Research Article

New Energy Power Generation Enterprise Credit Evaluation Based on Fuzzy Best-Worst and Improved Matter-Element Extension Method

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Under the background of the new power system, the proportion of new energy power generation enterprises in the power market is gradually increasing. With the further expansion of China's power trading scale, the increasingly fierce market competition, and the instability of new energy output, the credit problems of new energy power generation enterprises in the trading process cannot be ignored. Therefore, improving and perfecting the credit system of new energy power generation enterprises is necessary for building a modern market system. Firstly, the credit indexes of new energy power generation enterprises are constructed from the three dimensions of performance ability, performance behavior, and performance willingness. Then, a credit index evaluation model of new energy power generation enterprises is proposed based on the fuzzy best-worst and improved matter-element extension method. Finally, an empirical study is carried out. The analysis results show that scheduling discipline compliance, historical credit, and participation rate of the market-oriented transaction have a more significant impact on the recognition of new energy power generation enterprises. They should focus on market transactions. The model proposed in this paper can effectively deal with the ambiguity of indexes in the credit evaluation of new energy power companies. Through comparison with other models, the effectiveness of the model proposed in this paper in the credit evaluation of power companies is further verified. Construction provides method support.

1. Introduction

In March 2015, the Communist Party of China (CPC) Central Committee and the State Council issued several opinions on further deepening the reform of the power system and its supporting documents, proposing to establish and improve the credit system of market subjects and strengthen the integrity construction of market subjects. Under the background of carbon peaking and carbon neutrality goals and a new power system, new energy power generation enterprises (NEPGE), which use clean energy such as wind energy and solar energy to generate electric power, will continue to increase their proportion in the market with their advantages of low cost, zero pollution, and sustainable energy supply [1], which provides a strong driving force for the transformation of energy structure in various countries. However, NEPGE has the characteristics of randomness and volatility. Large-scale new energy grid connection has significantly impacted the traditional energy market to maintain the balance of supply and demand. The fierce market competition and the domestic market have higher and higher requirements for enterprise integrity; good credit is the foundation of its healthy development [2]. Credit evaluation is one of the most effective ways to strengthen government supervision of market subject credit. Therefore, it is of great practical significance to establish the corresponding credit evaluation...
system and model, whether for the credit risk control of NEPGE or the credit supervision of the government on the main body of the power market [3].

The existing literature has less credit evaluation on NEPGE, mainly from the credit management of the power market involving market subjects’ credit indexes. Chen et al. investigated the credit evaluation mechanism of typical power wholesale markets in the USA and gave some suggestions for constructing a credit mechanism in China [4]. Xia et al. examined some credit problems among market participants, such as weak awareness of performance, oligopoly, and low enthusiasm [5]. Xu et al. divided the credit of market entities into those affected by the basic external environment, financial status, management ability, transaction performance, and other factors [6, 7]. Zhao et al. analyzed the reliability of the power market connected with new energy from the two reliability indexes of load expectation and expected nonpower supply energy [8]. Xie et al. classified different large power users and formulated other credit management policies to reduce the potential rate of wrong credit customers [9]. Zhou et al. selected external indexes, full process indexes, credit indexes, and early prevention indexes to evaluate the credit of retail power enterprises [10, 11]. Referring to the above literature, this paper selects credit indexes from the three dimensions of performance ability, performance willingness, and performance behavior to evaluate the credit of NEPGE.

As an important part of the credit activity process, the credit evaluation can not only reflect the authenticity of the early credit investigation but also play an important guiding role in enterprises’ transactions based on credit. Therefore, accurately evaluating the credit level to improve the initiative of NEPGE is the key to the design of a credit management mechanism. It is essential to select the appropriate weight determination method and index evaluation model. The methods to determine the index weight include entropy weight method [12, 13], analytic hierarchy process (AHP) [14], best-worst method (BWM) [15], fuzzy best-worst method (FBWM) [16, 17], etc. The entropy weight method is to weight the indexes on the premise that the level of evaluation indexes is very different. Still, there is little difference between the credit indexes of NEPGE, which will lead to a situation where the indexes are given a weight inconsistent with their importance [18]. The judgment matrix quantitative evaluation of the analytic hierarchy process adopts the 1–9 scale method proposed by Saaty. When there are many indexes in the evaluation system, the number of iterations and the amount of calculation increase accordingly. The best-worst method first selects the best index and the worst index and compares the best index and the worst index with other indexes, which solves the disadvantage of more iterations of AHP. Considering the limitations of human knowledge in credit evaluation and the uncertainty of decision-making experts in the decision-making process [19], this paper uses the FBWM to weight the index system.

Fuzzy comprehensive evaluation method [20], TOPSIS [21, 22], matter-element extension [23–25], and matter-element extension method [26] are common index evaluation models. Matter-element extension takes matter-element theory and extension set theory as the theoretical framework, establishes the classical domain, node domain, and evaluation level, and calculates the correlation degree of the matter-element to be evaluated concerning the rating level according to the measured data, to determine the level of the evaluation object [24]. However, if the value of an index of the matter-element to be evaluated exceeds the node field, when the value of the index is substituted into the correlation function calculation, the denominator will be zero, the correlation function value cannot be obtained, and the index cannot be evaluated [27]. Therefore, the conventional matter-element extension method should be improved when applying it.

In line with the above discussion, this paper selects the index system combining qualitative and quantitative indexes for credit evaluation of NEPGE and proposes a credit evaluation model of NEPGE in the power market based on the fuzzy best-worst and improved matter-element extension method to evaluate the diversified index system. The innovations of this paper are as follows:

1. Considering the characteristics of new energy power producers in the market, a new energy power producer credit evaluation index system including 15 secondary indicators is constructed from the three dimensions of performance ability, performance behavior, and willingness to perform, which can comprehensively reflect the credit status of new energy power producers and lay a foundation for accurately evaluating the credit level of new energy power producers.

2. Considering the characteristics of the index system, a credit evaluation model of new energy power producers based on FBWM and improved matter-element extension is constructed. On the one hand, the weight method based on FBWM has less demand for index data information and can fully consider the fuzziness and uncertainty of expert judgment, reduce the heterogeneity of expert evaluation results, and ensure the reliability of weight results; on the other hand, the improved matter-element extension method overcomes the limitation that the traditional matter-element extension method is challenging to deal with the index value exceeding the limit and has wider adaptability.

The rest of the paper is organized as follows: Section 2 constructs the credit evaluation index system of NEPGE, including performance ability, performance behavior, and performance willingness. Section 3 creates the credit evaluation model of NEPGE. Section 4 makes an empirical analysis of NEPGE, a sensitivity analysis of indexes, and a comparative analysis of evaluation methods. Section 5 concludes the paper and puts forward some implications.

2. Evaluation Index System

The setting of indexes can reflect the behavior orientation of market subjects and distinguish the good and bad of market members. This paper establishes the credit evaluation index system of NEPGE. When participating in the medium and
long-term market in the province, like other conventional power producers, NEPGE signs medium and long-term transaction contracts with power sales companies and wholesale users voluntarily. When participating in the spot market in the province, NEPGE mainly obtains market-oriented electricity space by reducing electricity prices, even floor prices and zero price. There are three main modes for new energy to participate in the inter-provincial and inter-regional medium and long-term market: new energy export transaction, the direct transaction between new energy and large users, and inter-provincial power generation proper transaction between new and conventional energy. The inter-provincial and inter-regional spot market transactions it participates in are an essential supplementary form of the medium and long-term market. NEPGE has credit problems in participating in the power market, no matter what kind of participation mode. Compared with poor credit generators, generators with good credit have more market resources, more substantial market competitiveness, and higher enterprise income.

This paper constructs the indexes from the perspective of NEPGE. The performance capacity, behavior, and willingness index are the top three criteria. Firstly, the performance capability index is a credit index that can reflect the enterprise's credit status and has nothing to do with the trading activities in the power market. This index evaluates the enterprise's credit from the enterprise's perspective. The performance behavior index may affect the recognition of NEPGE in participating in power market transactions. This index evaluates the credit of enterprises from the standpoint of enterprise transactions. The performance willingness index refers to the reward or punishment index given by the market trading institution to the NEPGE that has good performance in the power market or violates the trading rules. This index evaluates the enterprise's credit from the perspective of the regulator. This indicator assesses the recognition of enterprises from the perspective of regulators.

To sum up, the indexes of these three dimensions measure the credit risk of NEPGE from the perspectives of the enterprise itself, participating in transactions and regulators to make the credit evaluation more objective and comprehensive. The index system includes three first-level indexes and 15 second-level indexes. The specific descriptions of indexes and its type are shown in Table 1.

2.1. **Performance Ability Index.** The performance ability index reflects the actual capacity of NEPGE.

Total assets (C11) and a total installed capacity of power generation (C12) reflect the power sales capacity and enterprise scale of NEPGE. The asset-liability ratio (C13) is the ratio of total liabilities to total assets, which reflects the long-term solvency of NEPGE. If an enterprise’s asset-liability percentage is higher, it may cause it to fail to pay its debts in time and reduce the enterprise’s credit. Operating profit margin (C14) refers to the percentage of the operating profit from the operation of the enterprise in the net sales. As an indicator of the enterprise's operating efficiency, the greater the operating profit, the higher the enterprise’s credit. The above indexes are quantitative, and the data for indexes are obtained from the company’s financial statements. As the name suggests, historical credit (C15) is the credit status of the enterprise in the previous year. The data for this index are obtained from the APP named “Credit China.”

2.2. **Performance Behavior Index.** The performance behavior index represents the credit situation of NEPGE in the whole process of participating in market transactions.

Market-oriented transaction participation rate (C21) is the ratio of the number of NEPGEs participating in market transactions to the number of organized transactions. Market share (C22) reflects the competitive position of NEPGE in market transactions. Contract electricity performance rate (C23) is the ratio of the settlement electricity to the transaction contract electricity after the execution of the transaction contract, which provides a reference for the government to evaluate the credit of power producers. The settlement default rate (C24) directly affects the enterprise's credit in market transactions. The higher the settlement default rate, the lower the enterprise’s corresponding credit in market transactions. Predicted output deviation (C25) is the difference between the actual and predicted output of new energy units. The above indexes are quantitative, and the relevant data are obtained from the power trading platform.

2.3. **Performance Willingness Index.** The performance willingness index mainly indicates the performance of credit behavior caused by the subjective will of NEPGE.

Participation in the market management initiative (C31) means that the enterprise puts forward constructive opinions on market management based on its own needs, such as actively establishing or reporting complaints. Compliance with dispatch records (C32) refers to whether the enterprise complies with the power dispatching requirements. Performance of transaction results (C33) refers to whether the enterprise performs the transaction results of the power market. Timeliness of information disclosure (C34) refers to whether the enterprise actively discloses its information. Unfair competition (C35) mainly relates to collaboration, technical interference, secret theft, and other credit violations made by enterprises.

3. **Construction of Credit Evaluation Model for NEPGE**

3.1. **Credit Risk Index Weighting Based on FBWM.** FBWM is used for weighting in this paper. Guo proposed this method in 2017 [17] and combined fuzzy theory [28] with the best-worst method to solve experts' fuzziness and uncertainty in the decision-making process.

The NEPGE includes $n$ credit indexes. Experts or decision-makers can emphasize the two indexes in a language-level evaluation according to their knowledge and experience, for example, critical, slightly important, and very important. Then, the language grade evaluation results can be transformed into fuzzy triangular numbers according to
Step 1. Determine the best and the worst index.

For the constructed credit index system, decision-makers need to determine the best index $C_B$ and the worst index $C_w$ according to their knowledge and experience.

Step 2. The importance of the selected the best index is compared with other indexes in the same dimension.

The decision-makers compare the importance of the selected best indexes with other indexes in the same dimension of NEPGE. The comparison results are given in the form of language evaluation level so that the fuzzy best comparison vector can be constructed by

$$\bar{A} = (\bar{a}_{i1}, \bar{a}_{i2}, \ldots, \bar{a}_{ij})$$

Step 3. Each index is compared with the worst index.

The decision-maker compares the importance of each index and the worst index $C_w$ in the evaluation index system. The language evaluation level is given according to Table 3–1, so that the fuzzy worst comparison vector $\bar{A}_w$ can be constructed by

$$\bar{A}_w = (\bar{a}_{iw}, \bar{a}_{2w}, \ldots, \bar{a}_{nw}),$$

where $\bar{a}_{ij}$ is the fuzzy preference degree of the index $i$ relative to index $j$. It can be represented by fuzzy triangular numbers. The specific steps of using FBWM to determine the weight of each evaluation index are as follows.

$\bar{A}_w$ is the fuzzy worst comparison vector, and $\bar{A}_w$ is the fuzzy worst comparison vector.

Step 4. Determine the best fuzzy weight value ($\bar{w}_i$, $\bar{w}_j$, $\ldots$, $\bar{w}_n$) of each index.

$\bar{w}_i$ is the best fuzzy weight of the best index, $\bar{w}_j$ is the best fuzzy weight of each index, $\bar{w}_w$ is the worst fuzzy weight of the best index, $\bar{A}_B$ is the fuzzy best comparison vector, and $\bar{A}_w$ is the fuzzy worst comparison vector.

The ratio of $\bar{w}_B$ and $\bar{w}_j$ shall be consistent with the $\bar{A}_B$, and the ratio of $\bar{w}_i$ and $\bar{w}_w$ shall be consistent with the $\bar{A}_w$ as much as possible. According to this principle, the min-max problem with constraints can be constructed as shown in

$$\min \max \left\{ \left| \bar{w}_B - \bar{A}_B \right|, \left| \bar{w}_i - \bar{A}_w \right| \right\},$$

s.t. $\sum_{j=1}^{n} R(\bar{w}_j) = 1$, $w_j^w \leq \bar{w}_j^w \leq w_j^w$, $j = 1, 2, \ldots, n$, where $\bar{w}_j$ is the result of the importance of the best index $C_B$ and index $j$.

$$j = 1, 2, \ldots, n \text{ and } \bar{A}_B = (1, 1, 1).$$

Table 1: Credit index system for NEPGE.

<table>
<thead>
<tr>
<th>Goal</th>
<th>First-level index</th>
<th>Second-level index</th>
<th>Index type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total assets C11</td>
<td>Performance</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Total installed capacity of power generation C12</td>
<td>ability</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Asset-liability ratio C13</td>
<td>Performance</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>Operating profit margin C14</td>
<td>behavior</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Historical credit C15</td>
<td>Performance</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Participation rate of market-oriented transaction C21</td>
<td>willingness</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Market share C22</td>
<td>Performance</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Contract electricity performance rate C23</td>
<td>Performance</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Settlement default rate C24</td>
<td>Performance</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>Predicted output deviation C25</td>
<td>Performance</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>Participation in market management initiative C31</td>
<td>Performance</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Compliance with dispatch records C32</td>
<td>Performance</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Performance of transaction results C33</td>
<td>Performance</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Timeliness of information disclosure C34</td>
<td>Performance</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Unfair competition C35</td>
<td>Performance</td>
<td>Negative</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Transformation rules of linguistic variables of decision-maker.

<table>
<thead>
<tr>
<th>Linguistic terms</th>
<th>Membership function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equally important (EI)</td>
<td>(1, 1, 1)</td>
</tr>
<tr>
<td>Weakly important (WI)</td>
<td>(2/3, 1, 3/2)</td>
</tr>
<tr>
<td>Fairly important (FI)</td>
<td>(3/2, 2, 5/2)</td>
</tr>
<tr>
<td>Very important (VI)</td>
<td>(5/2, 3, 7/2)</td>
</tr>
<tr>
<td>Absolutely important (AI)</td>
<td>(7/2, 4, 9/2)</td>
</tr>
</tbody>
</table>

Table 3: Consistency index (CI) for FBWM.

<table>
<thead>
<tr>
<th>Linguistic terms</th>
<th>EI</th>
<th>WI</th>
<th>FI</th>
<th>VI</th>
<th>AI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{a}_{iw}$</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(5/2, 3, 7/2)</td>
<td>(7/2, 4, 9/2)</td>
</tr>
<tr>
<td>CI</td>
<td>3.00</td>
<td>3.80</td>
<td>5.20</td>
<td>6.69</td>
<td>8.04</td>
</tr>
</tbody>
</table>

where $\bar{a}_{ij}$ is the comparison result of the importance of the best index $C_B$ and index $j$.

$\bar{A}_w = (\bar{a}_{iw}, \bar{a}_{2w}, \ldots, \bar{a}_{nw}).$
where \( \bar{w}_B = (l_{B}^w, m_{B}^w, u_{B}^w) \), \( \bar{w}_j = (l_{j}^w, m_{j}^w, u_{j}^w) \), \( \bar{w}_W = (l_{W}^w, m_{W}^w, u_{W}^w) \), \( \bar{a}_{Bj} = (l_{Bj}, m_{Bj}, u_{Bj}) \), \( \bar{a}_{Wj} = (l_{Wj}, m_{Wj}, u_{Wj}) \). \( R(\bar{w}_j) \) converts the fuzzy weight value of index \( j \) into an accurate value, and it can be calculated by

\[
R(\bar{w}_j) = \frac{l_{j}^w + 4m_{j}^w + u_{j}^w}{6}. \tag{5}
\]

(4) can be transformed into a nonlinear constrained best problem, as shown

\[
\min \xi^*
\]

\[
\begin{align*}
\left| \frac{\bar{w}_B}{\bar{w}_j} - \bar{a}_{Bj} \right| & \leq \xi \\
\left| \frac{\bar{w}_j}{\bar{w}_W} - \bar{a}_{jW} \right| & \leq \xi_k \\
\sum_{j=1}^{n} R(\bar{w}_j) & = 1, \\
l_{j}^w & \leq m_{j}^w \leq u_{j}^w, \\
l_{j}^w & \geq 0, \\
\end{align*}
\tag{6}
\]

where \( \xi = (l^t, m^t, u^t) \), as \( l^t \leq m^t \leq u^t \), make \( \xi^* = (k^*, k^*, k^*) \). Equation (6) can be transformed into

\[
\min \xi^*
\]

\[
\begin{align*}
\left| \frac{\bar{w}_B}{\bar{w}_j} - \bar{a}_{Bj} \right| & \leq \xi \\
\left| \frac{\bar{w}_j}{\bar{w}_W} - \bar{a}_{jW} \right| & \leq \xi_k \\
\sum_{j=1}^{n} R(\bar{w}_j) & = 1, \\
l_{j}^w & \leq m_{j}^w \leq u_{j}^w, \\
l_{j}^w & \geq 0, \\
\end{align*}
\tag{7}
\]

By solving equations (3)–(7), the best fuzzy weight value of each index can be obtained, that is, the final fuzzy weight of each evaluation index \( W = (\bar{w}_1^*, \bar{w}_2^*, \ldots, \bar{w}_n^*) \).

When using the fuzzy best-worst method to determine the index weight, it is necessary to test the consistency of the fuzzy comparison between two indexes. The consistency index CR is usually used for judgment, and the specific calculation is shown in

\[
CR = \frac{R(\xi^*)}{CI}, \tag{8}
\]

where \( R(\xi^*) \) is the exact value of \( \xi^* \) and \( CI \) is the consistency index of FBWM. It can be determined according to different values of \( \bar{a}_{Bj} \) and Table 3.

3.2. Credit Risk Evaluation Model Based on Improved Matter-Element Extension Method. The traditional matter-element extension method was proposed in 1983 [29]. Based on the matter-element theory and extended set theory, the classical domain, node domain, and evaluation level are established.

Let \( U \) be the object. \( C \) and \( U \) represent the characteristics and quantities corresponding to \( U \), respectively. \( C \) and \( U \) is called the basic element of matter-element \( R \). The classical domain matter-element matrix \( R \) of the credit level of NEPGE is

\[
R = (U, C, V) = [R_1, R_2, \ldots, R_n]^T = \begin{bmatrix}
U & c_1 & v_1 \\
c_2 & v_2 \\
\vdots & \vdots \\
c_n & v_n
\end{bmatrix}. \tag{9}
\]

Step 1. Set classical domain and node domain.

The classical domain matter-element matrix \( R_1 \) of the credit level of NEPGE is

\[
R_j = (U_j, C_i, V_{ij}) = \begin{bmatrix}
U_j & c_1 & v_{ij} \\
c_2 & v_{ij} \\
\vdots & \vdots \\
c_n & v_{nj}
\end{bmatrix} = \begin{bmatrix}
U_j & c_1 & [a_{ij}, b_{ij}] \\
c_2 & [a_{ij}, b_{ij}] \\
\vdots & \vdots \\
c_n & [a_{nj}, b_{nj}]
\end{bmatrix}, \tag{10}
\]

where \( U_j \) represents the evaluation level of the \( j \)-th objective and \( \{c_1, c_2, \ldots, c_n\} \) represents the characteristics of \( U_j \). \( \{v_{ij}, v_{ij}, \ldots, v_{nj}\} \) represents the value of \( U_j \), which is classical domain. \([a_{nj}, b_{nj}]\) represents the upper and lower bounds of \( \{v_{ij}, v_{ij}, \ldots, v_{nj}\} \), respectively.

\[
R_p = (U, C_i, V_{ij}) = \begin{bmatrix}
U & c_1 & V_{1u} \\
c_2 & V_{2u} \\
\vdots & \vdots \\
c_n & V_{mu}
\end{bmatrix} = \begin{bmatrix}
U & c_1 & [a_{1u}, b_{1u}] \\
c_2 & [a_{2u}, b_{2u}] \\
\vdots & \vdots \\
c_n & [a_{nu}, b_{nu}]
\end{bmatrix}, \tag{11}
\]

where \( U \) stands for all evaluation levels and \( \{v_{1u}, v_{2u}, \ldots, v_{mu}\} \) is the value range of \( U \).
corresponding to \( \{c_1, c_2, \ldots, c_n\} \), that is, the node domain.

Step 2. Set matter-element to be evaluated

\[
R_0 = (U_0, C_n, V_n) = \begin{bmatrix}
U_0 & c_1 & v_1 \\
& c_2 & v_2 \\
& \vdots & \vdots \\
& c_n & v_n \\
\end{bmatrix},
\]

where \( R_0 \) is the matter-element to be evaluated and \( \{v_1, v_2, \ldots, v_n\} \) is the measured data of \( U_0 \) corresponding to \( \{c_1, c_2, \ldots, c_n\} \).

Step 3. Set index weight.

The weight value of each evaluation index is determined based on the fuzzy best-worst method.

\[
W = (w_1, w_2, \ldots, w_n).
\]

The traditional matter-element extension method generally adopts the principle of full membership, but too much information may be lost in applying this method, resulting in its low effectiveness [29, 30]; therefore, it needs to be improved. In this paper, closeness replaces the principle of full membership [26, 31], as shown in Step 4.

Step 4: Establish the closeness function and calculate the closeness function value.

The distance between the matter-element to be evaluated and the normalized node can be expressed by

\[
D(\nu) = \sqrt{\frac{a_{ij}^{'} + b_{ij}^{'}}{2} - \frac{b_{ij}^{'}}{2}},
\]

where \( a \) and \( b \) represent the left and right endpoint values of the normalized section field, respectively.

The formula of asymmetric closeness can be expressed by

\[
N = 1 - \frac{1}{n(n + 1)} \sum_{i=1}^{n} Dw_i,
\]

where \( N \) represents closeness, \( D \) represents distance, and \( w_i \) represents the index weight.

The closeness between the matter-element to be evaluated and each evaluation grade can be obtained by combining (14) and (15).

\[
N_j(p_0) = 1 - \frac{1}{n(n + 1)} \sum_{i=1}^{n} D_j(v_i)w_i(X),
\]

where \( N_j(p_0) \) represents the closeness between the matter-element to be evaluated and each level, and \( D_j(v_i) \) represents the distance between the matter-element to be evaluated and the normalized section. \( w_i(X) \) represents the weight of each index. \( n \) is the number of evaluated index.

Step 5: Rating

If \( N_j(p_0) = \max\{N_j(p_0)\} \) and \( (j = 1, 2, 3, \ldots, m) \) are satisfied, it is said that \( R \) is closer to level \( j' \).

The logical framework and calculation flow of the credit evaluation model of NEPGE based on FBWM and the improved matter-element extension method are shown in Figure 1.

4. Case Analysis

In this section, the actual data of a new energy power producer is awarded for empirical analysis. Firstly, the weight of each index is determined by FBWM. Then, the improved matter-element extension method evaluates the credit index level. Finally, empirical analysis and sensitivity analysis are carried out to verify the applicability and superiority of the model.

4.1. Calculation of the Index Weights. Firstly, according to the selection of all experts, among the three primary indexes of performance ability (\( R_1 \)), performance behavior (\( R_2 \)), and performance willingness (\( R_3 \)), the best index is \( R_1 \), and the worst index is \( R_3 \). The comparison results between the two and other indexes are shown in Tables 4 and 5.

According to the comparison results between the best and worst indexes and each index, the fuzzy comparison vectors corresponding to the best and worst indexes are as follows:

\[
\bar{A}_B = \begin{bmatrix} \frac{7}{2}, \frac{9}{2} \\ \frac{4}{2}, \frac{2}{2} \end{bmatrix}, (1, 1, 1), \begin{bmatrix} \frac{3}{2}, \frac{5}{2} \end{bmatrix},
\bar{A}_W = \begin{bmatrix} 1, 1, 1, \frac{7}{2}, \frac{4}{2}, \frac{9}{2} \\ \frac{2}{2}, \frac{3}{2}, \frac{5}{2} \end{bmatrix}.
\]

The best fuzzy weight vectors of the three primary indexes are

\[
\bar{W}_{R1}^* = (0.1233, 0.1251, 0.1273), \quad \bar{W}_{R2}^* = (0.4733, 0.5449, 0.5948), \quad \bar{W}_{R3}^* = (0.2752, 0.3311, 0.4018),
\]

\[
\bar{C}_R = (0.3542, 0.3542, 0.3542).
\]

The best weight of each first-level index is

\[
W_{R1}^* = 0.1252; W_{R2}^* = 0.5377; W_{R3}^* = 0.3360.
\]

Give weight to the secondary indexes corresponding to the three primary indexes: performance ability index (\( R_1 \)), performance behavior index (\( R_2 \)), and performance willingness index (\( R_3 \)). Similarly, according to the questionnaire results of experts, the best and worst indexes of the evaluation indexes corresponding to the three indexes are obtained, as shown in Table 6.

Compare the importance of the evaluation indexes of the three primary indexes with the corresponding best and worst indexes, and the results are shown in Tables 7 and 8.

According to the comparison results in Tables 7 and 8, Tables 9 and 10 can be concluded.
We can calculate the second-level indexes’ weight graph as shown in Figure 2.

According to Figure 2, the weight of the scheduling discipline compliance ($C_{32}$) index is relatively the highest, followed by historical credit ($C_{15}$) and participation rate of the market-oriented transaction ($C_{21}$). Therefore, to improve their credit level, NEPGE must abide by dispatching discipline and enhance the participation rate of market-oriented transactions to survive in the power market for a long time.

### 4.2. Credit Risk Assessment of NEPGE

This document assumes that the credit level of NEPGE is divided into four groups: poor, generally poor, generally good, and good.

(i) The classic domain is set as follows:
Table 7: Comparison of importance between the best index and other indexes.

<table>
<thead>
<tr>
<th>The best index</th>
<th>C_{11}</th>
<th>C_{12}</th>
<th>C_{13}</th>
<th>C_{14}</th>
<th>C_{22}</th>
<th>C_{23}</th>
<th>C_{24}</th>
<th>C_{25}</th>
<th>C_{31}</th>
<th>C_{32}</th>
<th>C_{33}</th>
<th>C_{34}</th>
<th>C_{35}</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_{15}</td>
<td>FL</td>
<td>AI</td>
<td>WI</td>
<td>FL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>C_{21}</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>FL</td>
<td>WI</td>
<td>FL</td>
<td>AI</td>
<td>—</td>
<td>—</td>
<td>WI</td>
<td>AI</td>
<td>FL</td>
</tr>
<tr>
<td>C_{32}</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>WI</td>
<td>AI</td>
<td>FL</td>
</tr>
</tbody>
</table>

Table 8: Comparison of the importance of other indexes with the worst indexes.

<table>
<thead>
<tr>
<th>The worst index</th>
<th>C_{11}</th>
<th>C_{13}</th>
<th>C_{14}</th>
<th>C_{15}</th>
<th>C_{21}</th>
<th>C_{23}</th>
<th>C_{24}</th>
<th>C_{25}</th>
<th>C_{31}</th>
<th>C_{32}</th>
<th>C_{33}</th>
<th>C_{34}</th>
<th>C_{35}</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_{12}</td>
<td>WI</td>
<td>FL</td>
<td>FL</td>
<td>FL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>C_{25}</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>AI</td>
<td>WI</td>
<td>WI</td>
<td>FL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>C_{33}</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 9: The best and worst fuzzy comparison vectors corresponding to the five evaluation indexes corresponding to the primary-level index.

<table>
<thead>
<tr>
<th>Index</th>
<th>( \lambda_B )</th>
<th>( \lambda_W )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_1 )</td>
<td>[(3/2, 2, 5/2), (7/2, 4, 9/2), (2/3, 1, 3/2), (3/2, 2, 5/2), (1, 1, 1)]</td>
<td>[(2/3, 1, 3/2), (1, 1, 1), (3/2, 2, 5/2), (3/2, 2, 5/2), (7/2, 4, 9/2)]</td>
</tr>
<tr>
<td>( R_2 )</td>
<td>[(1, 1, 1), (3/2, 2, 5/2), (2/3, 1, 3/2), (3/2, 2, 5/2), (3/2, 2, 5/2), (7/2, 4, 9/2)]</td>
<td>[(2/3, 2, 5/2), (2/3, 1, 3/2), (2/3, 1, 3/2), (3/2, 2, 5/2), (1, 1, 1)]</td>
</tr>
<tr>
<td>( R_3 )</td>
<td>[(2/3, 1, 3/2), (7/2, 4, 9/2), (3/2, 2, 5/2), (5/2, 3, 7/2)]</td>
<td>[(3/2, 2, 5/2), (7/2, 4, 9/2), (1, 1, 1), (2/3, 1, 3/2), (5/2, 3, 7/2)]</td>
</tr>
</tbody>
</table>

Table 10: The best fuzzy weight vector of the five evaluation indexes corresponding to the primary index.

<table>
<thead>
<tr>
<th>Index</th>
<th>( R_1 )</th>
<th>( R_2 )</th>
<th>( R_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tilde{W}_1 )</td>
<td>(0.1230, 0.1409, 0.01750)</td>
<td>(0.3123, 0.3400, 0.3790)</td>
<td>(0.1833, 0.2176, 0.2502)</td>
</tr>
<tr>
<td>( \tilde{W}_2 )</td>
<td>(0.0919, 0.0966, 0.1061)</td>
<td>(0.1320, 0.1573, 0.1927)</td>
<td>(0.3589, 0.3839, 0.4030)</td>
</tr>
<tr>
<td>( \tilde{W}_3 )</td>
<td>(0.1230, 0.1409, 0.01750)</td>
<td>(0.1857, 0.2150, 0.2518)</td>
<td>(0.0771, 0.0799, 0.0866)</td>
</tr>
<tr>
<td>( \tilde{W}_4 )</td>
<td>(0.0919, 0.0966, 0.1061)</td>
<td>(0.1398, 0.1763, 0.2513)</td>
<td>(0.1343, 0.1406, 0.1701)</td>
</tr>
<tr>
<td>( \tilde{W}_5 )</td>
<td>(0.3190, 0.3424, 0.3682)</td>
<td>(0.0949, 0.0995, 0.1065)</td>
<td>(0.1481, 0.1751, 0.2099)</td>
</tr>
</tbody>
</table>

\[
R_1 = \begin{bmatrix}
P_1 \langle 3000, 4000 \rangle \\
C_2 \langle 200, 400 \rangle \\
C_3 \langle 75, 100 \rangle \\
C_4 \langle 0, 25 \rangle \\
C_5 \langle 0, 25 \rangle \\
C_6 \langle 0, 25 \rangle \\
C_7 \langle 0, 25 \rangle \\
C_8 \langle 0, 25 \rangle \\
C_9 \langle 75, 100 \rangle \\
C_{10} \langle 75, 100 \rangle \\
C_{11} \langle 0, 25 \rangle \\
C_{12} \langle 0, 25 \rangle \\
C_{13} \langle 0, 25 \rangle \\
C_{14} \langle 0, 25 \rangle \\
C_{15} \langle 75, 100 \rangle
dot \end{bmatrix}
\]

\[
R_2 = \begin{bmatrix}
P_2 \langle 4000, 5000 \rangle \\
C_2 \langle 400, 600 \rangle \\
C_3 \langle 50, 75 \rangle \\
C_4 \langle 25, 50 \rangle \\
C_5 \langle 25, 50 \rangle \\
C_6 \langle 25, 50 \rangle \\
C_7 \langle 25, 50 \rangle \\
C_8 \langle 25, 50 \rangle \\
C_9 \langle 50, 75 \rangle \\
C_{10} \langle 50, 75 \rangle \\
C_{11} \langle 25, 50 \rangle \\
C_{12} \langle 25, 50 \rangle \\
C_{13} \langle 25, 50 \rangle \\
C_{14} \langle 25, 50 \rangle \\
C_{15} \langle 50, 75 \rangle
dot \end{bmatrix}
\]

\[
R_3 = \begin{bmatrix}
P_3 \langle 5000, 6000 \rangle \\
C_2 \langle 600, 800 \rangle \\
C_3 \langle 25, 50 \rangle \\
C_4 \langle 50, 75 \rangle \\
C_5 \langle 50, 75 \rangle \\
C_6 \langle 50, 75 \rangle \\
C_7 \langle 50, 75 \rangle \\
C_8 \langle 50, 75 \rangle \\
C_9 \langle 25, 50 \rangle \\
C_{10} \langle 25, 50 \rangle \\
C_{11} \langle 50, 75 \rangle \\
C_{12} \langle 50, 75 \rangle \\
C_{13} \langle 50, 75 \rangle \\
C_{14} \langle 50, 75 \rangle \\
C_{15} \langle 50, 75 \rangle
dot \end{bmatrix}
\]

\[
R_4 = \begin{bmatrix}
P_4 \langle 6000, 7000 \rangle \\
C_2 \langle 800, 1000 \rangle \\
C_3 \langle 0, 25 \rangle \\
C_{10} \langle 75, 100 \rangle \\
C_{11} \langle 75, 100 \rangle \\
C_{12} \langle 75, 100 \rangle \\
C_{13} \langle 75, 100 \rangle \\
C_{14} \langle 75, 100 \rangle \\
C_{15} \langle 0, 25 \rangle
dot \end{bmatrix}
\]

(20)
(ii) The node domain $R_u$ and matter-element to be evaluated $R_i$ are determined by consulting relevant literature.

The closeness between the matter-element to be evaluated and each evaluation grade can be calculated according to Equation (22):

\begin{align*}
R_u &= \begin{bmatrix}
U_1 & C1 & \langle 0, 0.25 \rangle \\
C2 & \langle 0, 0.25 \rangle \\
C3 & \langle 0.25, 0.5 \rangle \\
C4 & \langle 0.25, 0.5 \rangle \\
C5 & \langle 0.25, 0.5 \rangle \\
C6 & \langle 0.25, 0.5 \rangle \\
C7 & \langle 0.25, 0.5 \rangle \\
C8 & \langle 0.25, 0.5 \rangle \\
C9 & \langle 0.25, 0.5 \rangle \\
C10 & \langle 0.25, 0.5 \rangle \\
C11 & \langle 0.25, 0.5 \rangle \\
C12 & \langle 0.25, 0.5 \rangle \\
C13 & \langle 0.25, 0.5 \rangle \\
C14 & \langle 0.25, 0.5 \rangle \\
C15 & \langle 0.25, 0.5 \rangle \\
\end{bmatrix} \\
R_i &= \begin{bmatrix}
U_2 & C1 & \langle 0.25, 0.5 \rangle \\
C2 & \langle 0.25, 0.5 \rangle \\
C3 & \langle 0.5, 0.75 \rangle \\
C4 & \langle 0.25, 0.5 \rangle \\
C5 & \langle 0.25, 0.5 \rangle \\
C6 & \langle 0.25, 0.5 \rangle \\
C7 & \langle 0.25, 0.5 \rangle \\
C8 & \langle 0.25, 0.5 \rangle \\
C9 & \langle 0.5, 0.75 \rangle \\
C10 & \langle 0.5, 0.75 \rangle \\
C11 & \langle 0.5, 0.75 \rangle \\
C12 & \langle 0.5, 0.75 \rangle \\
C13 & \langle 0.5, 0.75 \rangle \\
C14 & \langle 0.5, 0.75 \rangle \\
C15 & \langle 0.5, 0.75 \rangle \\
\end{bmatrix} \\
R_j &= \begin{bmatrix}
U_3 & C1 & \langle 0.5, 0.75 \rangle \\
C2 & \langle 0.5, 0.75 \rangle \\
C3 & \langle 0.25, 0.5 \rangle \\
C4 & \langle 0.5, 0.75 \rangle \\
C5 & \langle 0.5, 0.75 \rangle \\
C6 & \langle 0.5, 0.75 \rangle \\
C7 & \langle 0.5, 0.75 \rangle \\
C8 & \langle 0.5, 0.75 \rangle \\
C9 & \langle 0.25, 0.5 \rangle \\
C10 & \langle 0.25, 0.5 \rangle \\
C11 & \langle 0.5, 0.75 \rangle \\
C12 & \langle 0.5, 0.75 \rangle \\
C13 & \langle 0.5, 0.75 \rangle \\
C14 & \langle 0.5, 0.75 \rangle \\
C15 & \langle 0.25, 0.5 \rangle \\
\end{bmatrix} \\
R_k &= \begin{bmatrix}
U_4 & C1 & \langle 0.75, 1 \rangle \\
C2 & \langle 0.75, 1 \rangle \\
C3 & \langle 0.25, 0.5 \rangle \\
C4 & \langle 0.75, 1 \rangle \\
C5 & \langle 0.75, 1 \rangle \\
C6 & \langle 0.75, 1 \rangle \\
C7 & \langle 0.75, 1 \rangle \\
C8 & \langle 0.75, 1 \rangle \\
C9 & \langle 0.25, 0.25 \rangle \\
C10 & \langle 0.25, 0.25 \rangle \\
C11 & \langle 0.75, 1 \rangle \\
C12 & \langle 0.75, 1 \rangle \\
C13 & \langle 0.75, 1 \rangle \\
C14 & \langle 0.75, 1 \rangle \\
C15 & \langle 0.25, 0.25 \rangle \\
\end{bmatrix} \\
R_0 &= \begin{bmatrix}
U_0 & 6000 \\
C2 & \langle 200, 1000 \rangle \\
C3 & \langle 0, 100 \rangle \\
C4 & \langle 0, 100 \rangle \\
C5 & \langle 0, 100 \rangle \\
C6 & \langle 0, 100 \rangle \\
C7 & \langle 0, 100 \rangle \\
C8 & \langle 0, 0.25 \rangle \\
C9 & \langle 0, 100 \rangle \\
C10 & \langle 0, 100 \rangle \\
C11 & \langle 0, 100 \rangle \\
C12 & \langle 0, 100 \rangle \\
C13 & \langle 0, 100 \rangle \\
C14 & \langle 0, 100 \rangle \\
C15 & \langle 0, 100 \rangle \\
\end{bmatrix} \\
\end{align*}

Normalization processing

Calculate closeness.

According to (14), the closeness between the matter-element to be evaluated and each evaluation grade can be calculated:

\begin{align*}
N_1(u_0) &= 1 - \frac{1}{15 \ast (15 + 1)} \sum_{i=1}^{15} D_j(v_i)w_i, \\
N_2(u_0) &= 1 - \frac{1}{15 \ast (15 + 1)} \sum_{i=1}^{15} D_j(v_i)w_i,
\end{align*}

where $N_1(u_0)$, $N_2(u_0)$, $N_3(u_0)$, $N_4(u_0)$, respectively, represent the closeness between the credit indexes of NEPGE and the four grades (poor, generally poor, generally good, and good).

According to the calculation results of closeness, it can be seen that the value of 0.9987 is the largest, which also
means that the credit of the new energy power producer is at the “generally good” level.

4.3. Discussion

4.3.1. Comparative Analysis. In this section, to verify the rationality and superiority of the proposed method, the evaluation results of the proposed model are compared with those based on the traditional BWM method. The weight of each index under the traditional BWM weighting method is shown in Figure 3.

It can be seen from Figures 3 and 2 that the weight gap between indexes becomes larger without considering the group decision-making environment (the maximum weight of indexes in the BWM method is 0.0786, the minimum weight is 0.5318, the maximum weight of indexes in the FBWM method is 0.3438, and the minimum weight is 0.0806). However, the weight ranking of each index remains unchanged, and the importance of each index under the two methods has not changed, which confirms the rationality of the FBWM method proposed in this paper.

According to the weighting results of BWM, the new energy generator is evaluated. The closeness between the matter-element to be assessed and each level is as follows:

\[
BN_1(u_0) = 1 - \frac{1}{15*(15+1)} \sum_{i=1}^{15} D_i(v)w_i,
\]

\[
BN_2(u_0) = 1 - \frac{1}{15*(15+1)} \sum_{i=1}^{15} D_j(v)w_i,
\]

\[
BN_3(u_0) = 1 - \frac{1}{15*(15+1)} \sum_{i=1}^{15} D_j(v)w_i,
\]

\[
BN_4(u_0) = 1 - \frac{1}{15*(15+1)} \sum_{i=1}^{15} D_j(v)w_i,
\]

where \(BN_1(u_0), BN_2(u_0), BN_3(u_0), BN_4(u_0)\), respectively, represents the closeness between the credit of NEPGE and the four grades (poor, generally poor, generally good, and good) after calculating the weight based on BWM. It can be seen that under the original BWM method, each expert weights independently, and the total weight obtained is the average arithmetic result of each weight, which expands the heterogeneity between indexes. In this case, the credit rating of NEPGE is “generally good.”

4.3.2. Sensitive Analysis. To judge the impact of index changes on the project’s overall benefits, a sensitivity analysis of each index is needed. The sensitivity analysis is performed on the three most weighted indexes as examples, and the results are shown in Table 11.

In this paper, the first three indexes with the most significant weight, namely, “historical credit (C15),” “participation rate of the market-oriented transaction (C21),” and “scheduling discipline compliance (C32),” are selected to analyze the sensitivity of generator credit rating.

As can be seen from Table 10, when the “participation rate of market-oriented transaction (C21)” changes, the credit rating of NEPGE also changes. With the decline of indexes, the proximity between credit rating and “generally poor” rating has increased. When the “historical credit (C15)” decreases by 10%, the credit rating of NEPGE becomes “generally poor.” Therefore, NEPGE should pay more attention to its historical credit and not violate the relevant requirements in the power market. When the “participation rate of the market-oriented transaction (C21)” and “scheduling discipline compliance (C32)” are reduced to 20%, respectively, the credit rating of NEPGE becomes “generally poor.” When they float at \(-10\% \sim 20\%\), NEPGE’s credit rating is “generally good.” It is worth noting that with the continuous improvement of indexes, the proximity between “generally good” and “good” is also increasing.

After calculation, under the condition of keeping other indexes unchanged, when the “scheduling discipline compliance (C32)” reaches the maximum (the matter-element to be evaluated changes from 0.8 to 1), the credit of NEPGE still does not get “good” Therefore, to improve their credit level, in the power market, new energy power producers should not only enhance the compliance of dispatching discipline in the process of project operation but also comprehensively consider the impact of multi-dimensional factors.
5. Conclusions

The carbon peaking and carbon neutrality goal proposal means that the proportion of NEPGE in the main body of power generation in the electricity market will become larger and larger. Based on the complex power market as the background, this paper proposes 15 credit indexes from three dimensions. A comprehensive credit evaluation model for new energy generators is constructed based on fuzzy optimal worst theory and an improved matter-element extension model.

This paper uses the model to evaluate the credit of an actual NEPGE comprehensively, and the results show that its credit rating is relatively good. Among the evaluation indexes proposed in this paper, the compliance with dispatching discipline, historical credit status, and market-based transaction participation indexes such as rate are considered by most experts to be more critical. Therefore, NEPGE should focus on the above indexes when participating in the power market. At the same time, in the power market, this paper suggests that new energy power generation companies should improve their credit level to improve the compliance of dispatching discipline in the transaction process and comprehensively consider the impact of other multi-dimensional factors.

The model in this paper can effectively avoid the ambiguity of experts in the decision-making process. At the same time, this paper will further consider other relevant indexes for evaluation in subsequent research. The evaluation model and index system proposed in this paper can also be applied to other market members and have far-reaching significance for the steady construction of the electricity market.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent

Not applicable.

Conflicts of Interest

The authors declare that they have no competing interests.

Authors’ Contributions

Huiru Zhao guided the research; Bingkangli established the model and implemented the simulation; Yuan Wang wrote this article; Chenhui Li, Liang Guo, Yan Kou, and Wei Liu checked the language.

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References


