Grey Comprehensive Evaluation of Biomass Power Generation Project Based on Group Judgement

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Abstract. The comprehensive evaluation of benefit is an important task needed to be carried out at all stages of biomass power generation projects. This paper proposed an improved grey comprehensive evaluation method based on triangle whiten function. To improve the objectivity of weight calculation result of only reference comparison judgment method, this paper introduced group judgment to the weighting process. In the process of grey comprehensive evaluation, this paper invited a number of experts to estimate the benefit level of projects, and optimized the basic estimations based on the minimum variance principle to improve the accuracy of evaluation result. Taking a biomass power generation project as an example, the grey comprehensive evaluation result showed that the benefit level of this project was good. This example demonstrates the feasibility of grey comprehensive evaluation method based on group judgment for benefit evaluation of biomass power generation project.

1. Introduction

With the continuous consumption of fossil fuels such as coal, oil and natural gas, and the increasing environmental problems caused by fossil energy over-burning, the attention on renewable and clean energy is increasing. As a kind of renewable energy, biomass energy is stable, clean and safe, and the rational and efficient use of biomass energy has become an important issue for the development of current society. Biomass power generation is a major form of biomass energy utilization, including biomass direct combustion power generation, biomass mixed combustion power generation, biomass gasification power generation, methane electricity generation and so on [1]. As of 2015, the global installed capacity of biomass power is about 100 million kilowatts, of which the United States holds 15.9 million kilowatts and Brazil holds 11 million kilowatts. Biomass cogeneration has become an important heating mode in Europe, especially in the Nordic countries. China is rich in biomass resources, the national biomass resources which can be used as energy sources is approximately equivalent to 460 million tons of standard coal per year. As of 2015, the total installed capacity of biomass power generation in China is about 10.3 million kilowatts, of which agriculture and forest biomass direct combustion power generation holds about 5.3 million kilowatts, waste incineration power generation holds about 4.7 million kilowatts, and methane electricity generation holds about 0.3 million kilowatts, and the annual generated energy is about 52 billion kWh [2]. Biomass power generation has good environmental and social impact, but the deviation of actual economic benefits from expectations of it is also a troubling question, and it causes some of the environmental problems and food security issues [3]. Therefore, it is necessary to establish a comprehensive evaluation method,

which takes the investment return, environmental impact and social benefit as the basis for judging the feasibility and economy of biomass power generation projects.

The comprehensive evaluation index system of biomass power generation projects is usually established from the aspects of management level, technical effect, economic benefit, environmental impact and social benefit, while economic benefit, environmental impact and social benefit are the main analysis objects [4,5]. The commonly used comprehensive evaluation methods include PCA (principal component analysis), intelligent comprehensive evaluation method, fuzzy comprehensive evaluation method, and grey comprehensive evaluation method [6]. The main principle of PCA is dimension reduction. To simplify the comprehensive process, PCA analyzes the internal relationship between indicators based on multiple sets of data with same attributes, and transforms the complex indicators into an independent comprehensive index system which contains most of the information of the original indicators. Intelligent comprehensive evaluation method establishes a mapping from indicators to evaluation results through a lot of training and learning. The premise of using these two methods is that the number of comparable samples is large enough, but for biomass power generation projects, it is difficult to obtain sufficient comparable data, and therefore PCA and intelligent comprehensive evaluation method do not apply. Fuzzy comprehensive evaluation method and grey comprehensive evaluation method can be used for the evaluation of a single object, but the subjective degree of fuzzy comprehensive evaluation method is too high as experts directly determine the level of indicators, so this paper selects the grey comprehensive evaluation method based on triangle whiten function. The triangle whiten function describes the subjection degree of a value to a value range. Dai Ran uses the triangle whiten function to evaluate a hydraulic engineering project, and proves the accuracy and reliability of the model [7]. Qing Song, Wang Ye, and Peng Peng use the grey whitening weight function to evaluate the security risk of power system, and prove the feasibility and practicability of grey clustering method [8]. Liu Sifeng, Xie Naiming put forward the grey evaluation method based on center-point triangular whitenization weight function, and prove the validity of the method with an example [9].

The only reference comparison judgment method for weight calculation and the grey comprehensive evaluation method for evaluation are greatly influenced by subjective factors, so this paper applies group judgment to these two steps at the same time.

2. Grey comprehensive evaluation model of biomass power generation project based on group judgement

2.1. The establishment of evaluation index system
Evaluation index system is the link between evaluation method and evaluation object. Scientific and reasonable evaluation index system plays an important role in making a fair evaluation conclusion. In general, economic benefit is a core issue for investors, and an important criterion for operation level assessment. Due to the unique social publicity and environmental protection property of biomass power generation projects, the state and society attach great importance to its social and environmental benefit. In order to ensure the comprehensiveness of the evaluation process and the reliability of the evaluation result, the evaluation indicators can be divided into economic benefit, environmental benefit and social benefit. The index system is shown in Table 1.

Table 1. Comprehensive evaluation index system of biomass power generation project

Target layer	Criterion layer	Index layer	Index symbol
Comprehensive benefit evaluation of biomass power generation project	Economic benefit	Net present value	A_1
		Internal rate of return	A_2
		Payback period	A_3
		Return on total assets	A_4
	Social benefit	Improving the awareness of environmental protection	B_1

		Providing employment opportunities	B_2
		Increasing farmers' income	B_3
	Environmental benefit	SO_2, CO_2 emissions	C_1
		Dust effect	C_2
		Noise effect	C_3
		Wastewater impact	C_4

The selected economic benefit indicators reflect the investment value, investment efficiency and profitability of projects. The selection principle of social benefit indicators is to reflect the social environment contribution and social economy contribution of projects. Environmental benefit indicators mainly reflect the air pollution, dust pollution, noise pollution and wastewater discharge.

2.2. The weight calculation based on only reference comparison judgment method

In practical problems, it is difficult for experts to give an only and accurate relative importance estimation of two indicators, while it is relatively easy to use a certain value range to express their subjective understanding. Therefore, in this paper, experts use interval numbers to estimate their subjective understanding of relative importance between indicators.

The only reference comparison judgment method first selects the least important indicator, and then uses the relative importance of residual indicators to the least important one to calculate the weight of all indicators. Interval number $D = [d_1, d_2]$ ($1 \leq d_1 \leq d_2 \leq 9$) is used for the estimation work, where 1 for equally important and 9 for extremely important. The least important indicator is expressed by $D = 1$. The width of interval number is

$$L(D) = d_2 - d_1 \tag{1}$$

The midpoint of interval number is

$$M(D) = \frac{d_1 + d_2}{2} . \tag{2}$$

The interval mapping function with experts' risk attitude is

$$\varphi_\varepsilon(D) = M(D) + \varepsilon \times L(D) . \tag{3}$$

ε is the risk attitude factor: $-\frac{1}{2} \leq \varepsilon \leq 0$ for conservative type; $\varepsilon = 0$ for neutralities; $0 \leq \varepsilon \leq \frac{1}{2}$ for adventurers.

When there is only one expert, the weight of each indicator is:

$$w_i = \frac{\varphi_\varepsilon(D_i)}{\sum\limits_{l=1}^{m} \varphi_\varepsilon(D_l)} . \tag{4}$$

For the situation of L ($L > 1$) experts:
(1) Experts have the same qualitative judgment.

When L experts have the same judgment of the least important indicator x_{jm} of the index system $\{x_j\}$, let the interval estimation of the relative importance a_i of indicator x_{ji} and x_{jm} from expert k be $D_i^{(k)} = [d_{1i}^{(k)}, d_{2i}^{(k)}], (i = 1, 2, \cdots m; k = 1, 2, \cdots L)$.

Make the following treatment:

$$D_i = \bigcap_{k=1}^{L} D_i^{(k)} = [d_{1i}, d_{2i}] . \tag{5}$$

Where

$$d_{1i} = \max_k \{d_{1i}^{(k)}\}, d_{2i} = \min_k \{d_{2i}^{(k)}\} . \tag{6}$$

The average blindness of the interval number a_i of L experts can be calculated as follows:

$$R_i = \frac{1}{L} \sum_{k=1}^{L} [(d_{1i} - d_{1i}^{(k)}) + (d_{2i}^{(k)} - d_{2i})], i = 1, 2, ..., m . \tag{7}$$

$$0 \le R_i \le d_{1i} - d_{2i} + d_{2i}^* - d_{1i}^* .$$

Where

$$d_{1i}^* = \min_k \{d_{1i}^{(k)}\}, d_{2i}^* = \max_k \{d_{2i}^{(k)}\} . \tag{8}$$

Make the following treatment: $D_i^* = [d_{1i}^*, d_{2i}^*]$. Calculate parameters:

$$\lambda_i = \frac{1}{2L} \sum_{k=1}^{L} \frac{n(D_i^{(k)})}{n(D_i^*)}, i = 1, 2, ..., m . \tag{9}$$

Assuming that:

$$\varphi_{\lambda_i}(D_i) = n(D_i) + \lambda_i e(D_i) . \tag{10}$$

The weight of each indicator can be calculated as follows:

$$w_i = \frac{\varphi_{\lambda_i}(D_i)}{\sum_{l=1}^{m} \varphi_{\lambda_l}(D_l)}, i = 1, 2, ..., m . \tag{11}$$

(2) Experts have different qualitative judgment.

When L experts have different idea of the least important indicator of the index system $\{x_j\}$, there are two cases.

For the L_0 experts who have the same qualitative judgment of the least important indicator, the weight w_i^1 can be analyzed by the above steps.

For the remaining $L - L_0$ experts with different views:

$$w_i^2 = \frac{1}{L - L_0} \sum_{*k=1}^{L-L_0} w_i^{(*k)}, i = 1, 2, \cdots m . \tag{12}$$

The comprehensive weight can be calculated by the next step:

$$w_i = k_1 \times w_i^1 + k_2 \times w_i^2 . \tag{13}$$

Where $k_1 = \dfrac{L_0}{L}, k_2 = \dfrac{L - L_0}{L}$.

2.3. Grey comprehensive evaluation of biomass power generation project based on triangle whiten function

Whitenization weight function describes the "preference degree " of a grey number for values within different value ranges. Continuous function with determinate starting and end point, increasing function on the left side, and decreasing function on the right side, is called the typical whitenization weight function, as shown in Figure 1.
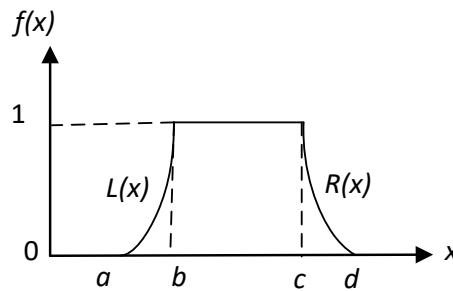
Figure 1. Typical whitenization weight function

In practical applications, in order to facilitate programming and computing, $L(x)$ and $R(x)$ are often simplified to linear function. When $L(x)$ and $R(x)$ in Figure 1 use linear function, and b , c merge into one point, whitenization weight function turns into triangle whiten function $f(x)$, as shown in Figure 2.
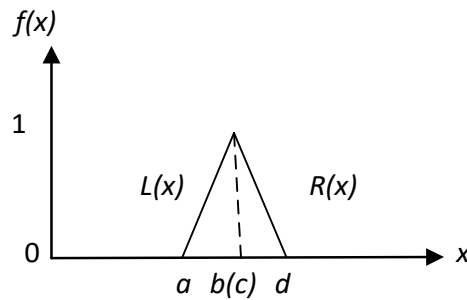

Figure 2. Triangle whiten function

Assuming that there are m indicators, s grey categories, L invited experts. The sample observation of evaluation object on the indicator j provided by expert i is $x_j^{(i)}$, $i = 1, 2, 3, \ldots, L$, $j = 1, 2, \ldots, m$. The specific comprehensive evaluation steps based on $x_j^{(i)}$ are as follows:

(1) Determine the evaluation grey classifications, and select the threshold

According to the requirement of comprehensive evaluation of biomass power generation projects, determine the number of evaluation grey classifications to be s. Combine the realities of biomass power generation projects with similar experiences to determine the value range of indicators. The value range of each indicator is divided into s groups. For example, the value range $[a_{j,1}, \ a_{j,s+1}]$ of indicator j is divided into $[a_{j,1}, \ a_{j,2}]$, $\cdots$, $[a_{j,k}, \ a_{j,k+1}]$, $\cdots$, $[a_{j,s}, \ a_{j,s+1}]$. The threshold $a_{j,k}$ can be determined according to the actual requirement or related research result.

(2) Optimize observations

In order to improve the objectivity of evaluation results, L sets of initial estimations given by experts should be optimized according to the minimum variance principle. $x_1^{(i)}, x_2^{(i)}, \cdots x_m^{(i)}$ is the initial estimation from expert i. Set the optimized observations being $x_1, x_2, \cdots x_m$, the variance σ^2_j can be calculated by the following equation:

$$\sigma^2_j = \sum_{i=1}^{L}(x_j^{(i)} - x_j)^2 = \sum_{i=1}^{L}(x_j^{(i)})^2 + L \times (x_j)^2 - 2 \times x_j \times \sum_{i=1}^{L} x_j^{(i)}, j = 1, 2, \cdots m . \quad (14)$$

The partial derivative of the above equation is:

$$(\sigma^2{}_j)' = 2 \times L \times x_j - 2 \times \sum_{i=1}^{L} x_j^{(i)}.$$ (15)

When $\sigma^2{}_j$ obtains the minimum value,

$$x_j = \frac{\sum_{i=1}^{L} x_j^{(i)}}{L}$$ (16)

Whereby the optimized observations $x_1, x_2, \cdots x_m$ can be calculated.

(3) Establish the triangle whiten function

Set the triangle whiten function value of $\dfrac{a_{j,k} + a_{j,k+1}}{2}$ to the grey classification k is 1. Connect $(\dfrac{a_{j,k} + a_{j,k+1}}{2}, 1)$ with the starting point $a_{j,k-1}$ of grey classification $k-1$ and the end point $a_{j,k+2}$ of grey classification $k+1$, obtain the triangle whiten function $f_j^k(x_j), j = 1, 2, \ldots, m; k = 1, 2, \ldots, s$ of grey classification k. The triangle whiten function describes the subjection degree of a value to a value range.

$$f_j^k(x_j) = \begin{cases} 0, x_j \notin \left[a_{j,k-1}, a_{j,k+2} \right] \\ \dfrac{x_j - a_{j,k-1}}{\lambda_{j,k} - a_{j,k-1}}, x_j \in \left[a_{j,k-1}, \lambda_{j,k} \right]. \\ \dfrac{a_{j,k+2} - x_j}{a_{j,k+2} - \lambda_{j,k}}, x_j \in \left[\lambda_{j,k}, a_{j,k+2} \right] \end{cases}$$ (17)

Where

$$\lambda_{j,k} = \frac{a_{j,k} + a_{j,k+1}}{2}.$$

For $f_j^1(x_j)$ and $f_j^s(x_j)$, the value range can be extended to $a_{j,0}$ and $a_{j,s+2}$ according to the specific situation, as shown in Figure 3.
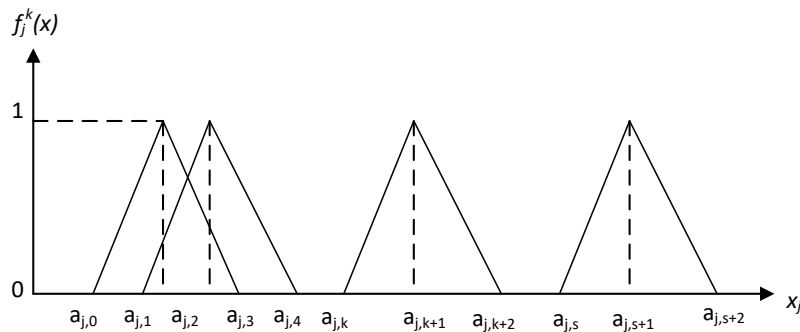

Figure 3. Triangle whiten function and its extension

(4) Calculate the comprehensive clustering coefficient

Calculate the comprehensive clustering coefficient $\sigma^k (k = 1, 2, \ldots, s)$ of grey classification k:

$$\sigma^k = \sum_{j=1}^{m} f_j^k(x_j) \times w_j .$$ (18)

x_j is the optimized observation of indicator j. $f_j^k(x_j)$ is the triangle whiten function of grey classification k. w_j is the weight of indicator j.

It can be judged that the evaluation object belongs to grey classification k^* according to $\max\limits_{1 \le k \le s}\{\sigma^k\} = \sigma^{k^*}$.

3. Case study

This paper assumes that there is a garbage power generation project with two 400t / d grate incinerators and one $2 \times 7.5MW$ condensing steam turbine-generator unit. Actual economic benefits are shown in Table 2.

Taking the benefit evaluation of a $1 \times 30MW$ biomass power generation project as an example, the project is equipped with a $130t/h$ high temperature and high-pressure biomass boiler. The remaining wheats, corn stalks and peanut shells are the main fuel, supplemented by other biomass fuels. The process water uses reclaimed water from sewage treatment plants, while domestic water, firewater and alternative water sources for production come from groundwater. Ash and slag handling system is used in this project. Actual economic benefits are shown in Table 2.

Table 2. The statistic table of actual economic benefits

Indicator (unit)	Actual value
Net present value (ten thousand yuan)	9000
Internal rate of return (%)	12.5
Payback period (year)	8.5
Return on total assets (%)	9.5

Improving the awareness of environmental protection: Biomass power generation projects can effectively solve the environmental pollution caused by traditional straw combustion, help local residents to explore clean and economic treatment of straw, and improve the environmental awareness of residents.

Providing employment opportunities: The project requires a lot of labor force during construction and operation. In addition, to a certain extent, the project can promote the development of peripheral catering trade and other sideline, and thus improve the employment situation.

Increasing farmers' income: To a certain extent, the project improves the income level of the local residents. In addition, it can help farmers to transform the biomass resources into commodity resources, form characteristic industry, promote the farmers' income and drive the local economic development.

SO_2, CO_2 emissions: The project has a spot of dust, SO_2 and NO_X emission. It uses high altitude discharge, long distance conveying, diffusion, dilution and other measures, so the impact of pollutants on the surrounding environment is small.

Dust effect: The fuel straw is piled up in a storage shed or an open-air storage yard. The top of the storage shed is closed, and the open-air storage yard is covered with canvas in the event of windy weather. Ash and slag handling system is designed to prevent dust pollution, so the dust pollution is relatively light.

Noise effect: The noise value of the project is 75 ~ 100d B (A). Boiler room, pump room and other places with large noise work independently. Induced draft fan and other machines with large rotation noise use low-noise equipment. Appropriate greening can play a positive role in dustproof, noise reduction and beautifying the environment.

Wastewater impact: The project has a sewage treatment station and a wastewater pumping station. Domestic sewage, chemical wastewater and waste water from circulation is collected by the sewage network and then discharged into the sewage treatment station. Part of the treated waste water is used for slag removal and ash removal, and the remaining part is discharged into sewage treatment plant through wastewater pumping station.

According to the performance of this project, we can evaluate its comprehensive benefits. Specific steps are as follows.

3.1. Calculate the weight of evaluation indicators

Invite 5 experts to make independent judgment on the least important indicator and give interval numbers of relative importance. The relative importance judgment is shown in Table 3.

Table 3. The result of relative importance judgment

Index symbol	$D_i^{(1)}$	$D_i^{(2)}$	$D_i^{(3)}$	$D_i^{(4)}$	$D_i^{(5)}$
A_1	[4,6]	[7,8]	[7,8]	[6,8]	[7,9]
A_2	[7,9]	[6,8]	[6,8]	[6,9]	[7,9]
A_3	[6,8]	[6,8]	[4,6]	[5,6]	[4,6]
A_4	[4,6]	[4,5]	[4,6]	[5,6]	[4,6]
B_1	[2,4]	1	1	1	1
B_2	1	[2,4]	[2,4]	[3,5]	[2,5]
B_3	[6,8]	[4,6]	[3,5]	[4,5]	[3,5]
C_1	[7,9]	[7,9]	[6,8]	[6,9]	[6,8]
C_2	[6,8]	[6,8]	[4,6]	[5,6]	[4,6]
C_3	[2,4]	[2,4]	[3,5]	[3,4]	[2,4]
C_4	[3,5]	[3,5]	[3,5]	[4,6]	[4,5]

Calculate D_i and D_i^* for the latter four experts with same qualitative judgment on the least important factor, the result is shown in table 4.

Table 4. The calculation result of D_i and D_i^*

Index symbol	D_i	D_i^*
A_1	[7,8]	[6,9]
A_2	[7,8]	[6,9]
A_3	[6,6]	[4,8]
A_4	[5,5]	[4,6]
B_1	[1,1]	[1,1]
B_2	[3,4]	[2,5]
B_3	[4,5]	[3,6]
C_1	[7,8]	[6,9]
C_2	[6,6]	[4,8]
C_3	[3,4]	[2,5]
C_4	[4,5]	[3,6]

Combine Eq. 9 with Eq.11 to calculate the weight opinion w_i^1 of the latter four experts. The weight w_i^2 for the first interval estimation group can be calculated by Eq. 3. The comprehensive weight w_i can be calculated according to Eq.12 and Eq.13. The calculation result is shown in table 5.

Table 5. Weight calculation process and results

Index symbol	w_i^1	w_i^2	w_i
A_1	0.13	0.09	0.12

A_2	0.13	0.13	0.13
A_3	0.10	0.12	0.10
A_4	0.08	0.09	0.08
B_1	0.02	0.06	0.03
B_2	0.07	0.01	0.06
B_3	0.08	0.12	0.09
C_1	0.13	0.13	0.13
C_2	0.10	0.12	0.10
C_3	0.07	0.06	0.06
C_4	0.08	0.07	0.08

3.2. Evaluate the comprehensive benefit of biomass power generation project
(1) Determine the evaluation grey classifications, and select the threshold.

Evaluation indicators in this paper include qualitative and quantitative indicators simultaneously. In order to facilitate the calculation, qualitative and quantitative indicators are treated in the same way. Experts estimate the actual performance of the project, and the estimations are taken as the observation variable of the triangle whiten function.

Assuming that there are four grey classifications: excellent, good, medium and poor. The value range of them is shown in Table 6.

Table 6. The value range of excellent, good, medium and poor grey classification

Grey classification	Excellent	Good	Medium	Poor
Value range	[85,95]	[75,85)	[65,75)	[55,65)

(2) Optimize initial observation

Invite 5 experts to evaluate the performance of the biomass power generation project, obtain 5 sets of initial observation, and optimize the initial observation according to Eq. 16.

Table 7. The initial observation and optimized observation of evaluation Indicators

Index symbol	$x_j^{(1)}$	$x_j^{(2)}$	$x_j^{(3)}$	$x_j^{(4)}$	$x_j^{(5)}$	x_j
A_1	88	77	80	82	70	79
A_2	85	78	83	87	70	81
A_3	85	77	80	85	70	79
A_4	88	78	80	88	72	81
B_1	80	72	78	85	70	77
B_2	85	73	81	80	70	78
B_3	87	70	80	80	73	78
C_1	87	81	82	88	74	82
C_2	85	72	80	80	70	77
C_3	85	80	70	87	60	76
C_4	80	70	80	87	60	75

(3) Establish triangle whiten function

Extend the value range to $a_0 = 45$, $a_6 = 105$. Establish triangle whiten function based on table 6.

$$f_j^{\mathrm{P}}(x_j) = \begin{cases} 0, x_j \notin [45,75] \\ \dfrac{x_j - 45}{60 - 45}, x_j \in [45,60] \\ \dfrac{75 - x_j}{75 - 60}, x_j \in [60,75] \end{cases} \tag{19}$$

$$f_j^{\mathrm{M}}(x_j) = \begin{cases} 0, x_j \notin [55,85] \\ \dfrac{x_j - 55}{70 - 55}, x_j \in [55,70] \\ \dfrac{85 - x_j}{85 - 70}, x_j \in [70,85] \end{cases} \tag{20}$$

$$f_j^{\mathrm{G}}(x_j) = \begin{cases} 0, x_j \notin [65,95] \\ \dfrac{x_j - 65}{80 - 65}, x_j \in [65,80] \\ \dfrac{95 - x_j}{95 - 80}, x_j \in [80,95] \end{cases} \tag{21}$$

$$f_j^{\mathrm{E}}(x_j) = \begin{cases} 0, x_j \notin [75,105] \\ \dfrac{x_j - 75}{90 - 75}, x_j \in [75,90] \\ \dfrac{105 - x_j}{105 - 90}, x_j \in [90,105] \end{cases} \tag{22}$$

(4) Calculate the comprehensive clustering coefficient

Substitute the optimized observation in Table 7 into the above function to calculate the subjection degree of each indicator to each grey classification, and calculate the comprehensive clustering coefficient according to Eq.18. The calculation results are shown in Table 8.

Table 8. Comprehensive clustering coefficient calculation results

Index symbol	$f_j^{\mathrm{P}}(x_j)$	$f_j^{\mathrm{M}}(x_j)$	$f_j^{\mathrm{G}}(x_j)$	$f_j^{\mathrm{E}}(x_j)$
A_1	0.00	0.37	0.96	0.29
A_2	0.00	0.29	0.96	0.37
A_3	0.00	0.37	0.96	0.29
A_4	0.00	0.25	0.92	0.41
B_1	0.00	0.53	0.80	0.13
B_2	0.00	0.48	0.85	0.19
B_3	0.00	0.47	0.87	0.20
C_1	0.00	0.17	0.84	0.49
C_2	0.00	0.51	0.83	0.16
C_3	0.00	0.57	0.76	0.09
C_4	0.00	0.64	0.69	0.00
σ^k	0	3.31	7.01	2.06

As can be seen from the above table, "good" level has the highest comprehensive clustering coefficient, that is, the benefit evaluation result of this project is "good".

4. Conclusion
(1) In this paper, the grey comprehensive evaluation index system of biomass power generation project is established from three aspects: economic benefit, environmental benefit and social benefit.

(2) In this paper, the grey comprehensive evaluation model based on triangle whiten function is improved by introducing group judgment to the weight calculation process and evaluation process, so as to improve the objectivity of the comprehensive evaluation result.

(3) The case study result shows that experts pay more attention to the economic and environmental benefit of biomass power generation projects, and for social benefit, increasing farmers' income is more important. The comprehensive evaluation result of this target project is "good". This example proves the feasibility of grey comprehensive evaluation method based on group judgment in the benefit evaluation of biomass power generation projects.

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