

Evaluation of Green Suppliers Based on a Hybrid Weighting Approach and GRA Method

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Abstract. To align with the national dual carbon strategy and facilitate low-carbon production for enterprises, this paper incorporates the concept of green supply chain management and develops a scientifically sound evaluation index system for green suppliers by comprehensively considering five factors: quality, availability, cost, environmental management performance, and technology. The analytic hierarchy process and entropy weight method are employed to assign subjective and objective weights to each evaluation index while the grey correlation degree analysis method is utilized to rank and sort suppliers in order to select the optimal green supplier. Finally, an empirical example is presented to verify the reliability of our model.

Keywords: Green supplier selection; AHP; Entropy method; GRA.

1. Introduction

Currently, China's economy and society are facing a series of issues such as environmental damage and resource depletion. To cope with these challenges, the "carbon peak" and "carbon neutrality" policy systems have emerged. In this context, the value of a green supply chain is becoming more and more prominent, and more and more enterprises are committed to the green transformation of the supply chain. In the process of building a sustainable green supply chain, green suppliers are located in the upstream of the supply chain, and they can pass on the effects of cost saving and environmental protection to the downstream links through the supply chain, which is of great significance for enterprises to respond to the national dual carbon strategy and achieve low-carbon production. Therefore, how to correctly and objectively select green suppliers has become a problem to be solved by enterprises.

2. Research status at home and abroad

As for the evaluation and selection of green suppliers, domestic and foreign scholars have focused on the evaluation indicators and evaluation methods of suppliers. For example, combined with the supplier's own quality, Li Shucheng and Hu Fang^[1] incorporated green information into the evaluation index and evaluated and selected green suppliers by using the multi-level fuzzy comprehensive evaluation method; Considering the green production, environmental protection capacity, resource utilization capacity and energy utilization capacity of suppliers. Guo Bin^[2] et al. first determined the weight values of indicators at all levels by ANP, and then used the TOPSIS method to evaluate and select green suppliers. Liao Jilin and Zhang Ruidan^[3] added five new green indicators and combined AHP with TOPSIS to provide a method for papermaking enterprises to select green suppliers. Tsai Chi Kuo et al.^[4] determined 17 evaluation indicators in the two dimensions of environment and management system according to EICC, and used DANP and VIKOR methods to evaluate the environmental performance of suppliers. Lixin Shen et al.^[5] applied fuzzy set theory to transform the subjective judgment of evaluators and scored suppliers by fuzzy TOPSIS. Kuo et al.^[6] proposed a fuzzy neural network based on a continuous genetic algorithm (CGA) to evaluate suppliers.

The above methods have their own advantages and disadvantages. The fuzzy comprehensive evaluation method is subjective in setting weights, resulting in a certain deviation in the evaluation results; The analytic hierarchy process depends on expert scoring and has strong subjectivity; TOPSIS is a comprehensive evaluation method, which has no strict limitation on the sample size, no need to

test the data, and simple calculation, but it can not deal with the uncertainty and fuzziness of the external situation well; The calculation of the neural network is complex, so it is easy to reduce the accuracy of the evaluation results. To enhance the credibility of the evaluation index and obtain more scientific and reasonable evaluation results, in this paper, the analytic hierarchy process was combined with the entropy weight method to weight the subjective and objective combination of the evaluation index, calculate the comprehensive weight of each index, and evaluate and select the green suppliers by using the grey correlation analysis method.

3. Green supplier selection model based on combination weighting method and grey correlation analysis method

3.1. Determining the weight of evaluation index

(1) Subjective weighting method-analytic hierarchy process

Analytic Hierarchy Process (AHP) is a relatively subjective system analysis method, which is suitable for decision-making problems with complex structure, many decision criteria and difficult to quantify. The main idea of this method is to decompose a complex problem into several levels and factors, make a comparative judgment on the importance of the two indicators, and establish a judgment matrix. Then, by calculating the maximum eigenvalue of the judgment matrix and the corresponding eigenvector, the weight of the importance of different schemes can be obtained, providing the basis for the selection of the best scheme^[7]. The steps of determining the subjective weight of each index by the analytic hierarchy process are as follows:

Step 1: Decompose the decision-making problem according to the relationship between the goal of the decision-making problem, the decision-making criterion and the decision-making object, and establish a hierarchical structure model.

Step 2: The consistent matrix method is used to construct the judgment matrix, that is, the evaluation indexes are compared with each other, and the relative scale is used to simplify the comparison of different indexes and improve the accuracy. Taking the criterion layer as an example, the judgment matrix $A = (a_{ij})_{m \times n}$, ($i = 1, 2, \dots, n$; $j = 1, 2, \dots, m$) can be constructed.

$$A = (a_{ij})_{m \times n} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}$$

Table 1 shows the scale and meaning.

Table 1 Scale and meaning

Scale	Meaning
1	The two indicators are of equal importance.
3	One index is slightly more important than the other.
5	Obviously important
7	Very important
9	Extremely important
2, 4, 6, 8	Median of the above two adjacent judgments
Reciprocal	The judgment of index i in comparison j is a_{ij} , and the judgment of index j in comparison i is $\frac{1}{a_{ij}}$.

Step 3: Perform hierarchical single sorting. First, multiply each row of elements in the judgment matrix and then conduct n extractions of a root:

$$\bar{W}_i = \sqrt[n]{\prod_{j=1}^n a_{ij}}, i, j = 1, 2, \dots, n \quad (1)$$

Then, the normalized processing of $\bar{W}_i$ is carried out to obtain the ranking weight vector w_i , which indicates the relative importance of the evaluation index at the same level to a certain evaluation index at the previous level. $W = (w_1, w_2, \dots, w_n)^T$ is the obtained feature vector, which is also the result of the single ranking of the judgment matrix level, where w_i is its i th component.

$$w_i = \frac{\bar{W}_i}{\sum_{i=1}^n \bar{W}_i} \quad (2)$$

Finally, the maximum eigenvalue $\lambda_{\max}$ of the judgment matrix is solved.

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^n \frac{A \cdot w_i}{w_i} \quad (3)$$

Step 4: Use the consistency index for testing.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (4)$$

Where $CI = 0$ means that the judgment matrix is completely consistent. The larger CI , the worse the consistency of the judgment matrix is.

Step 5: Introduce a modified judgment index RI as an index to measure the consistency of the judgment index.

$$CR = \frac{CI}{RI} \quad (5)$$

The usual values of RI are shown in Table 2 below.

Table 2 Values of RI

Order of matrix	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

When $CR < 0.1$, it indicates that the consistency test of the judgment matrix A passes, and the feature vector of A can be used to calculate the weight vector; if $CR \geq 0.01$, the correction of the judgment matrix A should be considered.

Step 6: The corresponding evaluation indexes in the criterion layer and the index layer are multiplied respectively to obtain the comprehensive weight value of each index in the factor layer for the target layer.

(2) Objective weighting method-entropy weighting method

The entropy weight method is an objective weighting method. Its principle is to determine the weight according to the amount of information reflected by the degree of variation of each evaluation index value^[8]. The steps for determining the objective weight of each index by the entropy weight method are as follows:

Step 1: Assume that an enterprise has n suppliers and m evaluation indexes, and the positive matrix $X = (X_{ij})_{m \times n}$, ($i = 1, 2, \dots, n$; $j = 1, 2, \dots, m$) is constructed, where X_{ij} refers to the j th evaluation index of the i th supplier.

$$X = (X_{ij})_{m \times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

As different evaluation indexes have different dimensions, the critical value method is used to standardize the evaluation indexes.

Let the normalized matrix be Z , and the elements in Z are denoted by:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}} \quad (6)$$

Cost indexes:

$$x_{ij} = \frac{x_{ij} - \min\{x_{1j}, \cdots, x_{nj}\}}{\max\{x_{1j}, \cdots, x_{nj}\} - \min\{x_{1j}, \cdots, x_{nj}\}} \quad (7)$$

Benefit indexes:

$$y_{ij} = \frac{\max\{x_{1j}, \cdots, x_{nj}\} - x_{ij}}{\max\{x_{1j}, \cdots, x_{nj}\} - \min\{x_{1j}, \cdots, x_{nj}\}} \quad (8)$$

Step 2: Calculate the proportion p_{ij} of the i th supplier under the j th evaluation index.

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^n z_{ij}} \quad (9)$$

Step 3: Calculate the information entropy e_j and information utility value d_j of each evaluation index, and normalize them to obtain the entropy weight w_j of each evaluation index.

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n p_{ij} \ln(p_{ij}), \quad j = 1, 2, \cdots, m \quad (10)$$

Where n represents the number of suppliers, $\frac{1}{\ln n} > 0$, and $e_j \geq 0$.

$$d_j = 1 - e_j \quad (11)$$

$$w_j = \frac{d_j}{\sum_{j=1}^m d_j}, \quad j = 1, 2, \cdots, m \quad (12)$$

(3) Combination weighting

The subjective weight w_i obtained by the analytic hierarchy process and the objective weight w_j obtained by the entropy weight method are combined to obtain the comprehensive weight W_t of each evaluation index.

$$W_t = \frac{w_i \times w_j}{\sum_{i,j=1}^n w_i \times w_j}, \quad i, j = 1, 2, \cdots, n \quad (13)$$

3.2. Green Supplier Rating

Grey Relation Analysis (GRA) is a new analysis method in grey system theory. It measures the correlation between factors according to the degree of similarity or dissimilarity between factors, which overcomes the limitations of traditional mathematical evaluation model methods^[9]. The steps for grey correlation analysis are as follows:

Step 1: Determine the evaluation object and evaluation criteria. Suppose there are m evaluation objects and n evaluation indexes, the reference sequence is $x_0 = \{x_0(k) | k = 1, 2, \dots, n\}$, and the comparison sequence is $x_i = \{x_i(k) | k = 1, 2, \dots, n\}$, $i = 1, 2, \dots, m$.

Step 2: Determine the weight corresponding to each index value. Here, the comprehensive weight W_t obtained by the combination weighting method above is used as the weight of each evaluation index.

Step 3: Calculate the correlation coefficient $\xi_i(k)$ between the comparison sequence and the reference sequence on the k th index.

$$\xi_i(k) = \frac{\min_s \min_t |x_0(t) - x_s(t)| + \rho \max_s \max_t |x_0(t) - x_s(t)|}{|x_0(k) - x_i(k)| + \rho \max_s \max_t |x_0(t) - x_s(t)|} \quad (14)$$

Where ρ is the resolution coefficient, and its range is $[0, 1]$, and $\min_s \min_t |x_0(t) - x_s(t)|$ and $\max_s \max_t |x_0(t) - x_s(t)|$ are the two-stage minimum difference and the two-stage maximum difference, respectively. The smaller the resolution coefficient ρ is, the greater the difference between the correlation coefficients is, and the stronger the discrimination ability is, usually 0.5.

Step 4: Calculate the grey weighted correlation r_i of the i th evaluation object to the ideal object.

$$r_i = \sum_{k=1}^n w_k \xi_i(k) \quad (15)$$

Step 5: Analyze the calculation results and establish the correlation order of each evaluation object according to the size of the grey weighted correlation. The greater the correlation, the greater the importance of the evaluation object to the evaluation criteria, which is the best of all evaluation objects.

4. Instance analysis

To verify the feasibility of the combination weighting and multi-level fuzzy comprehensive evaluation model established in this paper, taking H company as an example^[10], four suppliers are selected for application description.

Based on the concept of green supply chain management, the existing literature is analyzed and summarized, and combining the actual situation of manufacturing enterprises and by following the principle of index system construction, a scientific and reasonable green supplier evaluation index system is constructed, as shown in Table 3.

Table 3 Green supplier evaluation index system

Target layer A	Criterion layer B	Factor layer C
Green supplier evaluation A	Quality B_1	Product percent of pass C_{11}
		Completeness of the quality manual C_{12}
		Research and development investment rate C_{13}
	Procurability B_2	Order fill rate C_{21}
		On time delivery C_{22}
		Delivery lead time C_{23}
	Cost B_3	Product price stability C_{31}
		Transportation cost C_{32}
		Quantity discount C_{33}
	Environmental management performance B_4	Reutilization rate of cargo carriers C_{41}
		Environment management system authentication C_{42}
		Staff's environmental awareness training C_{43}
	Technological level B_5	Proportion of research staff C_{51}
		Utilization rate of automation equipment C_{52}
		Proportion of R&D of innovative projects C_{53}

The original scores made by the experts of the company on the evaluation indicators of the four suppliers are shown in Table 4.

Table 4 Raw evaluation data of suppliers

Index	Supplier A	Supplier B	Supplier C	Supplier D
C_{11}	95.74%	97.97%	97.56%	100%
C_{12}	9	9.5	8.5	8
C_{13}	15.6%	14.8%	12.9%	10.5%
C_{21}	9	7	8	8.5
C_{22}	98.51%	96.69%	96.77%	100%
C_{23}	91.67%	94.74%	95.24%	86.67%
C_{31}	98%	95%	97%	96%
C_{32}	107.13	110.36	109.23	106.78
C_{33}	92.23%	90.47%	89.39%	91.36%
C_{41}	81.82%	83.33%	75.47%	75%
C_{42}	6.5	6	5	7
C_{43}	5	4	5.5	6
C_{51}	11.29%	11.92%	10.33%	10.9%
C_{52}	26.25%	32.14%	40%	29.69%
C_{53}	15.79%	22.73%	19.35%	14.86%

4.1. Determination of comprehensive weight

Step 1: Obtain the subjective weight determined by the analytic hierarchy process according to Formulas (1) and (2):

$$w_i = (0.146, 0.032, 0.084, 0.044, 0.019, 0.098, 0.011, \\ 0.063, 0.026, 0.129, 0.242, 0.046, 0.008, 0.020, 0.035)$$

Step 2: Obtain the objective weight determined by the entropy weight method according to Formulas (9) to (12):

$$w_j = (0.057, 0.098, 0.055, 0.056, 0.062, 0.076, 0.089, \\ 0.063, 0.057, 0.055, 0.104, 0.052, 0.059, 0.061, 0.056)$$

Step 3: Obtain the combination weight of each evaluation index according to Formula (13):

$$W_t = (0.116, 0.044, 0.065, 0.034, 0.017, 0.104, 0.013, \\ 0.055, 0.020, 0.099, 0.351, 0.033, 0.006, 0.017, 0.027)$$

4.2. Data standardization

The original evaluation data of green suppliers are normalized, and the maximum value of each evaluation index after processing is taken as the evaluation standard, that is, the reference sequence, and the rest as the comparison sequence. The results are shown in Table 5.

Table 5 Comparison sequence and reference sequence values

Index	Supplier A	Supplier B	Supplier C	Supplier D	Reference sequence
C_{11}	0	0.524	0.427	1	1
C_{12}	0.667	1	0.333	0	1
C_{13}	1	0.843	0.471	0	1
C_{21}	1	0	0.500	0.750	1
C_{22}	0.550	0	0.024	1	1
C_{23}	0.583	0.942	1	0	1
C_{31}	1	0	0.667	0.333	1
C_{32}	0.098	1	0.684	0	1
C_{33}	1	0.380	0	0.694	1
C_{41}	0.819	1	0.056	0	1
C_{42}	0.750	0.500	0	1	1
C_{43}	0.500	0	0.750	1	1
C_{51}	0.604	1	0	0.359	1
C_{52}	0	0.428	1	0.250	1
C_{53}	0.118	1	0.571	0	1

4.3. Calculation of grey correlation coefficient

According to Formula (14), the grey coefficient r_i of the evaluation standard of the i th supplier is calculated, and the results are shown in Table 6.

Table 6 Grey correlation coefficient

Index	Supplier A	Supplier B	Supplier C	Supplier D
C_{11}	0.333	0.512	0.466	1
C_{12}	0.600	1	0.429	0.333
C_{13}	1	0.761	0.486	0.333
C_{21}	1	0.333	0.500	0.667
C_{22}	0.526	0.333	0.339	1
C_{23}	0.546	0.896	1	0.333
C_{31}	1	0.333	0.600	0.429
C_{32}	0.357	1	0.613	0.333
C_{33}	1	0.447	0.333	0.620
C_{41}	0.734	1	0.346	0.333
C_{42}	0.667	0.500	0.333	1
C_{43}	0.500	0.333	0.667	1
C_{51}	0.558	1	0.333	0.438
C_{52}	0.333	0.467	1	0.400
C_{53}	0.362	1	0.538	0.333

4.4. Result ranking

According to Formula (15), the grey weighted correlation degree of each supplier is calculated, that is, the comprehensive score. The results show that the scores of Supplier A, Supplier B, Supplier C, and Supplier D are 0.624, 0.657, 0.486, and 0.698, respectively. Supplier D has the highest comprehensive score, so Supplier D is selected as the best green supplier.

5. Conclusion

Based on the theory of green supply chain management, a scientific and comprehensive green supplier evaluation index system is constructed, and a green supplier selection model based on the combination weighting method and grey correlation analysis method is established to eliminate the subjective arbitrariness of decision makers to a certain extent. The reliability of the model is demonstrated in the form of an example, thus providing a scientific and effective method for enterprises to select green suppliers.

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