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Study on the Comprehensive Benefit Evaluation of Transnational Power Networking Projects Based on Multi-Project Stakeholder Perspectives

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Abstract: Interconnection of transnational power grids plays an important role in realizing the optimal allocation of energy resources. It can also deepen regional economic cooperation, achieve energy conservation and emission reduction, and improve people's livelihood. This paper constructs a comprehensive benefit evaluation index system for transnational power networking projects which is suitable for the four stakeholders of investors, international lending institutions, sending-oriented states, and receiving-oriented states. Therefore, on the basis of this index system, this paper adopted the weight determination method based on the order relation method and Gini coefficient method to synthesize subjective and objective information. Then the comprehensive benefit evaluation of such projects was carried out by matter-element extension model with grey relational projection value. Therefore, the problem with the Euclid approach degree leading to a low discrimination of many samples to be evaluated was effectively solved. The final empirical analysis results showed that the focus and evaluation results of the comprehensive benefits of such projects from the perspective of different stakeholders were quite different. The results of comprehensive benefit evaluation will improve the accuracy of decision-making and the objectivity of evaluation, so as to provide decision-making references for different stakeholders.

Keywords: transnational power networking projects; comprehensive benefit evaluation; order relation method; Gini coefficient method; matter-element extension model based on grey relational projection value

1. Introduction

At present, the world's energy development is faced with three major problems: resource shortage, environmental pollution, and climate change. The Belt and Road Initiative proposes the concept of global green energy and low-carbon development, which has to be in conformity with the theme of the global green energy transformation [1]. With the support of China's "one belt and one way" initiative, transnational power networking projects also contribute to balancing the development of the power industry and decreasing the population without electricity [2]. Transnational power networking along the "one belt and one road" has been large-scale. By the end of 2015, 50 countries in 64 core countries along the route have built-up transnational transmission lines and have carried out cross-border power trade with neighboring countries [3]. In recent years, many power enterprises have carried out overseas electric power construction projects [4]. Because of its huge scale and high complexity, there are many core project stakeholders, such as construction units, material supply units, and supervision units. Meanwhile, governments, media, and social public welfare organizations have participated in the large-scale transnational power networking projects [5]. Therefore, under the rubric of the "one belt and one road" power interconnection, a comprehensive systematic and scientific benefit evaluation system for transnational networking engineering was constructed from the perspective of project stakeholders, which can provide certain theoretical support for different stakeholders in making relevant decision-making activities.

With the deepening of research, the benefit evaluation of power grid construction projects has gradually expanded from economic benefits to social and ecological environment. He et al. [6] proposed an improved evaluation index system including net present value, internal rate of return, etc. Bakhshi et al. [7] evaluated the economic benefits of a photovoltaic grid connected power generation system. Tian et al. [8] established an evaluation index of ultra-high voltage grid social benefits based on lifecycle cost. Sidhu et al. [9] analyzed the benefits of grid-scale power storage location and system-wide determined the realistic combination of those social benefits, and juxtaposed them against the social costs across the useful lifecycle of the battery to determine the techno-economic performance. Zeng et al. [10] designed the Smart distribution network environmental benefit evaluation index system covering four aspects. Zeng et al. [11] constructed an evaluation index system for ecological environment sensitivity of typical power grid projects on the Qinghai Tibet Plateau.

In recent years, the comprehensive benefit evaluation of power grid construction projects has become a research hotspot. Xu et al. [12] proposed a method to evaluate probabilistic comprehensive benefits of joint wind power and storage systems considering constraints of peak load regulation capacity. According to the characteristics of distribution network, Wu et al. [13] used the analytic hierarchy process and extension evaluation method improved by interval number theory to quantify the comprehensive benefits of a distribution network project. Büyüközkan et al. [14] used multi-criteria decision-making technology and an analytic hierarchy process to build a comprehensive evaluation index system for comprehensive evaluation of energy investment project. Du et al. [15] introduced group judgment and exponential scaling and used improved grey system whitening weight function to evaluate the comprehensive benefits of power grid companies. Li et al. [16] proposed an improved grey target decision model based on moment estimation method, in which combinatorial weight integration technology and the Mahalanob distance are coupled. Zhang et al. [17] introduced variable weight theory to modify and improve the accuracy of abnormal weight and used a cloud model to evaluate a distribution network comprehensively. Zeng, et al. [18] proposed a new development direction in the field of future integrated energy system modeling and benefit evaluation system research.

Literature on the comprehensive benefit evaluation of a power grid based on different stakeholders are scarce at home and abroad. Xia et al. [19] identified the stakeholders of hydropower projects and their input–output factors based on stakeholder theories and highlights the four most important core stakeholders. Rahmani-andebili et al. [20] presented details of changes in the power market regulations. In this paper, the power market players are independently modeled in the agent-based virtual power market environment, and then the power market is simulated from the regulator's viewpoint. Ma et al. [21] explored the decisive risks attributed to each stakeholder by considering a green development project's stage. Xia et al. [22] identified four linkage modes between risk and stakeholder management.

Previous studies have made some achievements, but the comprehensive benefits of multi-stakeholder transnational power networking projects have not yet formed a systematic evaluation system. In the whole project cycle, especially in the decision-making stage, different stakeholders will exert different influences on transnational power networking projects. In view of the characteristics of such projects, this paper constructs a comprehensive benefit evaluation index system from the perspective of multi-agent and proposes a matter-element extension model based on grey relational projection value. On the one hand, it verifies that the focus and evaluation results of the comprehensive benefits of such projects are quite different from the perspective of different stakeholders. On the other hand, it provides references for different stakeholders to make investment decisions and improves the comprehensiveness and objectivity of the comprehensive benefit research of such projects.

The main contributions of this paper are as follows:

(1) The idea of multi-stakeholders is introduced into the comprehensive benefit evaluation of such projects.
(2) The improved comprehensive evaluation method improves the accuracy of the results.
(3) The results of evaluation of such projects provide references for different stakeholders to make investment decisions.

The rest of this paper is structured as follows: Section 2 introduces the research procedure and the method employed in this paper; Section 3 describes the benefit index system of such projects. Section 4 proposes a case analysis to validate the index system and the evaluation model established in this paper. The conclusions are drawn in Section 6.

2. Methods

As system engineering, transnational networking projects involve many stakeholders in the whole lifecycle of the project. Among them, investors, international lending institutions, sending countries, and receiving countries are most closely related to projects. Therefore, it is necessary to stand in the perspective of different stakeholders before the implementation of the project to conduct comprehensive benefits evaluation, so as to improve the accuracy of decision-making. The research process in this paper is illustrated in Figure 1.

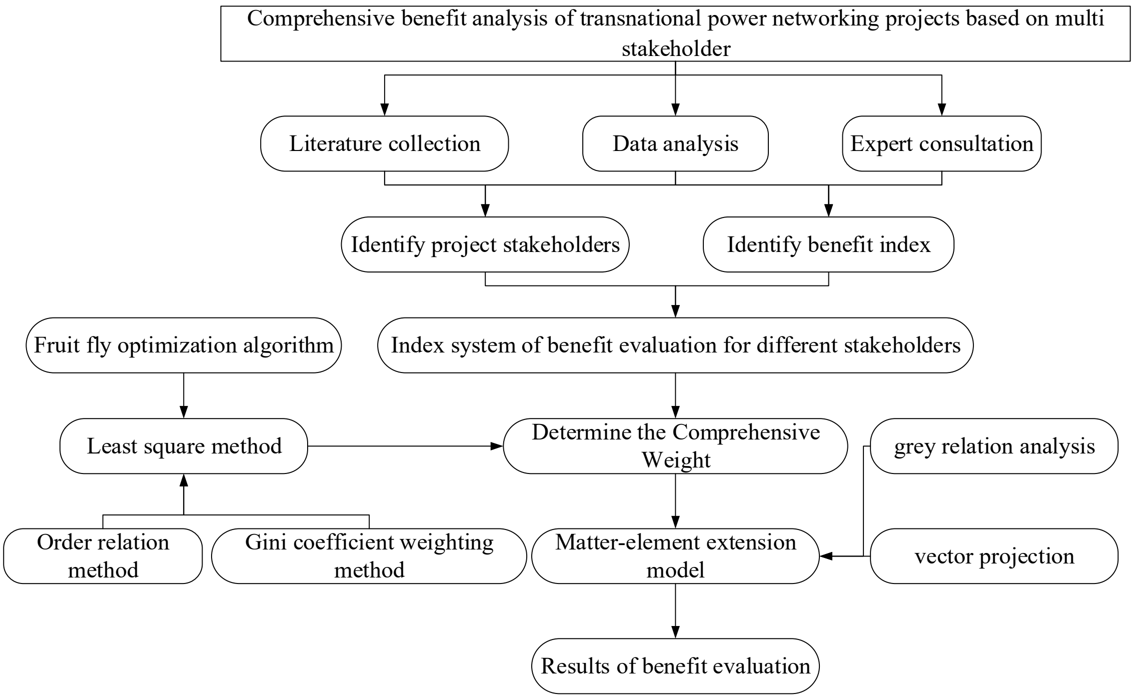

Figure 1. Research procedure.

2.1. Weight Determination

Index weight reflects the importance of indicators to the assessed objects [23]. In this paper, the order relation method and Gini coefficient weighting method are combined to determine the index weight by the least squares method, which effectively improves the rationality of the results.

2.1.1. Order Relations Method

Order relations method is an intuitive and effective method to determine subjective weights. It makes full use of experts' experience and obtains the importance ranking of all indices [24]. The following steps constitute the order relations method:

Step 1: Determine Order Relations

The index order relation of the evaluation criterion is $Y_1 > Y_2 > \cdots Y_m$.

Step 2: Determine the relative importance degree of adjacent index.

The relative importance degree of adjacent index can be described as:

$$r_k = Y_{k-1}/Y_k \tag{1}$$

where r_k is the ratio of the importance of expert evaluation indices Y_{k-1} and Y_k ($k = m, m-1, \cdots, 3, 2$).

Step 3: Determine the weight u_k.

The weight can be calculated by following equations.

$$u_k = \left(1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_i\right)^{-1} \tag{2}$$

$$u_{k-1} = r_k u_k (k = m-1, \cdots, 2) \tag{3}$$

2.1.2. Gini Coefficient Weighting Method

Gini coefficient weighting method is an objective weighting method which calculates Gini coefficient and normalizes it to get index weight [25].

Step 1: Calculating the Gini coefficient value of the evaluation index.

$$G_k = \sum_{i=1}^{n} \sum_{j=1}^{n} \left|Y_{ki} - Y_{kj}\right| / 2n^2 \mu_k \tag{4}$$

where G_k is Gini coefficient value of index k; n is the total number of objects to be evaluated; Y_{ki} and Y_{kj} are the index k of data i and j, respectively; μ_k is the expected value of index k.

Step 2: Calculating the Gini coefficient weight of index.

$$v_k = G_k / (\sum_{i=1}^{m} G_i) \tag{5}$$

where v_k is Gini coefficient weight of index k; m is the total number of indices.

2.1.3. Least Squares Method

The subjective weighting method embodies the value of the index, the objective weight reflects the information of the index; each has its own characteristics and the comprehensive evaluation should reflect the unification of the two. The weight of each index given by the objective weighting method is $V = [v_1, v_2 \cdots, v_m]^T$. The optimal combination weight of each index is $W = [w_1, w_2 \cdots, w_m]^T$. The standardized data matrix with m evaluation indices and n evaluation objects is $Z = (Z_{ik})_{n \cdot m}$. The evaluation value of the evaluation object i is $f_i = \sum_{i=1}^{m} w_k z_{ik}$, $i = 1, 2, \cdots, n$, so as to establish the combinational evaluation model optimized by least squares method. The model is shown in the following equation [26]:

$$\begin{aligned} &\min H(w) = \sum_{i=1}^{n} \sum_{k=1}^{m} \left\{[(u_k - w_k) z_{ik}]^2 + [(v_k - w_k) z_{ik}]^2\right\} \\ &s.t. \sum_{k=1}^{m} w_k = 1, w_k \geq 0 \ \ (k = 1, 2, \cdots, m) \end{aligned} \tag{6}$$

2.2. Matter-Element Extension Model Based on Grey Relational Projection Value

The fuzzy matter-element evaluation method can synthesize multiple evaluation indexes into one index to evaluate ranking according to the degree of similarity between the sample to be evaluated and the standard sample [27]. In this paper, the Euclid approach degree which describes the similarity degree between the sample to be evaluated and the standard sample in the fuzzy matter element analysis method is improved by combining the grey relational projection method. Moreover, the projection value of the sample to be evaluated on the standard sample is used for comprehensive evaluation. The concrete steps of the matter-element extension model based on grey relational projection value are as follows:

Step 1: Constructing n dimensional compound fuzzy matter-element R_{mn} of m things.

$$R_{mn} = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ C_1 & x_{11} & x_{21} & \cdots & x_{m1} \\ C_2 & x_{12} & x_{22} & \cdots & x_{m2} \\ \vdots & \vdots & \vdots & \ldots & \vdots \\ C_n & x_{1n} & x_{2n} & \cdots & x_{mn} \end{bmatrix}$$

The n characteristics of M are $C_1, C_2, \cdots, C_n$, and its corresponding fuzzy value is $X_1, X_2, \cdots, X_n$. At that time, n dimensional fuzzy matter element R_n is formed. If there are m things in common: $M_1, M_2, \cdots, M_n$, and each thing has the same n characteristics: $C_1, C_2, \cdots, C_n$, then the n dimensional compound fuzzy matter element R_{mn} of m things is formed.

Step 2: According to the principle of preferred subjection degree, the composite fuzzy matter-element $\widetilde{R}$ is calculated.

The evaluation indices C_i are transformed into "effective" indices and normalized. The equations are as follows:

$$\mu_{ji} = \frac{x_{ji}}{\max x_{ji}} \tag{7}$$

Then the composite fuzzy matter-element of preferred subjection degree $\widetilde{R}$ is represented by:

$$\widetilde{R} = \begin{bmatrix} & M_0 & M_1 & M_2 & \cdots & M_m \\ C_1 & \mu_{01} & \mu_{11} & \mu_{21} & \cdots & \mu_{m1} \\ C_2 & \mu_{02} & \mu_{12} & \mu_{22} & \cdots & \mu_{m2} \\ \vdots & \vdots & \vdots & \vdots & \ldots & \vdots \\ C_n & \mu_{0n} & \mu_{1n} & \mu_{2n} & \cdots & \mu_{mn} \end{bmatrix}$$

Step 3: Calculating projection weights and projection values.

If the weight of the index i is ω_i, then the weight of the composite fuzzy matter-element is considered as R_W. R_W is represented by:

$$R_W = \begin{bmatrix} & M_0 & M_1 & M_2 & \cdots & M_m \\ C_1 & \omega_1 & \omega_1\mu_{11} & \omega_1\mu_{21} & \cdots & \omega_1\mu_{m1} \\ C_2 & \omega_2 & \omega_2\mu_{12} & \omega_2\mu_{22} & \cdots & \omega_2\mu_{m2} \\ \vdots & \vdots & \vdots & \vdots & \ldots & \vdots \\ C_n & \omega_n & \omega_n\mu_{1n} & \omega_n\mu_{2n} & \cdots & \omega_n\mu_{mn} \end{bmatrix}$$

In order to fully consider the degree of "similarity" with the standard matter element, the size of the matrix and the angle cosine are comprehensively considered by combining the correlation projection method of grey system theory. That is to say, considering the projection value of the fuzzy matter element M_j on the standard fuzzy matter element M_0, the proximity between each fuzzy matter element M_j and standard fuzzy matter element M_0 can be reflected comprehensively and accurately [28]. The projection value of M_j on M_0 can be calculated by the following Formula (8).

$$d_j = \|M_j\| \cos\theta = \|M_j\| \cdot \frac{M_j \cdot M_0}{\|M_j\| \cdot \|M_0\|} = \frac{M_j \cdot M_0}{\|M_0\|} = \frac{\sum\limits_{i=1}^{n} \omega_i \mu_{ji} \omega_i}{\sqrt{\sum\limits_{i=1}^{n} \omega_i{}^2}} = \frac{\omega_i{}^2}{\sqrt{\sum\limits_{i=1}^{n} \omega_i{}^2}} \sum_{i=1}^{n} \mu_{ji} \quad (j = 1, 2, \ldots, m) \tag{8}$$

where $\frac{\omega_i{}^2}{\sqrt{\sum\limits_{i=1}^{n} \omega_i{}^2}}$ is called projection weight, and comprehensive evaluation can be made according to the size of the projection value d_j.

Step 4: The projection values are sorted according to the numerical value so as to determine the optimal scheme.

3. Index System of Different Stakeholders

Transnational power networking projects are the interconnected construction of power networks between two or more countries or regions to realize efficient and stable transmission of power resources across countries. On the one hand, this characteristic makes the whole project lifecycle of such projects need to involve the coordination and cooperation of different organizations and departments, and the project involves more stakeholders; on the other hand, the different stakeholders involved in the project are often based on different interest perspectives when making relevant investment decisions. From the above two aspects, it is of great practical significance to divide and determine project stakeholders for such projects, and to analyze the comprehensive benefits of such projects from the perspective of different project stakeholders.

3.1. Comprehensive Benefit Index System of Transnational Power Networking Projects Based on Investors' Perspective

As the initiator and owner of the project, the investor provides direction or assistance for the project in the form of funds or technology. In the process of relevant investment decision-making of transnational power networking projects, the investors who takes investment return as a basic guide mainly proceeds from the angle of economic benefit and takes into account the social impact of the project as the basis for their corresponding decision-making. The comprehensive benefit evaluation index system of such projects based on the investors' perspective is shown in Figure 2.

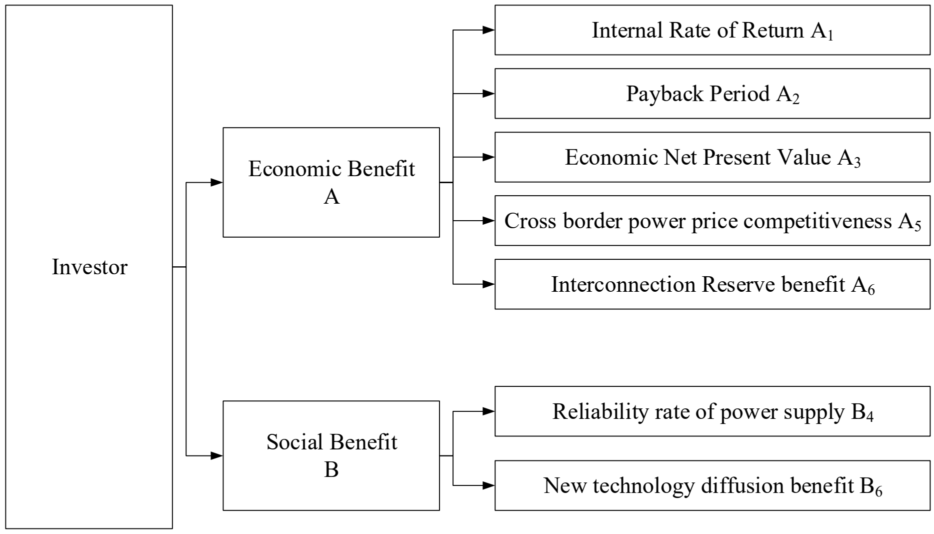

Figure 2. The comprehensive benefit evaluation index system of transnational power networking projects based on investors' perspective.

3.2. Comprehensive Benefit Index System of Transnational Power Networking Projects Based on the Perspective of International Lending Institutions

International loans are an important source of construction funds for transnational power networking projects. Therefore, from the perspective of international lending institutions, the comprehensive benefits of the implementation of transnational power networking projects are analyzed. On the one hand, it can realize self-evaluation of projects for relevant enterprises before making investment and financing decisions for transnational networking projects and provide guarantees for the smooth access to financial support from international financial organizations. On the other hand, it can provide a reference for the assessment of loan applications of international financial organizations for such projects. Based on the above analysis, the comprehensive benefit evaluation index system of such projects from the perspective of international lending institutions is shown in the Figure 3.

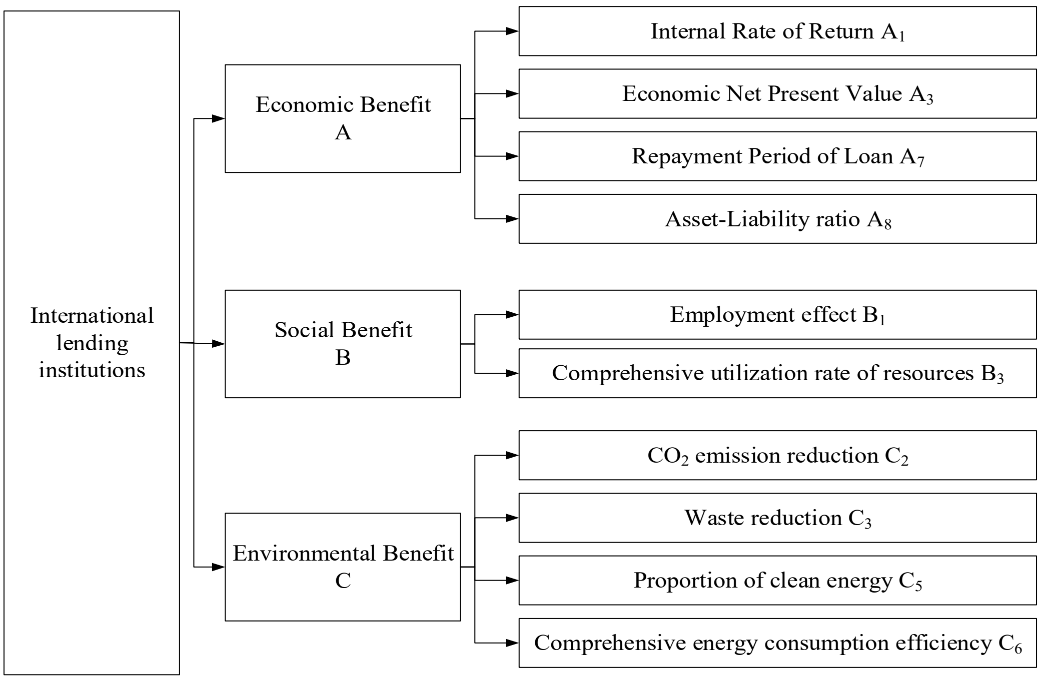

Figure 3. The comprehensive benefits evaluation index system of transnational power networking projects based on the perspective of international lending institutions.

3.3. Comprehensive Benefit Index System of Transnational Interconnection Projects Based on the Perspective of the Sending-Oriented State

Sending-oriented states are not only the key to balancing the development of regional energy industries and giving full play to the complementarity of the power industry among countries, but are also important promoters of the transformation of regional energy production structures. The planning and implementation of transnational power networking projects, on the one hand, effectively promotes the upgrading of the power market scale of the sending-oriented state and realizes the transformation of the energy resources advantages of the sending-oriented states to the economic advantages. On the other hand, it also improves the development and utilization level and utilization efficiency of energy resources of the sending-oriented states. Combined with the above analysis, the comprehensive benefit evaluation index system of such projects based on the perspective of the sending-oriented state is shown in Figure 4.

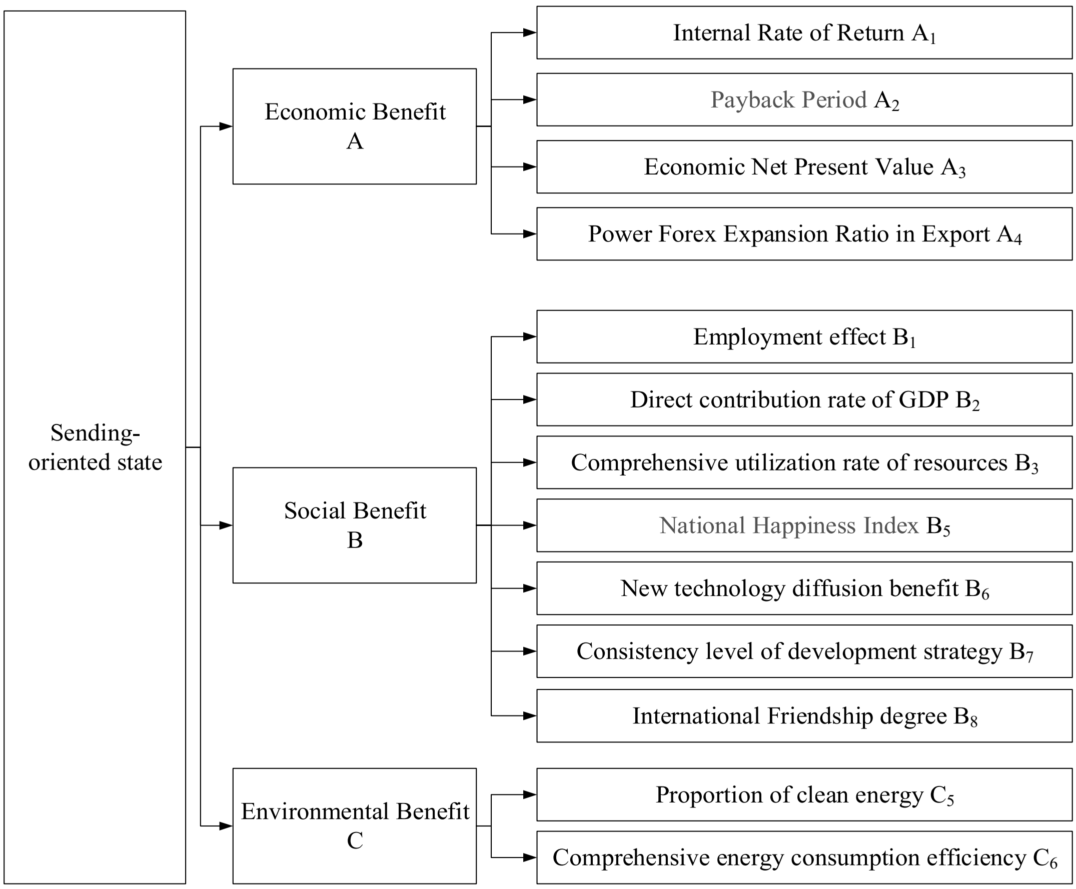

Figure 4. The comprehensive benefits evaluation index system of transnational power networking projects based on the perspective of sending-oriented states.

3.4. Comprehensive Benefit Index System of Transnational Interconnection Projects Based on the Perspective of Receiving-Oriented State

Receiving-oriented states are important promoters and beneficiaries of the implementation of transnational power networking project planning. On the one hand, the implementation of the project can effectively meet the electricity demand of receiving-oriented states; on the other hand, the implementation of the project realizes the input of clean energy such as wind power, hydropower, and photoelectricity, which has a significant positive impact on the energy consumption structure and mode of energy consumption in receiving-oriented states. Based on the above analysis, the comprehensive benefit evaluation index system of such projects from the perspective of receiving-oriented states is shown in Figure 5.

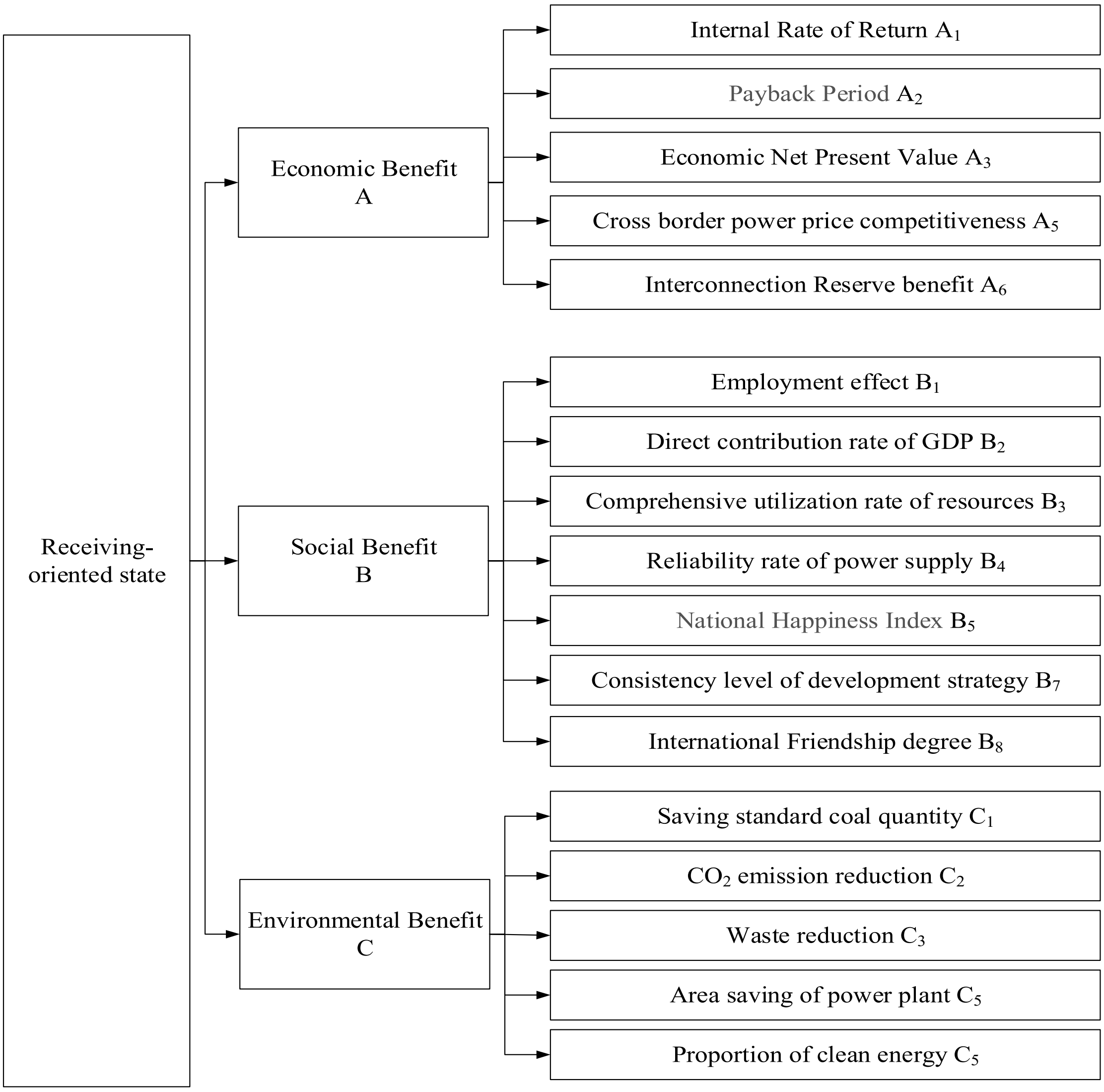

Figure 5. The comprehensive benefit evaluation index system of transnational power networking projects based on the perspective of receiving-oriented states.

3.5. Comprehensive Benefit Index Instruction for Transnational Power Networking Projects Based on Multi-Project Stakeholders

3.5.1. Economic Indices

(1) Internal rate of return

Internal rate of return is a meaningful parameter for prospective owners of these power systems [29]. It refers to the discount rate when the total present value of project capital inflows equals the total present value of capital flows and the net present value equals zero. The calculation method is as follows:

$$i^* = \frac{NPV_n \times (i_{n+1} - i_n)}{NPV_n + |NPV_{n+1}|} + i_n \tag{9}$$

where i_n is a low trial discount rate; i_{n+1} is a higher trial discount rate; NPV_n is the net present value corresponding to i_n; NPV_{n+1} is the net present value corresponding to i_{n+1}. Usually, when the gap between i_n and i_{n+1} is not more than 2%: $|i_n - i_{n+1}| \leq 2\%$, the error is acceptable.

(2) Payback period

The payback period refers to the period required to recover all investment with the net income of each year from the date of project construction. It can be calculated by the following formula:

$$\sum\nolimits_{t=1}^{T_p} NB_t = \sum\nolimits_{t=0}^{T_p} (B-C)_t = K \tag{10}$$

where K is the total investment; B_t represents income in year t; C_t represents the expenditure in year t; NB_t is the net income in year t; T_p is the payback period for the investment.

(3) Economic net present value

Economic net present value refers to the sum of the net benefit flow of each year in the project calculation period converted to the present value at the beginning of the project construction period with the social discount rate. The decision to proceed with a power engineering project is often preceded by some form of net present value analysis [30]. The formula is as follows:

$$ENPV = \sum_{i=0}^{n} \frac{B_{Ti} - C_{Ti}}{(1+r)^i} \tag{11}$$

where B_{Ti} and C_{Ti} are the total benefits and total expenses occurring in the year i, respectively; n is the calculation period of the project; and r is the social discount rate.

(4) Power forex expansion ratio in export

Power forex expansion ratio in export refers to the appreciation of foreign exchange generated by the export of electricity products from the sending-oriented state. The calculation method is as follows:

$$Eer = \frac{Fee}{Tpi} \times 100\% \tag{12}$$

where Eer, Fee, and Tpi respectively represent power forex expansion ratio in export and foreign exchange earnings from electric products and total project investment.

(5) Cross border power price competitiveness

Cross border power price competitiveness measures the price advantage of imported power products compared with the same type of power products in power importing countries. This index is mainly used to measure the economic benefits of power importing countries involved in transnational power networking projects. The formula is as follows:

$$CS_t = T_r - T_s \tag{13}$$

where CS_t is cross-border power price competitiveness; T_r is receiving terminal price; T_s is sending end to net price and it is the sum of sending terminal price and transmission price.

(6) Interconnection reserve benefit

Interconnection reserve benefit refers to the increase or decrease of reserve capacity after interconnection of power grids.

(7) Repayment period of loan

Repayment period of loan refers to the time required to repay the loan principal and construction interest with the funds available for repayment after the project is put into operation under the state financial regulations and the specific financial conditions of the project. It can be defined by:

$$I_d = \sum_{i=1}^{P_d} R_t \tag{14}$$

where I_d is the sum of the loan principal and the interest during the construction period; P_d is the loan repayment period; R_t is the funds available for repayment in year t.

(8) Asset-liability ratio

Asset-liability ratio reflects the proportion of total assets in a project borrowed by debt. It has more explanatory power to study the adjustment behavior of asset-liability ratio of China's power grid companies from a dynamic point of view [31]. The formula is as follows:

$$DAr = \frac{Ti}{Ta} \times 100\% \tag{15}$$

where total liabilities Ti include long-term liabilities and short-term liabilities; the total assets Ta is net after deducting accumulated depreciation.

3.5.2. Social Indices

(9) Employment effect

The construction and operation of power grid projects involves design, construction, maintenance, and other specialties, which provide direct or indirect employment opportunities for society. The employment effect indicators reflect the employment benefits brought about by this project. The calculation method is as follows:

$$Ee = Ne/Di \tag{16}$$

where Ee represents employment effect; Ne and Di respectively represent new employment population and direct investment of this project.

(10) Direct contribution rate of GDP

The contribution to economic growth is one of the important criteria for judging the quality of projects. The direct contribution rate of GDP can be used to determine the impact of transnational power networking projects on the national economy. The formula is as follows:

$$S = \frac{C}{G} \times 100\% \tag{17}$$

where S represents the direct contribution rate of GDP; C represents the annual income of electricity sales, and G represents the GDP of corresponding year.

(11) Comprehensive utilization rate of resources

Through the establishment of transnational power networking project, the sending-oriented state can optimize the allocation of resources rationally, thus increasing the comprehensive utilization rate of the national power generation resources. The formula is as follows:

$$Rue = \frac{Ru}{Rr} \times 100\% \tag{18}$$

(12) Reliability rate of power supply

After the interconnection of power grids, the reserve capacity of each power system can support each other, thereby improving the power supply system's ability to sustain power supply and reducing power outage losses. Studying power supply reliability supports safety assessment, machine availability assessment, and can potentially improve power supply performance [32]. The calculation method is as follow:

$$RSI = \left(1 - \frac{t}{T}\right) \times 100\% \tag{19}$$

where RSI refers to the power supply reliability rate, t represents the average power outage time of users, and T represents the annual number of hours.

(13) National happiness index

The national happiness index is an index to measure the economic development, social progress, residents' living and happiness level of a country or region. After the establishment of a transnational power networking project, the quantity and quality of power supply in receiving-oriented states have been greatly improved. As a result, users have been more satisfied and contented, and the NHI (national happiness index) has been improved.

(14) New technology diffusion benefit

Once the new technology is mature, it may be widely used at low cost by the participants in the broad market. The wider the use of the new technology, the greater the diffusion efficiency of the new technology.

(15) Consistency level of development strategy

For large- and medium-sized power grid projects, it is necessary to analyze whether the projects are compatible with national and regional development priorities of global energy-related agreements and development plans. The establishment of transnational power networking projects is conducive to the adaptability of regional development planning.

(16) International friendship degree

The establishment of transnational power networking projects will help to enhance the international friendship between receiving-oriented states and sending-oriented states and promote the long-term cooperation between the two countries in the fields of economy, science, and technology.

3.5.3. Environmental Indices

(17) Saving standard coal quantity

The transnational power networking project effectively reduces the burning of fossil energy resources such as coal in the power industry and optimizes the energy structure through the clean power grid connection. Therefore, the estimated total electricity transported during the project period is calculated, and according to the average coal consumption per kilowatt-hour of thermal power plants in the receiving area, the saved standard coal quantity of such projects is calculated.

(18) CO_2 emission reduction

Transnational power networking projects reduce CO_2 emissions through clean energy transfer. Therefore, by calculating the total amount of CO_2 expected to be transported during the project period and combining it with the average power supply emissions per kilowatt/hour of power plants in the receiving area, we can calculate the reduction of CO_2 in such projects [33].

(19) Waste reduction

Transnational power networking projects reduce slag generation in the power generation process by reducing the combustion of fossil energy resources such as coal in the power industry. Therefore, the total amount of slag transported during the project period is estimated and combined with the total amount of slag produced by power supply per kilowatt/hour in the receiving area, and the total amount of slag reduced in such project is calculated.

(20) Area saving of power plant

Transnational power networking projects can meet local electricity demand by transmitting electricity and reduce the local power generation burden and the number of power plants, thus reducing the area of thermal power plants. It can be defined by:

$$\Delta S = S_o - S_p \tag{20}$$

where ΔS is the area saved after the establishment of transnational networking projects; S_o and S_p represent the area used for power plants before and after the establishment of transnational networking projects, respectively.

(21) Proportion of clean energy

Promoting "two substitutes" to form a clean energy-dominated energy pattern, the core of which is to continuously improve the efficiency and economy of clean energy development. The establishment of transnational power networking project helps to increase the proportion of clean energy use, which can be calculated by the ratio of clean energy generation to total transmission power in the transmission process.

(22) Comprehensive energy consumption efficiency

Transnational power networking projects can directly or indirectly enhance the local comprehensive energy consumption efficiency. According to the relevant provisions of the General Principles for Circulation of the Comprehensive Energy Consumption, the comprehensive energy consumption efficiency of the project reflects the energy-saving effect produced by the implementation of the project construction. The specific computing method is as follows:

$$E' = E/O \tag{21}$$

where E' is the comprehensive energy consumption efficiency of the project; E is the value of the comprehensive energy consumption of the project in that year; O is the net output of the project in that year.

4. Case Study

On the basis of summing up the work of the previous chapters, the transnational high-voltage direct current transmission project introduced in Reference [34] is taken as the evaluation object, and according to the index system and evaluation model established, the benefit levels of two different schemes are extracted from different stakeholder perspectives. Scheme I: +660 kV, converter station double valve hall in series, transmission capacity 4400 MW, 6 × 720 conductor; Scheme II: +800 kV, transmission capacity 8000 MW, 6 × 1250 conductor. Scheme II can meet the current (8 × 660) and prospective (16 × 660) transmission requirements. Scheme I can only meet the current power transmission requirements and cannot meet the development and construction of subsequent power stations.

4.1. Basic Information of the Project to be Evaluated

Through the calculation of the project data in the case background, the data of each index is standardized by the expert scoring method. The results are shown in Table 1.

Table 1. Calculation and normalization of comprehensive benefits evaluation index data of different schemes.

Index *i*	Scheme I		Scheme II	
	Observed Value	Normalized Value	Observed Value	Normalized Value
Internal Rate of Return A1 (%)	3.76%	0.54	6.21%	0.72
Payback Period A2 (year)	10.33	0.52	8.67	0.81
Economic Net Present Value A3 (100 million)	21.48	0.6	16.86	0.55
Power Forex Expansion Ratio in Export A4 (%)	9.87%	0.85	8.02%	0.8
Cross Border Power Price Competitiveness A5 (Yuan/Kwh)	0.31	0.8	0.24	0.72
Interconnection Reserve Benefit A6 (100 million))	6.75	0.58	4.82	0.55
Repayment Period of Loan A7 (year)	28.63	0.79	31.79	0.63
Asset-Liability Ratio A8 (%)	0.90	0.57	0.88	0.74
Employment Effect B1 (per/100 million)	507	0.58	732	0.71
Direct Contribution Rate of GDP B2 (%)	8.37%	0.82	8.32%	0.80
Comprehensive Utilization Rate of Resources B3 (%)	81.05%	0.81	81.05%	0.81
Reliability Rate of Power Supply B4 (%)	99.97%	0.81	99.93%	0.78
National Happiness Index B5 (1)	83.04	0.83	81.99	0.82
New Technology Diffusion Benefit B6 (100 million)	64.9	0.64	78.2	0.78
Consistency Level of Development Strategy B7 (%)	80.67%	0.8	96.48%	0.96
International Friendship Degree B8 (1)	0.85	0.78	0.87	0.87
Saving Standard Coal Quantity C1 (Mtce)	1777.91	1	1777.91	1
CO_2 Emission Reduction C2 (Gt)	27.05	1	27.05	1
Waste reduction C3 (Gt)	6.15	1	6.15	1
Area Saving of Power Plant C4 (Gt)	62	0.58	45	0.42
Proportion of Clean Energy C5 (%)	100%	1	100%	1
Comprehensive Energy Consumption Efficiency C6 (%)	18.81%	0.49	19.32%	0.65

4.2. Weight Determination

(1) Order relation method

According to the actual situation and background of the transnational power networking project, an expert group of 10 persons was established. The members of the expert group covered many subjects such as economy (2 persons), technology (2 persons), environment (2 persons), government (1 person), bank (1 person), and power grid construction enterprise (2 persons). In view of the importance of experts to each index, expert 1 ranks the importance degree of investors' index system as an example, and the calculation process is shown in Table 2. In addition, the weights obtained by the expert group according to the order relation method are weighted averagely to get the weights of the comprehensive evaluation index system of investors.

Table 2. The weights obtained by order relations method based on investors (expert 1 as example).

Index *i*	A1	A2	A5	A3	B4	A6	B6
Rank	1	2	3	4	5	6	7
r_i		1.2	1.2	1.4	1.4	1.4	1.2
u_i	0.27	0.22	0.19	0.13	0.09	0.07	0.06

(2) Gini coefficient weighting method

According to $G_k = \sum_{i=1}^{n}\sum_{j=1}^{n}\left|Y_{ki} - Y_{kj}\right|/2n^2\mu_k$ and $v_k = G_k/(\sum_{i=1}^{m} G_i)$, taking the standardized data of investor evaluation index as an example, the calculation process of Gini coefficient is shown in Table 3.

Table 3. The weights obtained by Gini coefficient weighting method based on investors.

Index i	Scheme I	Scheme II	G_i	v_i
A1	0.54	0.72	0.07	0.24
A2	0.52	0.81	0.11	0.36
A3	0.60	0.55	0.02	0.07
A5	0.80	0.72	0.03	0.09
A6	0.58	0.55	0.01	0.04
B4	0.81	0.78	0.01	0.03
B6	0.64	0.78	0.05	0.16

The weights of other stakeholders are calculated by similar methods, so that the objective weight of Gini coefficient can be calculated, as shown in Table 4. In which the investors, international lending institutions, sending-oriented states, and receiving-oriented states are respectively represented by L1, L2, L3, and L4.

Table 4. The weights of each stakeholder obtained by order relation method and Gini coefficient weighting method.

Index i	L1		L2		L3		L4	
	u_i	v_i	u_i	v_i	u_i	v_i	u_i	v_i
A1	0.16	0.24	0.13	0.21	0.09	0.15	0.06	0.15
A2	0.15	0.36			0.07	0.23	0.06	0.24
A3	0.15	0.07	0.12	0.06	0.07	0.05	0.05	0.05
A4					0.12	0.03		
A5	0.15	0.09					0.03	0.06
A6	0.12	0.04					0.1	0.03
A7			0.15	0.17				
A8			0.14	0.19				
B1			0.13	0.15	0.09	0.11	0.07	0.11
B2					0.1	0.01	0.04	0.01
B3			0.1	0.00	0.06	0.00	0.09	0.00
B4	0.13	0.03					0.08	0.02
B5					0.06	0.01	0.07	0.01
B6	0.14	0.16			0.07	0.11		
B7					0.08	0.10	0.04	0.10
B8					0.09	0.06	0.07	0.06
C1							0.04	0.00
C2			0.09	0.00			0.08	0.00
C3			0.05	0.00			0.03	0.00
C4							0.03	0.17
C5			0.04	0.00	0.06	0.00	0.06	0.00
C6			0.05	0.00	0.04	0.15		

Note: u_i and v_i represent the weights of index i determined by order relation method and Gini coefficient method respectively.

(3) Least squares method

Fruit fly optimization algorithm is a new swarm intelligence optimization algorithm proposed by learning the foraging behavior of fruit fly swarm with super vision and olfaction. Compared with other optimization algorithms, fruit fly optimization algorithm has advantages in optimization speed and number of parameters [35]. In this paper, we use fruit fly optimization algorithm to solve the optimal combination weight obtained by least squares method. The results are shown in Table 5.

Table 5. The combined weights of each stakeholder.

Index *i*	L1	L2	L3	L4
A1	0.20	0.17	0.12	0.11
A2	0.26		0.15	0.15
A3	0.11	0.09	0.06	0.05
A4			0.08	
A5	0.12			0.04
A6	0.08			0.06
A7		0.16		
A8		0.17		
B1		0.14	0.10	0.09
B2			0.06	0.03
B3		0.05	0.03	0.05
B4	0.08			0.05
B5			0.03	0.04
B6	0.15		0.09	
B7			0.09	0.07
B8			0.07	0.06
C1				0.02
C2		0.05		0.04
C3		0.03		0.02
C4				0.10
C5		0.02	0.03	0.03
C6		0.13		

4.3. Benefit Evaluation of Two Schemes

(1) Evaluation of scheme based on investors

According to the principle of preferred subjection degree introduced in Section 2.2, the 7-dimensional composite fuzzy matter-element of two matter-elements $\widetilde{R}$ is calculated.

$$\widetilde{R} = \begin{bmatrix} & M_0 & M_1 & M_2 \\ A_1 & 1 & 0.75 & 1 \\ A_2 & 1 & 0.64 & 1 \\ A_3 & 1 & 1 & 0.92 \\ A_5 & 1 & 1 & 0.90 \\ A_6 & 1 & 1 & 0.95 \\ B_4 & 1 & 1 & 0.96 \\ B_6 & 1 & 0.82 & 1 \end{bmatrix}$$

The optimal composite fuzzy matter-element considering the combined weight is R_W.

$$R_W = \begin{bmatrix} & M_0 & M_1 & M_2 \\ A_1 & 0.20 & 0.15 & 0.20 \\ A_2 & 0.26 & 0.16 & 0.26 \\ A_3 & 0.11 & 0.11 & 0.10 \\ A_5 & 0.12 & 0.12 & 0.11 \\ A_6 & 0.08 & 0.08 & 0.08 \\ B_4 & 0.08 & 0.08 & 0.08 \\ B_6 & 0.15 & 0.12 & 0.15 \end{bmatrix}$$

According to Formula (8), the projection weights and projection values (d_j) are calculated, respectively. Finally, the comprehensive benefit evaluation results of Scheme I and Scheme II based on investors can be obtained. The results are shown in Table 6.

Table 6. Evaluation results of project benefit based on Investors.

Index i	Projection Weight	d_1	d_2
A1	0.10	0.07	0.10
A2	0.16	0.10	0.16
A3	0.03	0.03	0.03
A5	0.03	0.03	0.03
A6	0.02	0.02	0.02
B4	0.02	0.02	0.02
B6	0.06	0.05	0.06
projection values d_j		0.32	0.40

Note: d_1 and d_2 are the projection values of M_1 and M_2 on M_0, respectively.

(2) Evaluation based on international lending institutions, sending-oriented states, and receiving-oriented states

The results of comprehensive benefits based on international lending institutions, sending-oriented states, and receiving-oriented states (L2, L3, and L4) are shown in Table 7.

Table 7. Evaluation results of project benefit based on international lending institutions, sending-oriented states, and receiving-oriented states.

	Projection Weight			d_1			d_2		
Index i	**L2**	**L3**	**L4**	**L2**	**L3**	**L4**	**L2**	**L3**	**L4**
A1	0.08	0.05	0.04	0.06	0.04	0.03	0.08	0.05	0.04
A2		0.08	0.08		0.05	0.05		0.08	0.08
A3	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01
A4		0.02			0.02			0.02	
A5			0.01			0.01			0.01
A6			0.01			0.01			0.01
A7	0.07			0.07			0.06		
A8	0.08			0.06			0.08		
B1	0.05	0.03	0.03	0.04	0.03	0.02	0.05	0.03	0.03
B2		0.01	0		0.01	0		0.01	0
B3	0.01	0	0.01	0.01	0	0.01	0.01	0	0.01
B4			0.01			0.01			0.01
B5		0	0.01		0	0.01		0	0.01
B6		0.03			0.02			0.03	
B7		0.03	0.02		0.02	0.01		0.03	0.02
B8		0.02	0.01		0.02	0.01		0.02	0.01
C1			0			0			0
C2	0.01		0.01	0.01		0.01	0.01		0.01
C3	0		0	0		0	0		0
C4			0.04			0.04			0.03
C5	0	0	0	0	0	0	0	0	0
C6	0.05	0.03		0.03	0.02		0.05	0.03	
projection values d_j				0.31	0.24	0.23	0.35	0.3	0.27

5. Discussion

The evaluation index system established in this paper not only covers the economic, social, and environmental benefits, but also divides them from the perspective of different stakeholders. Figure 6 shows that the weight of the same index varies greatly among different stakeholders, which reflects the necessity and rationality of establishing the index system for different stakeholders. Internal rate of return and economic net present value are indices considered in the comprehensive benefit evaluation of the four stakeholders. In particular, the power forex expansion ratio is only included in the index system of the sending-oriented states, and the payback period and asset-liability ratio are only considered by the international lending institutions. Area saving of power plant is only within the scope of comprehensive benefit study in receiving-oriented states.

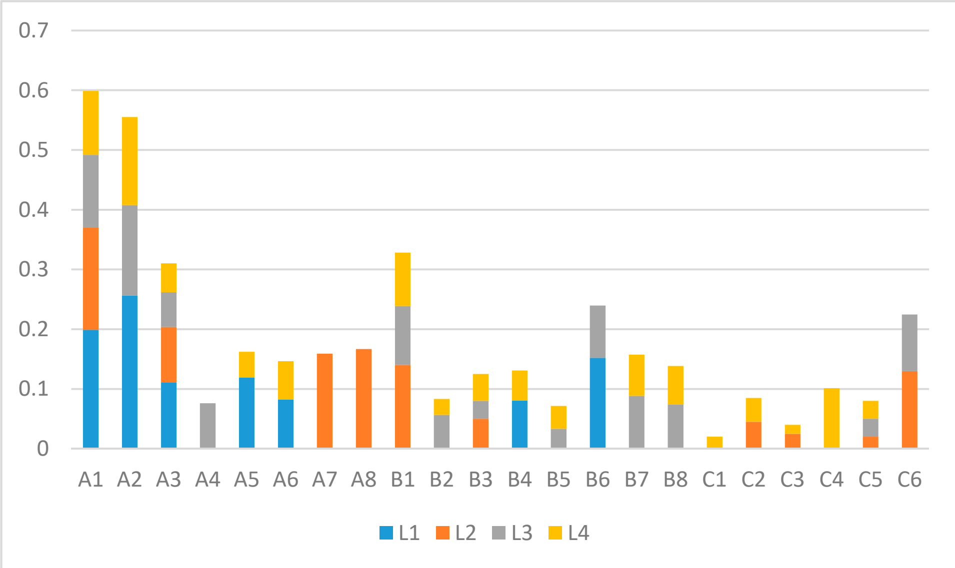

Figure 6. The weight ratio of benefit indices in different stakeholder evaluation.

It is also shown intuitively in Figure 7 that different stakeholders pay different attention to economic, social, and environmental benefits in the process of comprehensive benefit research. The proportions of economic, social, and environmental benefits indices in L3 were 41%, 47%, and 12%, respectively; those in L4 were 41%, 38%, and 21%, respectively; L1 only paid attention to economic and social benefits, accounting for 77% and 23%, respectively; and the proportions of economic, social, and environmental benefits indices in L2 were 59%, 19%, and 22%, respectively.

From the evaluation results of transnational power networking projects (Figure 8), the benefit level of Scheme II is better than that of Scheme I in terms of the stakeholder evaluation of four projects. These two schemes are gradually decreasing in the comprehensive benefit evaluation results of L1, L2, L3, and L4, which reflects that such projects rely on the financial support of the power industry and L2 and need more guidance and support from national governments. As an L1 who initiates and transfers a project, the decision-making willingness of the L3 and L4 can be foreseen through the evaluation results. In addition, the scheme can be adjusted reasonably according to the weight analysis of the indices, so as to improve the project pass rate at the decision-making stage.

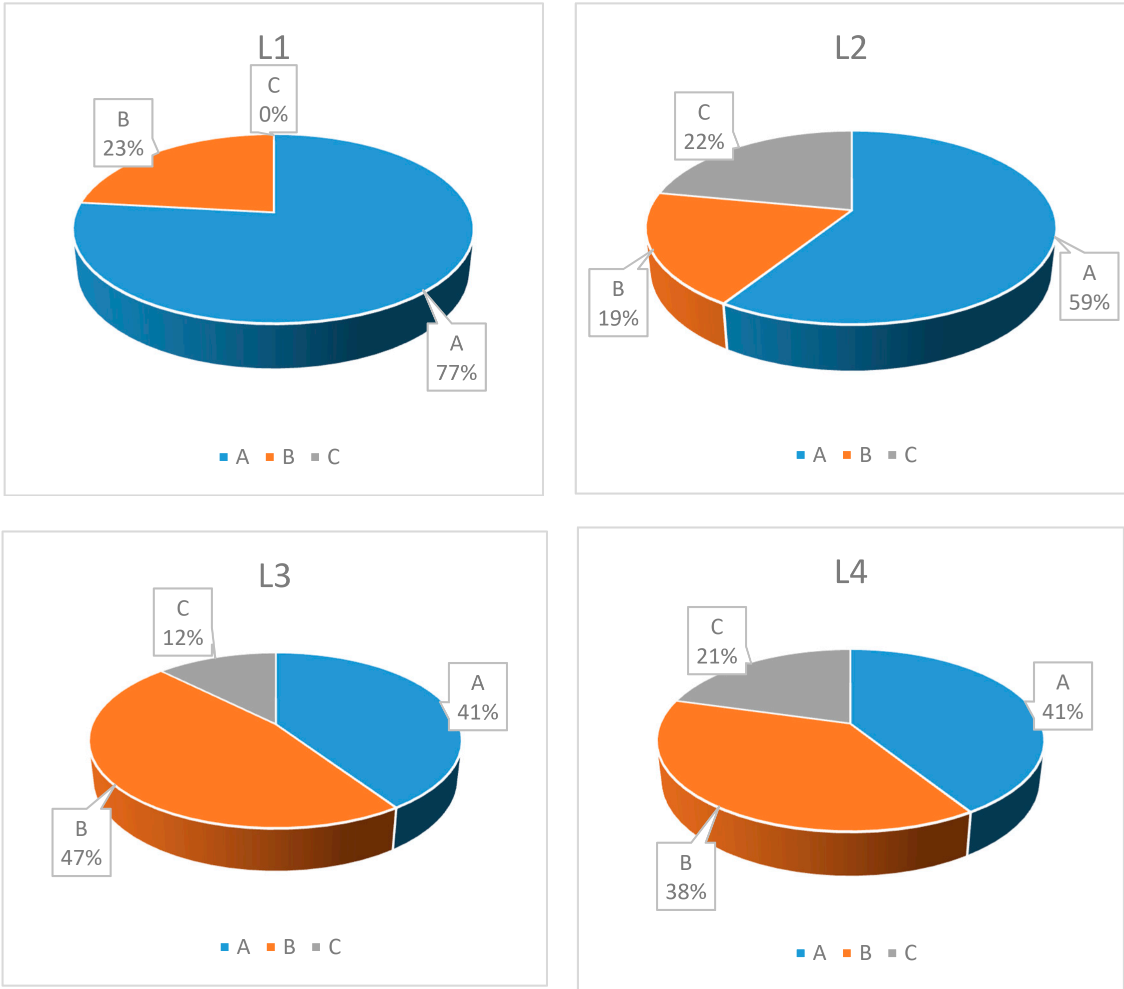

Figure 7. The weight ratio of benefit indices in different stakeholder evaluations.

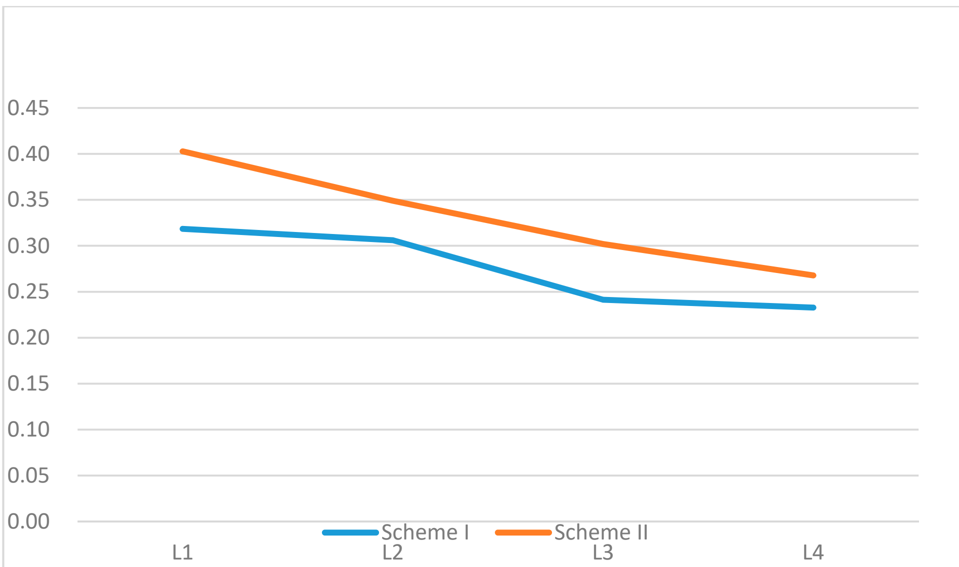

Figure 8. Comparison of the results of comprehensive benefit evaluation based on different project stakeholders.

6. Conclusions

Combining with the trend of interconnection of transnational power grids, this paper established a comprehensive benefit evaluation index system based on L1, L2, L3, and L4, which covers economic, social, and environmental perspectives. In the process of determining the weights, the Gini coefficient weighting method and ordinal relation method were combined to take both subjective and objective information into account. Moreover, on the basis of the improved grey projection value matter-element extension evaluation model, the scientific nature of the comprehensive benefit evaluation results was improved. Through the study of two different schemes of domestic high-voltage direct current transmission projects, it was proved that the weights and evaluation results were quite different from each stakeholder's perspective, and the rationality of the comprehensive benefit evaluation system based on different stakeholders was verified, thus improving the comprehensiveness and objectivity of the comprehensive benefit research of transnational networking projects.

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