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Research Article

Selection Ideal Coal Suppliers of Thermal Power Plants Using the Matter-Element Extension Model with Integrated Empowerment Method for Sustainability

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In order to reduce thermal power generation cost and improve its market competitiveness, considering fuel quality, cost, creditworthiness, and sustainable development capacity factors, this paper established the evaluation system for coal supplier selection of thermal power and put forward the coal supplier selection strategies for thermal power based on integrated empowering and ideal matter-element extension models. On the one hand, the integrated empowering model can overcome the limitations of subjective and objective methods to determine weights, better balance subjective, and objective information. On the other hand, since the evaluation results of the traditional element extension model may fall into the same class and only get part of the order results, in order to overcome this shortcoming, the idealistic matter-element extension model is constructed. It selects the ideal positive and negative matter-elements classical field and uses the closeness degree to replace traditional maximum degree of membership criterion and calculates the positive or negative distance between the matter-element to be evaluated and the ideal matter-element; then it can get the full order results of the evaluation schemes. Simulated and compared with the TOPSIS method, Romania selection method, and PROMETHEE method, numerical example results show that the method put forward by this paper is effective and reliable.

1. Introduction

The rapid development of China's economy promotes dramatic increase in social electricity consumption. As the major power generation type, thermal power installed capacity is increasing fast. By the end of 2013, full-bore capacity of thermal power units has reached 1.25 billion kilowatts, and total generating capacity reached 5.25 trillion kWh. However, subject to the China's tariff mechanism, thermal power tariff and coal prices do not realize linkage. On the one hand, thermal power grid tariff implements the benchmark price; on the other hand, the coal market is free competitive market model. This leads to generation efficiency of thermal power generation companies with greater uncertainty and causes China's five major power generation groups collective loss in recent years.

When benchmark price is implemented, thermal power generated revenue is up to grid-connection capacity. But the current scheduling mode of China's electricity market is still plan scheduling; the generated income of thermal power plants is relatively stable: this means the generated profit depends on generation costs. Due to thermal power costs mainly consisting of fixed costs and variable costs, fixed costs of thermal power plants are generally constant in operation period, but variable costs mainly consist of generation fuel-related costs and environmental costs [1]. Fuel costs are the major affecting factor, generally accounting for more than 75% of total variable costs [2]. In order to reduce power generation variation costs of generation companies and ensure stable power generation earnings in the next period of time, generation companies need to evaluate coal-fired supplier from fuel quality, fuel costs, reputation, long-term development capacity, and other factors, choose the best coal-fired supplier, sign long-term cooperation agreement, and maintain the stability of the fuel cost. Therefore, choosing reasonable coal suppliers for thermal power generation companies has great significance on reducing revenue uncertainty, improving market competitiveness, and achieving sustainable development.

The appropriate evaluation method is needed for evaluating coal suppliers. The process of comprehensive evaluation generally concludes indicator system construct, weight calculation, and scheme evaluation. Different weight calculation methods and evaluation methods will directly affect the evaluation results. In terms of indicator system construct, literature [3, 4] evaluated coal-fired supplier of thermal power companies using seven evaluation indicators. Literature [5, 6] optimized the overall indicator system but did not analyze the mutual influence relationship of various indicators. In order to analyze the mutual influence relationship, analytic hierarchy process (AHP), data envelopment analysis (DEA), and analytic network process (ANP) can be introduced. However, AHP and DEA methods have full compensatory characteristics; namely, high evaluation value under certain criteria can compensate for the low evaluation values under other criteria [7]. Therefore, ANP method should be introduced to solve the dependence and feedback relationship of various indicators [8].

In terms of weight calculation method, it is mainly divided into subjective weighting method and objective weighting method [9]. The subjective weighting methods rely on expert knowledge and experience in the judgment of subjective importance degree of each indicator [10]. The main methods have the eigenvalue method [11], sequence relations method [12], preference-based weighting method [13], and so forth. The objective weighting method determines indicators weight by using more complete mathematical theory and methods based on the original data [14], such as the entropy method and the rough set method [15]. The subjective weighting method reflects the evaluator's subjective judgment and intuition, but the result may have some subjective and arbitrary characteristics; the objective weighting methods avoid the subjectivity of evaluation results but ignore the necessary subjective information for security evaluation [16]. In order to utilize advantages and overcome disadvantages of the objective and subjective weighting methods, integrated empowerment theory is introduced to calculate the indicator weight coefficients under the target of minimum deviation between the objective and subjective weighting methods. In terms of the evaluation method, comprehensive evaluation method can be divided into classical evaluation methods and intelligent evaluation method. Classical evaluation methods mainly conclude elimination et choice translating reality (ELECTRE) method, the ideal point method, preference ranking organization methods for enrichment evaluations (PROMETHEE) method [17–19], and so forth. Intelligent evaluation methods mainly conclude the neural networks method, the support vector machines method [20], and so forth. The development of computer information technology promotes the intelligent evaluation method to be a widely used method [21]. However, information omission and indicators unreasonable standardization will lead to the evaluation results being incompatible and its credibility not being high [22]. In order to solve this problem, matter-element analysis theory is proposed and applied to the comprehensive evaluation of various industries. The evaluation results have some representation [23]. But the literature [24] found that traditional element extension may show some problems: (1) matter-element beyond the section field and (2) irrational expression of pixel pitch range distance. To solve this problem, the basic idea of the technique for order preference by similar to ideal solution (TOPSIS) method is introduced, and the existing sample data are used to select the best indicators for constructing ideal matter-element; calculate the gap between ideals matter-element and matter-element to be evaluated, and the matter-element with the least gap is the best.

Based on the above analysis, the ANP method and the entropy method were applied to get the subjective and objective weights of coal supplier evaluation indicators. Then, integration weighting model was put forward considering both subjective and objective factors. By choosing the positive and negative ideal matter-elements and substituting the maximum membership degree rule with the close degree, ideal matter-element extension model was constructed for coal suppliers' evaluation. The rest of the paper is organized as follows. Section 2 constructed coal suppliers' evaluation indicator system with four first class indicators and 15 second level indicators from the four aspects of fuel quality, cost factors, credibility, and sustainable development ability; the integration weighting model based on the ANP method and the entropy method is also constructed. Section 3 briefly introduced the traditional matter-element extension model; Section 4 analyzed the shortcomings of traditional matter-element extension model and constructed the ideal matter-element extension model by introducing the basic idea of TOPSIS method; and the empirical case study is conducted in Section 5. Finally, the conclusions are presented in Section 6.

2. Coal Supplier Evaluation Indicator Systems and Weight Calculation

2.1. Construction of Evaluation Indicator System. In this section, this paper constructed evaluation system for thermal power coal suppliers from four aspects of fuel quality, cost factors, credibility, and sustainability according to the actual situation of power generation companies. The indicator system concludes 4 primary indicators and 15 secondary indicators, as shown in Table 1.

2.2. Calculation of Integrated Weights

2.2.1. Calculation of Substantial Weights Based on ANP Method. The analytic network progress (ANP) is proposed by Professor Thomas L. Saaty at the University of Pittsburgh in 1996 as a decision method to adapt to nonindependent hierarchical structures [25]. Typical ANP hierarchy is composed of control layer and network layer. Control layer is composed of issues and decision criteria; network layer consists of all elements controlled by the control layer, elements of mutual influence, and mutual domination. The basic principal is that the weights of each principal are obtained by AHP method; the weights of elements in network layer are determined by the super matrix. Detailed steps are as follows.

Table 1: Coal supplier evaluation indicator system.

Primary indicator	Secondary indicator	Influence indicator
Fuel quality C_1	Caloric value C_{11}	C_{21}, C_{41}
	Volatile component C_{12}	C_{11}, C_{21}, C_{41}
	Moisture C_{13}	C_{11}, C_{21}, C_{41}
	Ash C_{14}	C_{11}, C_{21}, C_{41}
	Sulphur C_{15}	C_{21}, C_{41}
Costs C_2	Unit price of standard coal C_{21}	C_{41}
	Cost of transportation C_{22}	C_{21}, C_{41}
	Convenience of transportation C_{23}	C_{21}, C_{22}, C_{41}
	Cost of mining C_{24}	C_{21}, C_{41}
Credibility C_3	Contract execution C_{31}	C_{41}
	Deficit tons C_{32}	C_{41}
Sustainability C_4	Economic benefits C_{41}	C_{31}, C_{42}, C_{44}
	Economic scale C_{42}	C_{41}, C_{43}
	Minable capacity C_{43}	C_{41}
	Labour productivity C_{44}	C_{24}, C_{41}, C_{42}

(1) Systematic analysis and combination of decision-making problems form elements and element sets. Determine whether the existence of independence or dependent-feedback relationship between elements.

(2) Construct ANP structure. Determine the control layer and analyze the mutual influence among all system elements. Determine the mutual relationship between principles and elements.

(3) Construct ANP super matrix. Note there are elements $P_1, \ldots, P_n$ in the control layer. Under the control layer, network layer is composed of element sets $C_1, \ldots, C_n$, wherein C_i contains elements $e_{i1}, \ldots, e_{in}$, $i = 1, \ldots, N$; use control layer P_s $(s = 1, \ldots, m)$ as a principal, and use element e_{j1} in C_j as a principal. Indirectly advantage is compared by the influence of elements on e_{j1} in C_i; namely, construct judgment matrix. ANP model uses nine points system to represent strengths. Order vector can be obtained from the characteristic roots method. If order vector satisfies the consistency test, then the eigenvectors will be the ordered vector for network elements. The following matrix can be constructed by combining all the order vectors of network elements:

$$W_{ij} = \begin{bmatrix} w_{i1}^{j1} & w_{i1}^{j2} & \cdots & w_{i1}^{jn_j} \\ w_{i2}^{j1} & w_{i2}^{j2} & \cdots & w_{i2}^{jn_j} \\ \vdots & \vdots & \vdots & \vdots \\ w_{in_j}^{j1} & w_{in_j}^{j2} & \cdots & w_{in_j}^{jn_j} \end{bmatrix}, \qquad (1)$$

where W_{ij} represents the significance order vector of C_i to C_j. Combining the order vectors of mutual influence of all the network layer elements, a super matrix can be acquired under the control layer elements:

$$W = \begin{array}{c} 1 \\ \vdots \\ n_1 \\ 1 \\ \vdots \\ n_2 \\ \vdots \\ 1 \\ \vdots \\ n_N \end{array} \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ & & & \\ W_{21} & W_{22} & \cdots & W_{2N} \\ & & & \\ & & & \\ W_{N1} & W_{N2} & & W_{N3} \end{bmatrix}. \qquad (2)$$

Each element of the matrix is a matrix and the sum of them is 1, but it is not normalized matrix; therefore, normalize the supermatrix into weighted supermatrix $\overline{W} = (\overline{W})_{n\times n}$, where $\overline{W} = a_{ij}W_{ij}$ and a_{ij} is the weighting factor, $i, j = 1, 2, \ldots, n$.

(4) Calculate the super matrix.

To reflect the dependencies between the elements, we need to perform the stable process of the supermatrix, a measure of the limitation of relative ranking vector of each supermatrix:

$$\lim_{k\to\infty}\left(\frac{1}{N}\right)\sum_{k=1}^{N}\overline{W}^{k}. \qquad (3)$$

If the limitation is convergent and unique, the values of corresponding rows in element matrix are stable weight of evaluation indicators.

This paper uses target layer and factor layer of evaluation indicators as control layers and indicator layer as network

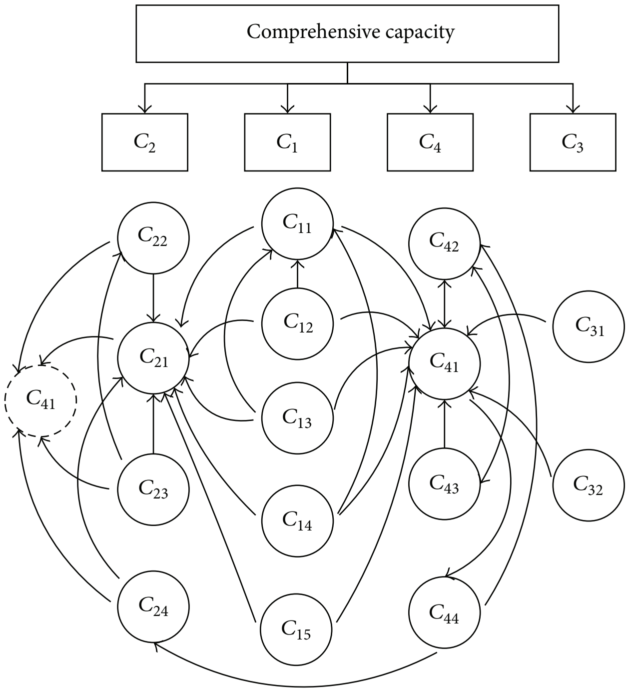

Figure 1: ANP model of the coal suppliers' selection.

layer and, considering the mutual influence of indicators in Table 1, constructs a hierarchical network coal supplier selection model, as in Figure 1.

2.2.2. Objective Weight Calculation Based on Entropy Method. Entropy was originally a thermodynamic concept; Shannon proposed the concept of information entropy in 1948 and applied it to all areas of society. Entropy method is an objective weighting method calculating the entropy of each indicator using information entropy primarily based on the degree of variability and then revises the weight of each indicator through the entropy into more objective weight of indicators.

Assuming coal supplier of power companies participating in comprehensive evaluation is $a = \{a_1, a_2, \ldots, a_n\}$, the comprehensive evaluation criteria of coal supplier is $u = \{u_1, u_2, \ldots, u_n\}$. Attribute value of coal supplier a_i $(i = 1, 2, \ldots, m)$ under the indicator u_j $(j = 1, 2, \ldots, n)$ is a_{ij}, and the decision matrix is $A = (a_{ij})_{m\times n}$; note that $M = (1, 2, \ldots, m)$ and $N = (1, 2, \ldots, n)$. The type of indicator is usually profit type and cost type, due to various dimensions of attributes; perform the dimensionless processing before decision-making.

For efficiency attributes

$$r_{ij} = \frac{a_{ij} - \min_i a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}. \tag{4}$$

For cost attributes

$$r_{ij} = \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}. \tag{5}$$

The dimensionless matrix $R = (r_{ij})_{m\times n}$ is normalized decision matrix.

(1) Calculate the entropy E_j of the attribute j:

$$E_j = -k \sum_{i=1}^{n} r_{ij} \ln\left(r_{ij}\right), \quad j = 1, 2, \ldots, m, \tag{6}$$

where $j = 1, 2, \ldots, m$ and $k = 1/\ln(n)$ are the constants related to the number of samples, in order to satisfy the condition $E_j \in [0, 1]$, $0 < r_{ij} < 1$, $\sum_{i=1}^{n} r_{ij} = 1$, when $r_{ij} = 0$, $r_{ij}\ln(r_{ij}) = 0$.

(2) Calculate the deviation:

$$d_j = 1 - E_j. \tag{7}$$

(3) Calculate the weights of indicators:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} = \frac{1 - E_j}{m - \sum_{j=1}^{m} E_j}, \quad \left(j = 1, 2, \ldots, m\right). \tag{8}$$

2.2.3. Optimal Combination Weight Based on Integrated Weight Methods. In order to overcome the lack of subjective and objective weighting methods, making the indicator balance both objective and subjective factors, aiming at minimizing the deviation of subjective and objective weights, comprehensive integrated weighting method is constructed to determine the weights of indicators.

Assuming coal supplier's subjective weighting vector by ANP method is $w' = (w_1', w_2', \ldots, w_n')^T$, $w_j' \in [0, 1]$, and $\sum_{j=1}^{n} w_j' = 1$ objective weighting vector by entropy method is $w'' = (w_1'', w_2'', \ldots, w_n'')^T$, $w_j'' \in [0, 1]$, and $\sum_{j=1}^{n} w_j'' = 1$. The final weighted vector of subjective and objective vectors is as follows:

$$w = \alpha w' + \beta w'', \tag{9}$$

where $\alpha, \beta > 0$ and $\alpha + \beta = 1$.

In order to fully reflect the subjective and objective information, this paper established an optimizing model for parameters α, β in the combined weights considering the convenience of weighted attributes, determined by subjective and objective weights.

According to formula (10), under the attribute u_j, the subjective weighted attribute of a_i is $r_{ij}\alpha w_j$, objective weighted attribute is $r_{ij}\beta w_j'$, and the deviation is $r_{ij}\alpha w_j - r_{ij}\beta w_j'$. Therefore, define the deviation of subjective and objective decision of plan a_i as

$$d_i = r_{ij}\alpha_j w_j - r_{ij}\beta_j w_j'. \tag{10}$$

Apparently, the smaller the a_i, the convergent the subjective and objective decision information. Therefore, optimizing model is constructed as follows:

$$\min D = \left(d_1, d_2, \ldots, d_m\right). \tag{11}$$

Apparently, this is a mutliobjective decision plan issue. Due to fair competition, there is no preference among various plans; therefore, the model above can be transferred to equivalent single-objective model as below.

Multiobjective decision planning issues:

$$\begin{aligned} \min \quad & Z=\sum_{i=1}^{m} d_i=\sum_{i=1}^{m}\sum_{j}^{n}\left(r_{ij}\alpha_j w_j - r_{ij}\beta_j w_j'\right) \\ \text{s.t.} \quad & \alpha_j+\beta_j=1 \quad \left(\alpha_j,\beta_j \geq 0\right). \end{aligned} \tag{12}$$

3. Thermal Coal Supplier Evaluation Model Based on Matter-Element Extension Model

The essence of matter-element method: first classify the objective of evaluation scheme into classes according to existed data. Data ranges of classes are defined by database and experts. Then feed the indicators into the classes set to perform multiobjective evaluation and compare the evaluation results with the correlation degree; the greater the correlation, the greater the convergence with the set of classes.

3.1. Matter-Element. Assuming matter N has a characteristic c with value v, the ordered triple $R = (N, c, v)$ as basic describing elements, matter-element for short.

Assuming matter N has multiple characteristics, described as n characteristics $c_1, c_2, \ldots, c_n$ and vectors v_1, $v_2, \ldots, v_n$, define matter-element R as N-dimensional matter-element, and note that

$$R=(N,C,V)=\begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix}=\begin{bmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix}, \tag{13}$$

where $R_i = (N_i, C_i, V_i)$, $i = 1, 2, \ldots, n$ is submatter-element of R, and $C = [c_1, c_2, \ldots, c_n]$ is characteristic vector with the value of $V = [v_1, v_2, \ldots, v_n]$.

3.2. Evaluation Procedure

(1) Determine the Classical Domain, Joint Domain and Matter-Element of Evaluated Objective. Consider

$$R_j=\left(N_j,C_i,V_{ji}\right)=\begin{bmatrix} N_j & c_1 & v_{j1} \\ & c_2 & v_{j2} \\ & \vdots & \vdots \\ & c_n & v_{jn} \end{bmatrix}, \tag{14}$$

where N_j is the jth level, $c_1, c_2, \ldots, c_n$ are n distinct characteristics, and $v_{j1}, v_{j2}, \ldots, v_{jn}$ is the value range of N_j about $c_1, c_2, \ldots, c_n$, called classical domain. Consider

$$R_p=\left(p,C_i,V_{pi}\right)=\begin{bmatrix} p & c_1 & \left\langle a_{p1},b_{p1}\right\rangle \\ & c_2 & \left\langle a_{p2},b_{p2}\right\rangle \\ & \vdots & \vdots \\ & c_n & \left\langle a_{pn},b_{pn}\right\rangle \end{bmatrix}, \tag{15}$$

where represents the whole levels set of evaluated objective and $v_{p1}, v_{p2}, \ldots, v_{pn}$ are value range of p about $c_1, c_2, \ldots, c_n$, called joint domain of p. Consider

$$R_0=\begin{bmatrix} p_0 & c_1 & v_1 \\ & c_2 & v_2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix}, \tag{16}$$

where p_0 is evaluated matter-element and $c_1, c_2, \ldots, c_n$ are specified data of about p_0.

(2) Normalizing Process. When the evaluation indicator exceeds the joint domain, there is a situation that the function of relevancy degree cannot be calculated; therefore, the evaluation of power generation cannot be performed by matter-element extension method. To overcome the shortcomings, this sector normalizes each classical domain and matter-element value based on original matter-element method and, dividing them with the right endpoint value b_{pi} of joint domain V_p, the results are the new classical domain and matter-element; calculation is shown as below:

$$\begin{gathered} R_j'=\left(N_j,C_i,V_{ji}'\right)=\begin{bmatrix} N_j & c_1 & \left\langle \dfrac{a_{j1}}{b_{p1}},\dfrac{b_{j1}}{b_{p1}}\right\rangle \\ & c_2 & \left\langle \dfrac{a_{j2}}{b_{p2}},\dfrac{b_{j2}}{b_{p2}}\right\rangle \\ & \vdots & \vdots \\ & c_n & \left\langle \dfrac{a_{jn}}{b_{pn}},\dfrac{b_{jn}}{b_{pn}}\right\rangle \end{bmatrix} \\ R_0'=\begin{bmatrix} p_0 & c_1 & \dfrac{v_1}{b_{p1}} \\ & c_2 & \dfrac{v_2}{b_{p2}} \\ & \vdots & \vdots \\ & c_n & \dfrac{v_n}{b_{pn}} \end{bmatrix}. \end{gathered} \tag{17}$$

(3) Calculation of Relevancy Degree. Consider

$$D\left(v,V_{ji}'\right)=\left|v-\frac{a+b}{2}\right|-\frac{b-a}{2}, \tag{18}$$

where v is the point value and a and b are the left and end endpoint values; therefore, the relevancy is

$$K_j\left(p_0\right)=1-\sum_{i=1}^{n} w_i D_{ij}. \tag{19}$$

If $K_j(p_0) = \max\{K_j(p_0)\}$ $(j = 1, 2, \ldots, m)$, then matter-element p_0 is in level j.

4. Ideal Matter-Element Extension Model

4.1. Ideal Matter-Element. The results reliability of the traditional matter-element evaluation is determined by the rationality of classical domain and joint domain. When the range of classical domain is inappropriate, all objectives may fall into the same scale, only partial order of evaluation can be acquired. To overcome this problem, the paper refers to the basic thought of the TOPSIS method to improve the traditional matter-element model. By setting the classical domain of positive and negative ideal matter-elements, using closeness degree to replace maximum degree of membership to measure the distance among evaluated and positive and negative ideal matter-elements, this paper constructed an ideal matter-element model. Generally, positive and negative matter-elements can be selected by experts; otherwise, the best and worst evaluation indicators can be selected as positive and negative matter-elements.

This paper draws on the method proposed in literature [21] to construct the positive and negative ideal matters: if indicator c_i is a positive indicator, then $v_{ji}^{+} = \max(v_i)$; if indicator c_i is a negative indicator, then $v_{ji}^{+} = \min(v_i)$; if indicator c_i is a fit indicator (the deviation is minimized), then $v_{ji}^{+} = \sigma(v_i)$; and if c_i is an interval indicator (best), then v_{ji}^{+} take the interval value, $v_{ji}^{+} = [u_{1i}, u_{2i}]$. Positive ideals matter R^{+} can be acquired; similarly, negative ideal matter R^{-} can be acquired.

4.2. Closeness Degree. Closeness degree is the measurement of convergence between evaluated samples and standard samples; the greater value means the greater degree of convergence and vice versa. Therefore pros and cons of evaluated indicators can be determined directly by the closeness degree, so as to classify positive and negative ideal matter-elements and calculate the grades of locations. In this section asymmetric closeness proposed in literature [26] is used as closeness function to calculate the value of closeness, summarized as below:

$$N = 1 - \frac{1}{n(n+1)} \sum_{i=1}^{n} D w_i, \tag{20}$$

where N represents degree of closeness; D represents distance; and w_i represents weight.

The closeness degree of valuated matter-element among all levels is

$$N_j(p_0) = 1 - \frac{1}{n(n+1)} \sum_{i=1}^{n} D_j(v_i') w_i(X), \tag{21}$$

where $D_j(v_i')$ is the closeness degree between the evaluated matter-element R_0 and normalized ideal matter-element; the specified calculation is as below:

$$\begin{aligned} D_j^{+}(v_i') &= \left| v_i' - v_{ji}^{+} \right|, \\ D_j^{-}(v_i') &= \left| v_i' - v_{ji}^{-} \right|. \end{aligned} \tag{22}$$

The closeness degree of evaluated matter-element and the ideal matter-elements is as follows:

$$\begin{aligned} N_j^{+}(p_0) &= 1 - \frac{1}{n(n+1)} \sum_{i=1}^{n} \left| v_i' - v_{ji}^{+} \right| w_i(X), \\ N_j^{-}(p_0) &= 1 - \frac{1}{n(n+1)} \sum_{i=1}^{n} \left| v_i' - v_{ji}^{-} \right| w_i(X). \end{aligned} \tag{23}$$

The comprehensive closeness degree is

$$\overline{N}_j(p_0) = \frac{N_j^{+}(p_0)}{N_j^{+}(p_0) + N_j^{-}(p_0)}. \tag{24}$$

5. Examples Analysis

5.1. Basic Data. Use the selection of coal supplier of one power plant as an example, there are 6 coal suppliers, and the evaluation indicators of each plan are shown in Table 2.

5.2. Calculate the Weights. Process the data into normalized and dimensionless data with formula (5) and formula (6), then input the standardized evaluation indicators into expert decision matrix, and get ANP partial weights, supermatrix weights, and weights of indicators. Solve the integrated weighting model with Gams software, and the α and β values with the minimized deviation are $[1, 1, 0.756, 0.78, 0.852, 1, 1, 0.803, 0.872, 1, 0.761, 1, 0.533, 0.871, 0.512]^{T}$ and $[0, 0, 0.244, 0.22, 0.148, 0, 0, 0.197, 0.128, 0, 0.239, 0, 0.467, 0.129, 0.488]^{T}$. Weight the subjective and objective weights and normalize the weights of indicators; the results are integrated weighted weights of indicators. Calculate the weights of indicators with ANP method, entropy method, and integrated weighting method, as shown in Table 3.

As shown in Table 3, there is a considerable difference between the results of subjective and objective weighting methods. However, the indicator difference of integrated weighting method is less; therefore it gives consideration to both subjective and objective information, achieve the goal of minimizing the difference between the subjective and objective weights.

5.3. Evaluation Results. In order to perform comparative analysis, this paper chooses TOPSIS method [26], PROMETHEE method [27], and ROMANIA method [28] to evaluate fired suppliers. The applicability of the evaluation methods is evaluated by the value of compatibility degree and differences degree, and the method with the highest compatibility degree and lowest differences degree is the best method.

5.3.1. Evaluation Results Based on the Matter-Element Extension Model. Thermal coal suppliers are classified by merits: excellent, good, average, pass, and fail. The classical domains of indicators of evaluation systems are determined by experts. Value range of standardized data is $[0, 1]$, and specific classical domains are shown in (25).

Table 2: The indicator data results of coal supplier.

Plan	C_{11}/(kJ/t)	C_{12}/%	C_{13}/%	C_{14}/%	C_{15}/%	C_{21}/(yuan/t)	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}/%	C_{41}	C_{42}	C_{43}/year	C_{44}
S_1	23.647	10.99	7.68	24.19	1.73	542.17	10	10	10	9	0.79	8.8	8.6	120	10
S_2	24.197	14.81	8.57	22.95	0.42	532.27	9	9	10	8.4	0.19	9	8.8	130	10
S_3	23.962	8.78	9.29	21.78	0.97	488.62	9.5	9.5	10	8.5	0.71	8.5	9	120	10
S_4	21.543	6.12	6.53	27.29	0.37	461.97	8	7.8	9	8	0.71	8	7.8	100	9
S_5	21.635	8.7	9.02	27.77	0.73	458.65	7.5	7.6	9	8.8	0.93	8.3	7.6	90	9
S_6	21.215	16.54	9.28	28.41	1.78	476.01	8.5	8.5	8	7	0.28	7.5	8	80	8

Classical domain and joint domain:

$$R_1 = \begin{bmatrix} N_1 & c_{11} & (0.6, 1) \\ & c_{12} & (0.8, 1) \\ & c_{13} & (0.8, 1) \\ & c_{14} & (0.7, 1) \\ & c_{15} & (0.8, 1) \\ & c_{21} & (0.5, 1) \\ & c_{22} & (0.7, 1) \\ & c_{23} & (0.8, 1) \\ & c_{24} & (0.7, 1) \\ & c_{31} & (0.8, 1) \\ & c_{32} & (0.8, 1) \\ & c_{41} & (0.7, 1) \\ & c_{42} & (0.5, 1) \\ & c_{43} & (0.6, 1) \\ & c_{44} & (0.8, 1) \end{bmatrix}, \qquad R_2 = \begin{bmatrix} N_2 & c_{11} & (0.4, 0.6) \\ & c_{12} & (0.6, 0.8) \\ & c_{13} & (0.5, 0.8) \\ & c_{14} & (0.5, 0.7) \\ & c_{15} & (0.6, 0.8) \\ & c_{21} & (0.4, 0.5) \\ & c_{22} & (0.5, 0.7) \\ & c_{23} & (0.5, 0.8) \\ & c_{24} & (0.5, 0.7) \\ & c_{31} & (0.6, 0.8) \\ & c_{32} & (0.6, 0.8) \\ & c_{41} & (0.5, 0.7) \\ & c_{42} & (0.4, 0.5) \\ & c_{43} & (0.4, 0.6) \\ & c_{44} & (0.6, 0.8) \end{bmatrix}$$

$$R_3 = \begin{bmatrix} N_3 & c_{11} & (0.3, 0.4) \\ & c_{12} & (0.4, 0.6) \\ & c_{13} & (0.3, 0.5) \\ & c_{14} & (0.3, 0.5) \\ & c_{15} & (0.3, 0.6) \\ & c_{21} & (0.3, 0.4) \\ & c_{22} & (0.3, 0.5) \\ & c_{23} & (0.3, 0.5) \\ & c_{24} & (0.4, 0.6) \\ & c_{31} & (0.4, 0.6) \\ & c_{32} & (0.4, 0.6) \\ & c_{41} & (0.3, 0.5) \\ & c_{42} & (0.3, 0.4) \\ & c_{43} & (0.3, 0.4) \\ & c_{44} & (0.3, 0.6) \end{bmatrix} \qquad R_4 = \begin{bmatrix} N_1 & c_{11} & (0.2, 0.3) \\ & c_{12} & (0.1, 0.4) \\ & c_{13} & (0.2, 0.3) \\ & c_{14} & (0.1, 0.3) \\ & c_{15} & (0.1, 0.3) \\ & c_{21} & (0.2, 0.3) \\ & c_{22} & (0.1, 0.3) \\ & c_{23} & (0.2, 0.3) \\ & c_{24} & (0.1, 0.3) \\ & c_{31} & (0.2, 0.4) \\ & c_{32} & (0.1, 0.4) \\ & c_{41} & (0.1, 0.3) \\ & c_{42} & (0.2, 0.3) \\ & c_{43} & (0.2, 0.3) \\ & c_{44} & (0.1, 0.3) \end{bmatrix}$$

$$R_1 = \begin{bmatrix} N_5 & c_{11} & (0, 0.2) \\ & c_{12} & (0, 0.1) \\ & c_{13} & (0, 0.2) \\ & c_{14} & (0, 0.1) \\ & c_{15} & (0, 0.1) \\ & c_{21} & (0, 0.2) \\ & c_{22} & (0, 0.1) \\ & c_{23} & (0, 0.2) \\ & c_{24} & (0, 0.1) \\ & c_{31} & (0, 0.2) \\ & c_{32} & (0, 0.1) \\ & c_{41} & (0, 0.1) \\ & c_{42} & (0, 0.2) \\ & c_{43} & (0, 0.4) \\ & c_{44} & (0.8, 1) \end{bmatrix}, \qquad R_p = \begin{bmatrix} N_p & c_{11} & (0, 1) \\ & c_{12} & (0, 1) \\ & c_{13} & (0, 1) \\ & c_{14} & (0, 1) \\ & c_{15} & (0, 1) \\ & c_{21} & (0, 1) \\ & c_{22} & (0, 1) \\ & c_{23} & (0, 1) \\ & c_{24} & (0, 1) \\ & c_{31} & (0, 1) \\ & c_{32} & (0, 1) \\ & c_{41} & (0, 1) \\ & c_{42} & (0, 1) \\ & c_{43} & (0, 1) \\ & c_{44} & (0, 1) \end{bmatrix}. \tag{25}$$

Evaluate the thermal coal suppliers with traditional matter-element model; the closeness of coal suppliers S_1–S_6 and each level are shown in Table 4.

Therefore, the comprehensive closeness of coal supplier S_1 is $[0.995143, 0.993739, 0.992883, 0.991767, 0.990646]$; considering the closeness between S_1 and each standard level, it is "Excellent" for a thermal coal supplier; in a similar way, S_2, S_3, and S_5 are also "Excellent"; the closeness of S_4 is $[0.993962, 0.993391, 0.994339, 0.993137, 0.991163]$, graded "Moderate"; the closeness of S_6 is $[0.992232, 0.991746, 0.992638, 0.993011, 0.992896]$, graded "Pass." Therefore, using the outranking relations thought of the PROMETHEE method, the order of coal suppliers under the traditional matter-element model is shown in Figure 2.

Judging from Figure 2, due to the subjectivity of the classical domain, the ordering of coal suppliers under traditional matter-element model is incomplete. If the range of classical domain is too wide, objectives of evaluation will fall into the same class, which will make it difficult to determine the relation among them. Due to the disadvantage of matter-element extension model, this paper evaluates the thermal coal suppliers with ideal matter-element extension model; first normalize the dimensionless data of coal suppliers; therefore select the positive and negative matter-elements R^+ and R^-, shown as (26).

Positive and negative ideal elements:

$$R^+ = \begin{bmatrix} M^+ & c_{11}^+ & 0.335 \\ & c_{12}^+ & 0.554 \\ & c_{13}^+ & 0.000 \\ & c_{14}^+ & 0.000 \\ & c_{15}^+ & 0.000 \\ & c_{21}^+ & 0.000 \\ & c_{22}^+ & 0.000 \\ & c_{23}^+ & 0.410 \\ & c_{24}^+ & 0.000 \\ & c_{31}^+ & 0.260 \\ & c_{32}^+ & 0.000 \\ & c_{41}^+ & 0.290 \\ & c_{42}^+ & 0.370 \\ & c_{43}^+ & 0.310 \\ & c_{44}^+ & 0.250 \end{bmatrix}, \qquad R^- = \begin{bmatrix} M^- & c_{11}^- & 0.000 \\ & c_{12}^- & 0.000 \\ & c_{13}^- & 0.515 \\ & c_{14}^- & 0.367 \\ & c_{15}^- & 0.301 \\ & c_{21}^- & 0.368 \\ & c_{22}^- & 0.417 \\ & c_{23}^- & 0.000 \\ & c_{24}^- & 1.000 \\ & c_{31}^- & 0.000 \\ & c_{32}^- & 0.561 \\ & c_{41}^- & 0.000 \\ & c_{42}^- & 0.000 \\ & c_{43}^- & 0.000 \\ & c_{44}^- & 0.250 \end{bmatrix}. \tag{26}$$

Using formulas (22)–(27) to get the closeness degree and comprehensive closeness degree among the evaluated,

Table 3: Three methods' weight results.

Element	ANP method			Entropy method	Integrated weighing method
	Partial weight	Relative weight	Weight		
C_{11}	0.479	0.080	0.130	0.080	0.120
C_{12}	0.256	0.043	0.069	0.038	0.063
C_{13}	0.140	0.024	0.038	0.118	0.053
C_{14}	0.081	0.014	0.022	0.078	0.031
C_{15}	0.043	0.007	0.012	0.069	0.019
C_{21}	0.693	0.161	0.259	0.040	0.238
C_{22}	0.191	0.044	0.071	0.038	0.065
C_{23}	0.038	0.009	0.014	0.057	0.021
C_{24}	0.018	0.019	0.029	0.198	0.047
C_{31}	0.822	0.046	0.074	0.037	0.068
C_{32}	0.178	0.010	0.016	0.051	0.022
C_{41}	0.190	0.103	0.167	0.044	0.154
C_{42}	0.057	0.103	0.050	0.057	0.049
C_{43}	0.009	0.005	0.008	0.054	0.013
C_{44}	0.045	0.025	0.040	0.042	0.038

Table 4: The evaluation results of the traditional matter-element extension model.

Closeness	Excellent	Good	Moderate	Pass	Fail	Level
S_1	0.995143	0.993739	0.992883	0.991767	0.990646	Excellent
S_2	0.995965	0.994307	0.992945	0.990975	0.988980	Excellent
S_3	0.997131	0.995100	0.993461	0.991951	0.988845	Excellent
S_4	0.993962	0.993391	0.994339	0.993137	0.991163	Moderate
S_5	0.994032	0.993430	0.993414	0.992214	0.990297	Excellent
S_6	0.992232	0.991746	0.992638	0.993011	0.992896	Pass

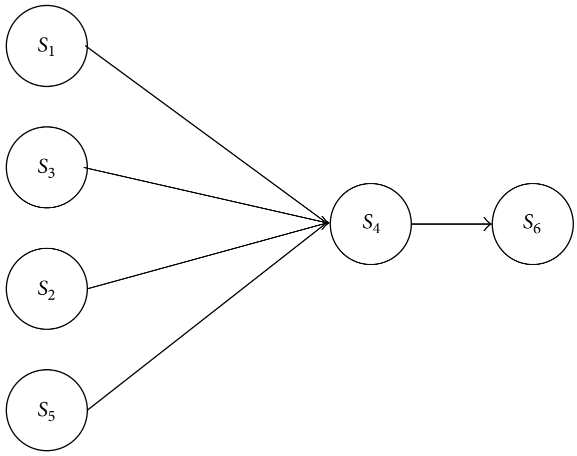

Figure 2: The evaluation results of traditional matter-element extension model.

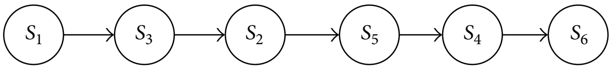

Figure 3: The evaluation result of ideal matter-element extension model.

positive, and negative matter-elements, details are shown in Figure 3.

According to comprehensive closeness degree, the coal suppliers can be ordered, the order of S_1–S_3 is consistent with results from traditional matter-element extension model; therefore, S_5 is better than S_4 and S_4 is better than S_6, details are shown in Figure 3.

5.3.2. Evaluation Results Based on the TOPSIS Method. Table 6 is the evaluation results based on the TOPSIS method. y_i^+/y_i^- is Euclidean distance between the evaluation scheme and positive/negative ideal scheme. $C_i = y_i^-/(y_i^+ + y^{i-})$ is queuing indicated value, emphasizing the distance between the evaluation scheme and negative ideal scheme. TOPSIS method orders the schemes according to the queued instruction value; the larger the value, the better the scheme and vice versa.

According to Table 6, the coal suppliers can be ordered as follows: $S_3 > S_5 > S_4 > S_1 > S_2 > S_6$.

5.3.3. Evaluation Results Based on the Romania Method. Table 7 is the evaluation results based on the Romania method. Romania method calculates score for each scheme

Table 5: The comprehensive closeness of the evaluated matter-element.

	$N_j^+(p_0)$	$N_j^-(p_0)$	$N_j(p_0)$	Rank
S_1	0.9978763	0.9889069	0.5022573	1
S_2	0.9956292	0.9911539	0.5011263	3
S_3	0.997574	0.9892092	0.5021051	2
S_4	0.9907195	0.9960636	0.4986551	5
S_5	0.9911868	0.9955963	0.4988903	4
S_6	0.989734	0.9970491	0.4981591	6

Table 6: The evaluation results based on the TOPSIS method.

	y_i^+	y_i^-	C_i	Order
S_1	0.5211	0.427	0.450374	4
S_2	0.5283	0.407	0.435275	5
S_3	0.2878	0.4662	0.618302	1
S_4	0.3628	0.5387	0.59756	3
S_5	0.3448	0.5561	0.617272	2
S_6	0.445	0.3005	0.403085	6

Table 7: The evaluation results based on the Romania method.

	S_1	S_2	S_3	S_4	S_5	S_6
Score	69.267	54.84	61.40	53.311	52.771	32.885
Order	1	3	2	4	5	6

according to (27) and makes indicators become comparability; the higher the score, the better the scheme. Consider

$$x'_{ij} = 99\frac{\left(x_{ij} - b_j\right)}{\left(a_j - b_j\right)} + 1. \qquad (27)$$

According to Table 7, the coal suppliers can be ordered as follows: $S_1 > S_3 > S_2 > S_4 > S_5 > S_6$.

5.3.4. Evaluation Results Based on the PROMETHEE Method.

Table 8 is the evaluation results Based on the PROMETHEE method. PROMETHEE method concludes PROMETHEE-I method and PROMETHEE-II method [27]. The paper mainly chooses PROMETHEE-II method, calculates outflows, inflows, and net flows of schemes, gets the outranking relationship of schemes, and orders the schemes.

According to Table 8, the coal suppliers can be ordered as follows: $S_2 > S_1 > S_3 > S_5 > S_4 > S_6$.

5.4. Sensitivity Analysis.

According to Table 5 to Table 8, we get evaluation results of coal-fired supplier based on the TOPSIS method, ROMANIA method, PROMETHEE method, and ideal matter-element model, shown in Table 9.

To evaluate the results of various evaluation methods, this paper evaluates the results with the representativeness and deviation degree of the results. The greater the compatibility degree, the greater the representativeness and reliability; the smaller the deviation degree is, the better the evaluation method is.

Table 8: The evaluation results based on the PROMETHEE-II method.

	Outflows	Inflows	Net flows
S_1	2.614838	1.347520	1.267318
S_2	2.818.489	1.466782	1.351707
S_3	2.344017	1.664391	0679627
S_4	1.706226	2.441154	−0.734930
S_5	1.881533	2.303875	−0.422340
S_6	1.114000	3.255465	−2141380

Table 9: The results comparison of evaluation program.

	S_1	S_2	S_3	S_4	S_5	S_6
TOPSIS	4	5	1	3	2	6
ROMANIA	1	3	2	4	5	6
PROMETHEE	2	1	3	5	4	6
Ideal matter-element	1	3	2	5	4	6

Table 10: The degree of compatibility and difference of the three approaches.

Method	Compatibility		Deviation		Rank
	Value	Rank	Value	Rank	
TOPSIS	0.323	4	2	2	4
ROMANIA	0.643	2	1	1	2
PROMETHEE	0.629	3	2	2	3
Ideal matter-element	0.657	1	1	1	1

The compatibility degree of each evaluation method is [27]:

$$r_{ij} = 1 - \frac{6}{n\left(n^2 - 1\right)}\sum_{k=1}^{n}\left(a_k^{(i)} - a_k^{(j)}\right)^2,$$
$$r_z = \sum_{j=1}^{h-1} w_j r_{ij}, \qquad (28)$$

where $a_k^{(i)}$ and $a_k^{(j)}$ are the rank of kth evaluation indicator under the evaluation method i and j, $i, j = 1, 2, h$; n is the total number of evaluation indicators; and h is the total number of evaluation methods. Usually, if there is no preference among the evaluation methods, $w_j = 1/h - 1$, where r_z is the compatibility degree.

The deviation degree of each evaluation plan is [28]

$$d_z = \frac{1}{h-1}\sum_{j=1}^{h} d_{zj}, \quad i, j = 1, 2, \ldots, h, \qquad (29)$$

where d_z is the deviation degree between one plan and the other $h - 1$ plans and d_{zj} is the count of evaluated objectives exceeding the determined range of j. Using the first 3 plans as benchmark, the compatibility and deviation degrees are shown in Table 10.

As shown in Table 10, compared with the other two evaluation methods, ideal matter-element extension model has the biggest compatibility and the smallest deviation degree; therefore the representativeness and reliability is best. Therefore, the order of thermal coal suppliers is $S_1 > S_3 > S_2 > S_5 > S_4 > S_6$.

6. Conclusions

The selection of the thermal coal suppliers is essential to reduce the generation costs. In order to optimize the selection of thermal coal suppliers, select the positive and negative ideal matter-elements and replace maximum membership degree principle with the closeness principle; this paper constructed an ideal matter-element extension model and example results show the following.

(1) Determining the weights of indicators by integrated method can have advantages of both subjective and objective weighting methods, overcome the shortcomings, implement the subjective and objective information, and enhance the representation of indicators.

(2) Compared with traditional matter-element extension model, the ideal matter-element extension model orders the schemes by determining the closeness degree among evaluated matter-element and ideal matter-elements; this method overcomes the shortcoming of the evaluation results of traditional matter-element extension model and performed a full order of evaluation companies. By sensitivity analysis, this paper found that ideal matter-element extension model has the highest compatibility and the lowest deviation degree; the representativeness and reliability are both higher than others.

(3) As shown in Table 2, when considering coal supplier selection, priority should be given to standard coal price, calorific value of coal and economic profit, second, convenience of transportation, contract execution, minable capacity, ash, and so forth.

The comprehensive results of evaluation of coal suppliers S_1, S_3, and S_2 are better than others, so the model mentioned in this paper is effective and practical.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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