared to normal wind power projects of local areas as well as the representativeness in these areas, there are four projects located in Laian county, Weishi county, Xingyang city, and Chaohu area, respectively, determined as the target projects for risk assessment by the senior managers; the geographic positions are shown in Figure 3. The target projects, denoted by P_1 , P_2 , P_3 , and P_4 , all pose typical characteristics of low-speed wind.

5.1. Determination of Target Projects and Weights of Risk Factors. Based on the assessment index system which consists of critical risk factors for a LSWPP, questionnaires are conducted to collect linguistic assessment for target projects. The experts who ranked the PO and ED for risk factors are invited to give linguistic assessment for LSWPP projects. All the experts involved in the assessment take charge of their own partial assessment work without any communications with each other and the experts should concentrate on the field under their area of expertise. After the questionnaires, the results are collected and listed in Table 4. The interrelationship between risk factors is shown in Table 5 where a symbol " $\sqrt$ " means the factor in this row has an effect on the factor in this column. For example, a symbol " $\sqrt$ " in the space crossed by row of C11 and column of C32 means C11 has certain influence on C32.

After clarifying the interrelationship between risk factors, we can use ANP method to calculate the weights of factors where a specialized software package named Super-Decision is employed to calculate the priorities of each risk factor and criterion. In the end, the computed result is summed up in Table 6.

As we already have linguistic assessment information, the linguistic variables can be transformed into a series of clouds by using the corresponding relation between linguistic variables and clouds in Table 4 so that assessment collected from experts can be shown as cloud model. Then we use the CAA operator mentioned in Section 4 to gather the different assessment variables into an aggregated rating where the parameter t in (21) equals 3 under this circumstance. We take the computational process of $\gamma_{14}(a_1)$ as an example to illustrate it. The aggregated clouds are shown in Table 7.

$$\begin{aligned} \gamma_{14}(a_1) &= \frac{1}{3} ((50, 3.935, 0.1) \oplus (75, 10.301, 0.262) \\ &\oplus (25, 10.302, 0.262)) = (50, 8.712, 0.222) \end{aligned} \quad (30)$$

5.2. LSWPPs Risk Ranking. Based on the assessment information and weights of risk factors, we can conduct the risk ranking of target LSWPPs by means of TOPSIS method and further obtain the optimal rank of projects.

- (1) Calculate the positive ideal point and negative ideal point for each risk factor in target projects whose data

FIGURE 2: Risk assessment process.

FIGURE 3: The geographic position of target projects.

TABLE 4: Linguistic assessment from experts for four target projects.

		E1				E2				E3			
		P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
C1	C11	L	RH	L	H	H	M	H	H	M	H	RL	H
	C12	L	M	RH	M	H	H	M	H	RH	RH	M	VH
	C13	H	L	L	RH	M	H	H	H	H	L	RL	RH
	C14	M	H	RL	M	H	H	M	H	L	RH	VL	M
	C15	RL	M	H	H	M	M	RL	M	RL	M	L	M
C2	C21	RH	RL	M	H	RL	M	L	M	M	M	RL	RH
	C22	VH	VL	M	RL	RL	L	L	M	RL	RL	M	M
	C23	M	H	L	VH	M	M	M	H	RH	RH	L	H
C3	C31	L	VH	H	M	M	L	M	M	M	H	RH	H
	C32	RH	RL	H	L	M	M	M	H	RL	RH	L	RH
	C33	L	L	RL	VL	L	L	RL	L	L	RH	RL	M
	C34	M	M	RL	RH	L	L	L	L	L	M	M	H
	C35	M	RL	H	RH	M	H	M	H	RL	RL	L	VH
C4	C41	H	H	RH	VH	H	M	H	H	M	L	RL	RH
	C42	RL	L	L	M	H	H	H	RH	H	VH	RH	H
	C43	H	H	M	RH	M	M	M	H	RH	RH	L	RL
	C44	M	H	RH	H	H	H	RL	H	RH	H	L	H

come from the optimal value and the worst value of assessment variables. The dereferencing is shown in Table 3.

- (2) Calculate the Euclidean distance between positive ideal point and target projects y_i^+ by equation (27).

$$y_1^+ = \sum_{k=1}^m w_k (x_{1k} - x_k^+)^2 = (291.633, 695.906, 0.450)$$

$$y_2^+ = \sum_{k=1}^m w_k (x_{2k} - x_k^+)^2 = (325.733, 753.565, 0.487)$$

TABLE 5: Interrelationship between risk factors.

	Technical risk					Environmental and social risk					Operating and political risk					Economic risk			
	C11	C12	C13	C14	C15	C21	C22	C23	C31	C32	C33	C34	C35	C41	C42	C43	C44		
C11		✓			✓					✓		✓	✓	✓		✓	✓		
C12			✓		✓					✓									
C13		✓		✓	✓														
C14	✓																		
C15	✓	✓						✓		✓		✓	✓	✓		✓	✓		
C21	✓		✓	✓	✓					✓	✓	✓	✓	✓			✓		
C22	✓	✓	✓	✓	✓	✓				✓		✓	✓	✓	✓		✓		
C23											✓		✓	✓			✓		
C31		✓								✓		✓	✓	✓		✓	✓		
C32												✓	✓	✓			✓		
C33									✓	✓		✓	✓	✓	✓	✓	✓		
C34									✓	✓						✓	✓		
C35									✓	✓							✓		
C41										✓		✓				✓	✓		
C42		✓			✓						✓		✓			✓	✓		
C43	✓								✓								✓		
C44													✓				✓		

TABLE 6: Critical risk factors and their weights by ANP.

Criterion	Risk factor	CRG	Weight
Technical risk	wind turbine selection risk (0.22091)	5.19	0.081240
	design/construction deficiencies (0.08711)	4.74	0.32036
	technology progressiveness (0.22230)	4.74	0.081750
	technology maturity (0.23866)	5.04	0.087767
	site selection risk (0.23101)	4.51	0.084952
Environmental and social risk	wind resource condition (0.43257)	5.41	0.096276
	topographic condition (0.34099)	4.77	0.075894
	electricity consumption demand (0.22645)	4.78	0.050400
	lack of commercialization operation mechanism (0.08372)	4.29	0.015840
Operating and political risk	construction period (0.34998)	4.60	0.066216
	change of supporting laws (0.05906)	4.80	0.011175
	delay in project approvals and permits (0.08119)	4.28	0.015361
	operation & maintenance risk (0.42605)	4.42	0.080610
	construction cost risk (0.18655)	4.71	0.041132
Economic risk	feed-in tariff risk (0.33065)	4.79	0.072902
	insolvency risk (0.25099)	4.61	0.055340
	profitability risk (0.23180)	4.66	0.051109

TABLE 7: Aggregated clouds for risk factors of target projects.

	P1	P2	P3	P4	Positive ideal point	Negative ideal point
C11	(50.0,8.7,0.22)	(61.5,7.4,0.19)	(46.8,9.2,0.23)	(75.0,10.3,0.26)	(75.0,10.3,0.26)	(46.8,7.35,0.19)
C12	(53.1,9.2,0.23)	(61.5,7.4,0.19)	(53.2,4.9,0.12)	(75.0,11.5,0.29)	(75.0,11.5,0.29)	(53.2,4.9,0.12)
C13	(66.7,8.7,0.22)	(41.7,10.3,0.26)	(46.8,9.2,0.23)	(64.7,7.9,0.20)	(66.7,10.3,0.26)	(41.7,7.9,0.20)
C14	(50.0,8.7,0.22)	(69.9,9.2,0.23)	(30.2,10.6,0.27)	(58.3,6.8,0.17)	(69.9,10.6,0.27)	(30.2,6.8,0.17)
C15	(43.6,5.7,0.14)	(50.0,3.9,0.10)	(46.8,9.28,0.23)	(58.3,6.8,0.17)	(58.3,9.2,0.23)	(43.6,3.9,0.10)
C21	(50.0,5.7,0.14)	(46.8,4.9,0.12)	(38.5,7.4,0.19)	(61.5,7.4,0.19)	(61.5,7.4,0.19)	(38.5,4.9,0.12)
C22	(60.3,10.9,0.28)	(21.8,11.9,0.30)	(41.7,6.8,0.17)	(46.8,4.9,0.12)	(60.3,11.9,0.30)	(21.8,4.9,0.12)
C23	(53.2,4.9,0.12)	(61.5,7.4,0.19)	(33.3,8.7,0.22)	(83.3,12.8,0.33)	(83.3,12.8,0.33)	(33.3,4.9,0.12)
C31	(41.7,6.8,0.17)	(66.7,12.8,0.33)	(61.5,7.4,0.19)	(58.3,6.8,0.17)	(66.7,12.8,0.33)	(41.7,6.8,0.17)
C32	(50.0,5.7,0.14)	(50.0,5.7,0.14)	(50.0,8.7,0.22)	(53.2,9.2,0.23)	(53.2,9.2,0.23)	(50.0,5.7,0.14)
C33	(25.0,10.3,0.26)	(36.5,9.2,0.23)	(40.5,6.4,0.16)	(25.0,11.5,0.29)	(40.5,11.5,0.29)	(25.0,5.7,0.14)
C34	(33.3,8.7,0.22)	(41.7,6.8,0.17)	(38.5,7.4,0.19)	(53.2,9.2,0.23)	(53.2,9.2,0.23)	(33.3,6.8,0.17)
C35	(46.8,4.9,0.12)	(52.0,7.9,0.20)	(50.0,8.8,0.22)	(78.2,11.9,0.30)	(78.2,11.9,0.30)	(46.8,4.9,0.12)
C41	(66.7,8.7,0.22)	(50.0,8.7,0.22)	(58.3,7.9,0.20)	(78.2,11.9,0.30)	(78.2,11.9,0.30)	(50.0,7.9,0.20)
C42	(63.5,9.2,0.23)	(66.7,12.8,0.33)	(53.2,9.2,0.23)	(61.5,7.4,0.19)	(66.7,12.8,0.33)	(53.2,7.4,0.19)
C43	(61.5,7.4,0.19)	(61.5,7.4,0.10)	(41.7,6.8,0.17)	(58.3,7.9,0.20)	(61.5,7.9,0.20)	(41.7,6.8,0.17)
C44	(61.5,7.4,0.19)	(75.0,10.3,0.26)	(41.7,7.9,0.20)	(75.0,10.3,0.26)	(75.0,10.3,0.26)	(41.7,7.4,0.19)

$$y_3^+ = \sum_{k=1}^m w_k (x_{3k} - x_k^+)^2 = (641.505, 728.245, 0.471)$$

$$y_1^- = \sum_{k=1}^m w_k (x_{1k} - x_k^-)^2 = (292.627, 398.925, 0.258)$$

$$y_4^+ = \sum_{k=1}^m w_k (x_{4k} - x_k^+)^2 = (32.016, 785.702, 0.508)$$

$$y_2^- = \sum_{k=1}^m w_k (x_{2k} - x_k^-)^2 = (314.704, 456.586, 0.295)$$

(31)

$$y_3^- = \sum_{k=1}^m w_k (x_{3k} - x_k^-)^2 = (45.923, 431.264, 0.279)$$

(32)

(3) Calculate the Euclidean distance between negative ideal point and target projects y_i^- by equation (28).

$$y_4^- = \sum_{k=1}^m w_k (x_{4k} - x_k^-)^2 = (636.057, 488.721, 0.316)$$

FIGURE 4: Queue indication value of target projects in cloud model.

- (4) Calculate the queue indication value Q_1 , Q_2 , Q_3 , and Q_4 , respectively.

$$\begin{aligned}
 Q_1 &= \frac{y_1^-}{y_1^+ + y_1^-} = \frac{(292.627, 398.925, 0.258)}{(291.633, 695.906, 0.450) + (292.627, 398.925, 0.258)} \\
 &= \frac{(292.627, 398.925, 0.258)}{(291.633 + 292.627, \sqrt{695.906^2 + 398.925^2}, \sqrt{0.450^2 + 0.258^2})} = \frac{(292.627, 398.925, 0.258)}{(584.260, 802.138545, 0.518909)} \\
 &= \left(\frac{292.627}{584.260}, \sqrt{\left(\frac{398.925}{584.260}\right)^2 + \frac{(292.627 * 802.138545)^2}{584.260^4}}, \sqrt{\left(\frac{0.258}{584.260}\right)^2 + \frac{(292.627 * 0.518909)^2}{584.260^4}} \right) \\
 &= (0.50085, 0.969032812, 0.000627)
 \end{aligned} \tag{33}$$

Similarly, we can obtain the numerical value of Q_2 , Q_3 , and Q_4 .

$$\begin{aligned}
 Q_2 &= (0.491389, 0.982493, 0.000636) \\
 Q_3 &= (0.066803, 0.677105, 0.000438) \\
 Q_4 &= (0.952076, 1.507973, 0.000976)
 \end{aligned} \tag{34}$$

Then we can generate clouds through queue indication values Q_1 , Q_2 , Q_3 , and Q_4 as shown in Figure 4. We assume that the ideal cloud is $C_0(0, 0, 0)$, and we can calculate the Hamming distance between ideal cloud and Q_1 , Q_2 , Q_3 , and Q_4 for the comparison of risk levels. By using (11) to (14), we can obtain the Hamming distances $D(C_0, C_1) = 2.949928$, $D(C_0, C_2) = 3.295574$, $D(C_0, C_3) = 2.041176$, and $D(C_0, C_4) = 5.35013$, respectively. $P(C_4 \geq C_2) = 0.61882$, $P(C_2 \geq C_1) = 0.527672$, and $P(C_1 \geq C_3) = 0.591037$ are all greater than 0.5, so the risk ranking of four target projects is $P_4 > P_2 > P_1 > P_3$ which means the fourth LSWPP has the greatest level of risk.

5.3. Calculation of Risk Factors' Memberships. As we have mentioned the calculation method of risk factors' memberships in the fourth section, here we obtain the membership for P_1 , P_2 , P_3 , and P_4 by using (22) to (24). The random number and the membership of each risk factor for each project are all shown in Tables 8, 9, 10, and 11 in

Appendix B. And the result of membership is shown as $P_i = (m(VL), m(L), m(RL), m(M), m(RH), m(H), m(VH))$. We can easily make out that P_1 , P_2 , P_3 , and P_4 belong to RH , RH , RL , and RH , respectively.

$$\begin{aligned}
 P_1 &= (0.13644, 0.310441, 0.531964, 0.552609, \\
 &\quad 0.621005, 0.452789, 0.222734) \\
 P_2 &= (0.158139, 0.330071, 0.490027, 0.619767, \\
 &\quad 0.642834, 0.499277, 0.242947) \\
 P_3 &= (0.244592, 0.493098, 0.795907, 0.63176, \\
 &\quad 0.511356, 0.314266, 0.150592) \\
 P_4 &= (0.077621, 0.201119, 0.342729, 0.531758, \\
 &\quad 0.731558, 0.664455, 0.365616)
 \end{aligned} \tag{35}$$

5.4. A Sensitivity Analysis. In order to examine the robustness of the proposed framework which aggregated ANP and the cloud theory, a sensitivity analysis is of great importance to conduct. The core thought is to test whether the ranking result will change a lot in the circumstance of risk factors' weights fluctuating and test the accuracy of membership as well. In this paper the sensitivity analysis is employed by increasing the weights of risk factors by 30%, 20%, and 10% as well

TABLE 8: Membership and random number of P1.

	VL	L	RL	M	RH	H	VH	Random number
C11	0.1955	0.3925	0.6558	0.4656	0.6544	0.4028	0.2070	8.811
C12	0.1781	0.3552	0.5798	0.4340	0.6800	0.4709	0.2500	9.453
C13	0.0576	0.1623	0.2785	0.4038	0.7158	0.7533	0.3936	8.980
C14	0.1907	0.3870	0.6512	0.4790	0.6497	0.3975	0.2023	8.565
C15	0.1946	0.4383	0.8390	0.6414	0.3883	0.2206	0.0825	5.612
C21	0.1269	0.3107	0.5823	0.7386	0.5802	0.3238	0.1403	5.554
C22	0.1341	0.2742	0.4367	0.3956	0.6199	0.6235	0.3409	10.369
C23	0.0831	0.2383	0.4604	0.7908	0.6863	0.3681	0.1597	4.982
C31	0.2410	0.5083	0.9406	0.5925	0.3771	0.2237	0.0903	6.752
C32	0.1281	0.3121	0.5837	0.7321	0.5816	0.3252	0.1415	5.604
C33	0.5136	0.9846	0.5238	0.2563	0.1750	0.1088	0.0297	9.974
C34	0.3780	0.7443	0.7294	0.3934	0.2664	0.1661	0.0630	8.658
C35	0.1375	0.3444	0.6797	0.7831	0.4450	0.2417	0.0887	4.623
C41	0.0525	0.1558	0.2708	0.3956	0.7293	0.7505	0.3894	8.726
C42	0.0914	0.2125	0.3505	0.4337	0.6795	0.6809	0.3625	9.460
C43	0.0564	0.1736	0.3157	0.4860	0.9069	0.5961	0.2948	6.997
C44	0.0667	0.1870	0.3315	0.5021	0.8594	0.6046	0.3040	7.480

TABLE 9: Membership and random number of P2.

	VL	L	RL	M	RH	H	VH	Random number
C11	0.0683	0.1889	0.3338	0.5045	0.9689	0.6059	0.3054	7.552
C12	0.0635	0.1828	0.3266	0.4972	0.9833	0.6020	0.3011	7.328
C13	0.2996	0.5669	0.8522	0.5675	0.4630	0.2986	0.1511	9.811
C14	0.0320	0.1233	0.2213	0.3242	0.6333	0.9916	0.4333	8.864
C15	0.0889	0.2620	0.5336	0.9828	0.5309	0.2771	0.1035	3.961
C21	0.1393	0.3467	0.6815	0.7848	0.4477	0.2441	0.0905	4.699
C22	0.5841	0.8932	0.4920	0.2554	0.1817	0.1186	0.0410	11.736
C23	0.0636	0.1829	0.3268	0.4973	0.9830	0.6021	0.3012	7.333
C31	0.1280	0.2486	0.3766	0.8775	0.8440	0.7890	0.4507	12.790
C32	0.1314	0.3162	0.5876	0.8567	0.5855	0.3292	0.1447	5.751
C33	0.3510	0.6734	0.7769	0.4791	0.3462	0.2219	0.1014	9.380
C34	0.2408	0.5080	0.9406	0.5921	0.3767	0.2233	0.0901	6.739
C35	0.1664	0.3477	0.5877	0.7873	0.7067	0.4253	0.2160	8.279
C41	0.1991	0.3965	0.6592	0.7281	0.6578	0.4066	0.2104	8.993
C42	0.1290	0.2497	0.3778	0.8760	0.8426	0.7894	0.4514	12.845
C43	0.0714	0.1929	0.3384	0.5091	0.9600	0.6084	0.3081	7.699
C44	0.0285	0.1103	0.1927	0.2736	0.5336	0.9882	0.5291	10.509

as decreasing the weights of risk factors by 30%, 20%, and 10% which will be compared to the initial weights derived from experts and ANP with the help of Super-Decision. The results which show the change of Hamming distance of each project under different weights are shown in Figure 5. And the results of membership have remained RH , RH , RL , and RH , respectively.

6. Critical Risk Factors Analysis

6.1. Technical Risk. (1) Wind turbine selection risk: with the rapid development of low-speed wind industry, the specific

type considering the characteristic of low-speed wind is emerging and gradually coming to its maturity. As for the turbine selection, investors should take into account the service life, the hub height of set, higher rotor diameter, and the material of wind turbine manufacturing.

(2) Design/construction deficiencies: for the design and construction problems, the private sector should pay more attention to the preliminary work which consists of wind resource investigation, the effect caused by raising tower height which can capture higher-speed wind resource, wake effect that may cause damage to turbine, low-speed wind farm line loss rate, and the set orientation.

TABLE 10: Membership and random number of P3.

	VL	L	RL	M	RH	H	VH	Random number
C11	0.2331	0.4552	0.9724	0.6665	0.5714	0.3585	0.1833	9.132
C12	0.0880	0.2446	0.4674	0.9976	0.6911	0.3737	0.1643	5.189
C13	0.2329	0.4550	0.9728	0.6667	0.5712	0.3583	0.1832	9.125
C14	0.4504	0.8479	0.6454	0.3782	0.2684	0.1757	0.0761	10.563
C15	0.2260	0.4474	0.9925	0.6736	0.5631	0.3502	0.1763	8.760
C21	0.2870	0.5911	0.9063	0.4929	0.3198	0.1921	0.0734	7.199
C22	0.2407	0.5080	0.9406	0.5920	0.3766	0.2233	0.0900	6.737
C23	0.3817	0.7467	0.7327	0.4003	0.2728	0.1713	0.0672	8.869
C31	0.0709	0.1923	0.3377	0.5084	0.9613	0.6080	0.3077	7.678
C32	0.2047	0.4029	0.6645	0.7208	0.6631	0.4128	0.2159	9.288
C33	0.2494	0.5302	0.9984	0.5376	0.3395	0.1992	0.0744	6.484
C34	0.2919	0.5956	0.8929	0.5010	0.3278	0.1986	0.0785	7.444
C35	0.1869	0.3826	0.6475	0.7451	0.6459	0.3932	0.1986	8.371
C41	0.1015	0.2410	0.4140	0.9367	0.8823	0.5408	0.2751	7.877
C42	0.1690	0.3445	0.5697	0.7876	0.7398	0.4615	0.2413	8.977
C43	0.2395	0.5067	0.9403	0.5902	0.3747	0.2217	0.0888	6.678
C44	0.2577	0.5255	0.9563	0.5875	0.4027	0.2453	0.1075	7.573

TABLE 11: Membership and random number of P4.

	VL	L	RL	M	RH	H	VH	Random number
C11	0.0271	0.1085	0.1906	0.2713	0.5321	0.9848	0.5282	10.435
C12	0.0509	0.1383	0.2257	0.3102	0.9937	0.9589	0.5448	11.726
C13	0.0485	0.1552	0.2781	0.4169	0.7847	0.6879	0.3486	7.805
C14	0.0786	0.2121	0.3813	0.5940	0.9405	0.5194	0.2542	6.802
C15	0.0843	0.2194	0.3897	0.9868	0.9261	0.5249	0.2595	7.067
C21	0.0713	0.1928	0.3383	0.5090	0.9602	0.6084	0.3081	7.696
C22	0.1417	0.3496	0.6839	0.7870	0.4513	0.2471	0.0928	4.798
C23	0.0147	0.0825	0.1453	0.2024	0.4129	0.7879	0.6803	12.649
C31	0.0748	0.2073	0.3758	0.5889	0.9398	0.5158	0.2508	6.632
C32	0.1802	0.3576	0.5821	0.7700	0.7251	0.4730	0.2519	9.562
C33	0.5352	0.9449	0.5564	0.3056	0.2194	0.1451	0.0587	11.564
C34	0.1618	0.3361	0.5616	0.7997	0.7499	0.4542	0.2345	8.614
C35	0.0332	0.1116	0.1878	0.2599	0.4936	0.9972	0.5928	11.891
C41	0.0299	0.1075	0.1830	0.2546	0.4898	0.9098	0.5907	11.709
C42	0.0703	0.1915	0.3367	0.5075	0.9632	0.6075	0.3072	7.647
C43	0.0973	0.2358	0.4081	0.9481	0.8922	0.5369	0.2713	7.677
C44	0.0276	0.1092	0.1914	0.2722	0.5327	0.9861	0.5285	10.463

FIGURE 5: Sensitivity analysis results.

(3) Technology progressiveness: this risk factor mainly requires the investors to ensure the advancement of equipment technology as the LSWPPs are technology-oriented industry. Advanced technical level brings about not only the reduction in total cost but also more efficient low-speed wind energy efficiency and more effective management at the same time which will observably reduce the risk level.

(4) Technology maturity: different from the technology progressiveness, this factor reflects the stability in use while this technique is employed in a LSWPP. For investors, what may affect the risk of this factor are the fan stability, service life and its reliability, and the compromise between high performance and appropriate costs.

(5) Site selection risk: this factor is the critical element that many scholars have involved in research including both microlevel and macrolevel. As for the risk assessment, prerequisite work such as the investigation of wind resource and climate conditions as well as the social requirement and the terms of transportation ought to be done perfectly so that the site selection risk can be under control.

6.2. Environmental and Social Risk. (1) Wind resource condition: local wind resource data comes from the anemometer tower that has been placed at the preselected site in advance. The accuracy of measurement and the fluctuation of local wind power should be guaranteed. What really matters in this risk factor are wind power density, mean maximum wind speed and mean wind speed, and so on and for investors, they should pay attention to the design and wind turbine selection in order to make sure of the full use of local wind resource as well as lowering down the total costs.

(2) Topographic condition: because of the complexity and unpredictability of geological condition in areas where the LSWPPs are mostly placed in, the requirement for prerequisite work for geological prospecting ought to be higher than the average, so, what investors of topographic condition should be concerned about is the geologic hazard such as earthquake, landslide, debris flow, rainstorm and diastrophism, terms of transportation especially for large pieces of equipment, and the potential harm to wind turbine.

(3) Electricity consumption demand: this factor mainly derives from local residents and local enterprises and factories. As the LSWPPs mostly supply power for the local power grid, long-distance transmission is out of consideration, so all the power a LSWPP generates will meet the demand nearby first. It is of great importance to evaluate the electricity consumption demand whose prediction will bring about guiding significance for power generation.

6.3. Operating and Political Risk. (1) Lack of commercialization operation mechanism: because the LSWPPs are newly arisen industries since the 12th five-year plan, a mature commercialization operation mechanism has not been formed. So, for investors, they should take in the potential risks in operation period as a LSWPP is in operation and learn to mitigate them by drawing lessons from the past projects and predicting them in advance.

(2) Construction period: the revenue of a LSWPP mainly comes from feed-in tariff which means the earlier a LSWPP is on stream, the more likely it can earn its cost within an acceptable time frame. What the investors should be concerned about is not only the design of the period but also the practical control to ensure lowering the risk from both perspectives.

(3) Change of supporting laws: this factor is a special one where the occurrence probability is relatively low with the stability of Chinese government, but once a change of supporting law has occurred, it will bring about deep influence for the entire industry. So it is important to constantly pay attention to the policies' change and the governments' movement.

(4) Delay in project approvals and permits: now in China, a specific approval process for LSWPPs has not been established yet, so it is a long and cumbersome process for these projects which may increase the risk of project delay. So, for investors, they should foresee the possible delays as much as they can in order to prepare for tackling the possible issues.

(5) Operation and maintenance risk: because of the complicated climate conditions and topographic conditions, the difficulty of operation and maintenance will rise significantly compared to the general wind power projects. In response to this factor, the investors should invite experienced operating personnel in order to minimize risk.

6.4. Economic Risk. (1) Construction cost risk: in response to this factor, investors should focus on the manufacturing materials such as adopting the light, high-strength mixture of carbon fiber and glass fiber for fan blade or researching and applying the tower of new structure in order to deal with the cost increases caused by the higher hub height. At the same time, using the key equipment which is designed and manufactured in our own country is also beneficial for reducing the construction cost, so it is meaningful to improve the research and development level in order to lower this risk.

(2) Feed-in tariff risk: in China, wind resource regions are divided into four parts and low-speed wind power is classified as the fourth-class wind resource region which takes account for over 68% of the total area of China. In view of the different wind resources, Chinese government has given different standards of feed-in tariff and with the rapid development of wind power industry, the feed-in tariff will gradually lower to the desulfurizing price eventually. In response to this factor, investors should look further ahead to predict the adjustment of feed-in tariff in order to calculate the revenue of LSWPPs to lower this risk.

(3) Insolvency risk: as there are few giant enterprises shifting their investment orientation into LSWPPs, currently, most of the investors are private section or relatively small investment groups who race to seize the market, so most of the capital sources are bank loans or financing. Therefore, preventing the break-even in cash-flow is a significant risk factor for investors which require them to invest reasonably.

(4) Profitability risk: most of the risk factors we mentioned above will influence the profitability of a LSWPP ultimately, so controlling this risk level is a comprehensive, complicated, and dynamic issue. In response to this factor, investors should make sure of the rational and effective design and construction on the rails and have the operation and maintenance under control.

7. Conclusions

Recently, with the severe shortage of fossil energy, the problem of environmental pollution is getting worse and China is in an urgent need of development of renewable energy in order to tackle these issues. As a relatively mature renewable energy technology, wind power has drawn more and more attention from the government all over the world. But due to

the irrational development and severe wind curtailment phenomenon, Chinese government has encouraged enterprises to shift investment orientation to LSWPPs in consideration of its superiority close to the electrical load and market. Most of the appropriate sites for LSWPPs are located in mideast and south China where the geological conditions and climate conditions are complicated and changeable, so the previous experience gained from large-scale wind power development can no longer be adapted to current LSWPPs development and the risks and opportunities coexist. Nowadays, scholars have not focused on the risk assessment of LSWPPs, so it is of significance to establish a risk assessment framework in order to guide the investment of LSWPPs.

In this paper, an ANP method-based risk assessment system combined with the cloud theory and TOPSIS method which can make up the shortcomings and flaws in traditional risk assessment methods is proposed for LSWPPs risk assessment. Firstly, this aggregated method can retain both fuzziness and randomness of linguistic information. Secondly, the ANP method we used in weights calculation can take the interrelationship of risk factors into consideration, which means the important information is not missing. Thirdly, this method gives not only the ranking of target projects but also the risk level of each project which has significant meanings for decision-makers and we can use this framework to evaluate the risk level of whole low-speed wind industry.

Then we conduct a case study of LSWPPs in Anhui province and Henan province on the basis of proposed aggregated method and test the sensitivity of risk assessment result. The membership results show that the risk levels of LSWPPs are relatively high which should concern investors. All the endeavors provide the evidence for proving the feasibility, stability, and rationality of ANP method-based risk assessment system combined with the cloud theory and TOPSIS method in LSWPPs risk assessment and provide more references for decision-makers.

But there are still limitations in our study. First, we selected Anhui province as the location of our potential target LSWPP projects, so we did not examine the feasibility of this evaluation model toward other projects. Then, as the technical maturity of LSWPP is rising, the critical risk factors will change in the future, so it is of great importance to integrate the policy environment and market environment to adjust the index system. For our future research, we will apply this evaluation method to other regions in China and then areas in other countries to examine its stability and feasibility. We will also focus on the latest fluctuation of policy and market in order to make this model adapt to the changing circumstances.

Appendix

A.

- (i) Wind resource condition: as the key parameter of wind power prospective design, wind resource condition directly affects the capacity and on-grid energy of low-speed wind power projects. And, at the same time, it will effectively influence the safety and reliability of low-speed wind farm set.
- (ii) Wind turbine selection risk: wind turbine selection is the key point of wind farm design. Proper turbine determination plays a helpful role in influencing the revenue of low-speed wind power projects. It mainly concerns security and economic. Security means the selection should verify the design requirement and corresponding security level on the basis of different wind resource conditions, for example, the maximum wind speed and turbulence intensity within fifty years are two basic indicators.
- (iii) Technology maturity: for the low-speed wind power projects with high maturity technology, investors take on relatively lower risk. Factors affecting the maturity of technology come mainly from the reliability and feasibility of technology.
- (iv) Change of supporting laws: as the low-speed wind power projects in China are in their infancy, the relevant supporting laws will experience lots of alteration and adjustment. These changes would directly influence the construction and investment of low-speed wind projects.
- (v) Feed-in tariff risk: feed-in tariff is the most direct element affecting the income of low-speed wind power projects and the development of low-speed wind power market, so, it can intuitively reveal the profitability of the project. Wind power unit cost under low-speed wind condition is relatively high; thus the feed-in tariff policy should offer the enterprises some level of support; otherwise the development of low-speed wind industry would get into trouble.
- (vi) Electricity consumption demand: the main propose for constructing low-speed wind power projects is to meet local electricity consumption demand. The electricity consumption demand has characteristic of fluctuation, so good electricity consumption forecast can guide the generating work of low-speed wind power projects.
- (vii) Topographic condition: topographic condition refers to the terrain feature of selected area. The terrain of mideast and south area in China is undulating, with many hills, water systems, and mountainous areas; meanwhile the fan installation platform and floor road design are more intricate.
- (viii) Design/construction deficiencies: during the design stage, the whole process of project design should be taken into consideration and the selection of design options should be within control. In the construction phase, the whole process should be in accordance with the scientific construction procedure in order to control the construction quality strictly.
- (ix) Technology progressiveness: this indicator mainly refers to the advanced technologies which are the driving force of low-speed wind power industry. It measures the advanced degree of renewable energy technologies and greatly improves the low-speed wind power efficiency and quality.

- (x) Construction cost risk: low-speed wind power farms are usually located in hilly areas whose terrain is complicated and the climate is fickle. At the same time, the infrastructure construction of these areas lags behind which brings about the high cost of civil engineering of low-speed wind power projects and transportation. Along with the wind turbine selection is the wind turbine cost, which dominates the total cost of equipment procurement.
- (xi) Profitability risk: the analysis of profitability starts from the perspective of financial index and then judges the earning risk of project in order to estimate whether the investment of these low-speed wind power projects is rational.
- (xii) Insolvency risk: for low-speed wind power projects, the investors mainly concentrate on enterprises interested in renewable energy investment and the sources of fund mostly are loans; thus it is of great importance to estimate the insolvency ability of certain low-speed wind power project. The capability of insolvency can be reflected by asset-liability ratio and loan repayment period.
- (xiii) Construction period: the actual duration is longer than the planned one, so that the project cannot be completed according to the contract period. If the construction period is prolonged, the cost will increase too.
- (xiv) Site selection risk: site selection risk refers to the uncertainty in a LSWPP site selecting. Inappropriate site selection may directly lead to inefficient power generation and increase of construction and maintenance cost or further result in the failure of a LSWPP.
- (xv) Operation and maintenance risk: On account of the environment risk factors in hilly areas, the operation and maintenance in these regions present certain risk. For example, the topographic condition may raise the bar in changing and repairing equipment parts and the climate conditions may influence the normal operation of low-speed wind equipment.
- (xvi) Lack of commercialization operation mechanism: most of China's wind power related enterprises are either directly operated under a power company or operated as a wholly owned subsidiary. The proportion of completely independent wind power business is still relatively small. Wind farm developments are still driven by government, rather than a commercial operation.
- (xvii) Delay in project approvals and permits: this risk refers to the fact that the construction of low-speed wind power project touched on kinds of benefits relationships and regulations, which may cause extension of construction period and further raise the risk of the target project.
- (xviii) Operation cost risk: as the operation time increases, the equipment will age and the running accuracy will lower because of the long service life of operation process; meanwhile, in the custody and idle period, deformation, metal corrosion, and materials deterioration will appear, which virtually increase operation expenses.
- (xix) Financial subsidy risk: financial subsidy is a market-based incentive policy approach that the government proposed to promote wind power technology and the investment for wind power projects. Current subsidy consists of the price spread between wind power benchmark price and desulfurizing price and appropriate allowance for construction investment caused by low-speed projects connecting to the grid system and operating maintenance cost based on the on-grid energy.
- (xx) Tax privilege risk: in order to encourage and support the development of wind power industry, specific tax privilege policies are established mainly including exemption or reduction of enterprise income tax, value-added tax preference policies, and fiscal capital tax policies.
- (xxi) Climate conditions: this mainly regards the risk that had arisen from the reconnaissance design stage which may give rise to unforeseen weather condition.
- (xxii) Wind resource assessment risk: the assessment ability of wind resource is of vital importance in prospective design phase. It is the process that uses the observation data like wind speed, wind direction, air temperature, and air density to estimate the wind power density and annual utilization hours.
- (xxiii) Wind farm set placement risk: low-speed wind farm sets are normally distributed in a relatively small scale, so the proper placement of low-speed wind farm sets counts for much. In spite of considering the distribution characteristics of wind resources, it is equally important to take ambient terrain condition and barrier around and the wake effect between wind sets.
- (xxiv) Independence R&D capacity: company's core technology determines its independent R&D capabilities. For the protection of core technology, enterprises should attach great importance to the application and protection of intellectual property and handling of trade secrets.
- (xxv) Land acquisition risk: in consideration of the construction characters of low-speed wind power projects, the residents, traffic conditions, and environmental protection of suitable sites for these projects in mid-east and south area in China are complicated. So, the acquisition difficulty would be a risk factor.
- (xxvi) Lack of coordination of the supply chain of wind power industry: the vast majority of domestic manufacturers concentrate on research and development of wind turbines, whereas little emphasis has been placed on gear box components. Key components such as electronic control systems and bearings still

rely on imports from overseas. As a result, there is poor coordination between the up and down streams of the supply chain.

- (xxvii) Market growth potential: as the manufacturing industry of low-speed wind power is heavily dependent on imports of raw materials and exports of key equipment like turbine, the market growth potential is highly vulnerable to external market volatility. The scale of market and the growth rate of wind power industry are a direct manifestation of potential.
- (xxviii) Public acceptance risk: public acceptance refers to whether local residents' attitude toward these low-speed wind power projects gives projects positive assistance. If the projects are recognized by the public, the development process will be accelerated; otherwise it will lag the process.
- (xxix) Related standards support: the definition of low-speed wind power has not been affirmed by government in China; thus relevant supporting standards have not been established. So, it is important for the enterprises and institutes to pay attention to the related standards such as the plan issued by the Standardization Administration of China in 2009 for ensuring the reliable grid connection of wind power and the stable operation of electric power systems.
- (xxx) Consulting risk: the consulting industry of China's wind power is still in its infancy. At present, there are few enterprises which can conduct consulting in the whole life cycle of the wind power projects, not to mention the low-speed wind power projects. Each project of low-speed wind power is complicated and different, so the consulting experience is also very important.
- (xxxi) Construction safety risk: as the low-speed wind power projects are mostly located in hilly areas whose terrain condition is complicated, the difficulty of construction will also increase which makes the construction a more severe task to ensure the construction safety of low-speed wind power projects.
- (xxxii) Competitiveness of other renewable energy: this factor mainly refers to influence conducted by other renewable energy like hydropower or PV power to low-speed wind power projects. The market competition may curtail market shares of low-speed wind and further influence the development of these projects.
- (xxxiii) Ecological balance risk: low-speed wind power projects are mostly located in areas with hills where the wind farm set is generally arranged along the ridge. These areas are usually underexploited which may cause the ecological damage and water and soil loss.
- (xxxiv) Wind curtailment: low-speed wind power projects that are already connected to the power grid are highly influenced by the power grid load regulation. As the wind power is fluctuating, it may stop generating when the load is unstable.
- (xxxv) Connection to power grid risk: due to the inherent intermittency and volatility of wind power especially the low-speed wind power, it may induce the low accuracy of grid prediction and further affect the stability and security of power grid. So from the perspective of benefit of grid companies, they dislike the connection to power grid of wind power. The civil engineering cost of low-speed wind power projects is relatively high; they depend on the generating revenue heavily, and thus, higher requirements are put forward to the connection technology.
- (xxxvi) Green power certificates risk: green power certificate refers to the electronic documents along with the only code identification issued by China National Renewable Energy Information Management Center on the basis of relevant provision of national energy administration management through national energy administration of renewable energy power generation project information management platform to the renewable energy enterprises. The core content of green power certificate includes renewable energy quota system, renewable energy consumption, and renewable energy green certificate trading system.
- (xxxvii) Insurance risk: many insurance companies are not willing to enter the wind power business regarding the relatively high risk of investment and immaturity of the market.
- (xxxviii) Inflation: the rise in the price level will lead to a decline in the money purchasing power and a direct increase in the construction and operating costs of the LSWPPs.

B.

See Tables 8, 9, 10, and 11 .

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Yunna Wu designed the framework; Shaoyu Ji established the evaluation index system, collected the data, and calculated the results; Shaoyu Ji and Jing Wang drew the figures and calculated random numbers; Zixin Song calculated weights of risk factors; finally, Shaoyu Ji wrote the paper and formatted the manuscript for submission.

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