A credit risk evaluation based on intuitionistic fuzzy set theory for the sustainable development of electricity retailing companies in China

Gejirifu De1,2 | Zhongfu Tan1,2,3 | Menglu Li1,2 | Lilin Huang1,2 | Qiang Wang1,2,4 | Huanhuan Li5

1School of Economics and Management, North China Electric Power University, Beijing, China
2Beijing Key Laboratory of New Energy and Low-Carbon Development, North China Electric Power University, Beijing, China
3School of Economics and Management, Yan’an University, Yan’an, China
4Department of Mechanical and Traffic Engineering, Ordos Institute of Technology, Ordos, China
5State Grid Chengdu Power Supply Company, Chengdu, China

Abstract
As China’s power market becomes more orderly, electricity retailing companies are influenced by multiple factors restricting their healthy, stable, and sustainable development. This paper explores these issues through four dimensions, the external basic environment, operating credit risk, financial credit risk, and transaction credit risk, and determines the credit risk evaluation index system, which includes 22 factors relevant to electricity retailing companies. To achieve this, this paper utilizes the characteristics of the intuitionistic fuzzy set theory and, in an uncertain environment, the proposed credit risk assessment model based on the intuitionistic fuzzy analytic hierarchy process (IFAHP). In order to improve the identification degree of the credit risk evaluation of electricity retailing companies, a penalty factor is introduced into the model, and the variable weight mechanism of dynamic adjustment hesitancy is proposed. Finally, we select five electricity retailing companies and use different evaluation methods to conduct a comprehensive credit risk evaluation, so as to improve the credit risk level of electricity retailing companies.

KEYWORDS credit risk evaluation, electricity retailing company, intuitionistic fuzzy set theory, the mechanism of variable weight

1 | INTRODUCTION

With the “Opinions on Further Deepening the Reform of the Power System” and the “Implementation Opinions on Promoting the Reform of the Power-Saving Side” issued by the State Council and the National Energy Administration, the relevant mechanisms and access conditions for the market on the sale side are clearly defined and 6389 retailing companies have been established in various regions. However, as an emerging market entity, the electricity
retailing company has replaced the original power supply company for some of the duties to buy electricity from the market and sell electricity to users in order to adapt to the new round of power system reform. Therefore, the market transaction process faces a series of credit risks. At the same time, according to the data of the China Electricity Council (2018), the national sales of various types reached 7096.48 million MWh, an increase of 10.79% from the previous year. Based on this, it is an urgent research to construct a scientific and reasonable credit risk evaluation system, standardize the trading mechanism of power market, and maintain the stability of power market from the perspective of sustainable development of electricity retailing companies.

In the actual credit risk evaluation process of electricity retailing companies, there are many factors affecting credit risk. The construction of the credit risk indicator system, the determination of the weight, and the choice of evaluation methods are crucial for accurate evaluation. At present, as an important link connecting the power generation side with the user side, the electricity retailing company has performed in-depth research and achieved good results. Liu et al analyzed the electricity purchase model of electricity retailing companies under the time-of-use tariff based on the connotation, type, and power sale process of the electricity retailing company. Peng et al analyzed the performance of electricity retailing companies in the spot market in combination with China’s two-round power market reforms. Song et al analyzed the trading patterns of electricity retailing companies under the two bidding mechanisms of MCP and PAB. He et al explored in depth the investment decision-making issues of power companies in the electricity market. Shu et al determined the optimal dynamic selling price in order to balance the interests between the grid system and large industrial users. Moreover, the sustainable development of electricity retailing companies should also include different dimensions such as social, economic, and security. Zhang et al analyzed the factors affecting the sustainable development of China’s power industry from the three dimensions of energy-climate-environment. Zhang et al constructed a credit evaluation index system for electricity retailing companies with 28 influencing factors from six dimensions: basic conditions, trustworthiness, trustworthy will, trustworthy performance, financial status, and credit history. Zhang et al constructed an evaluation index system including 12 assessment indicators that affect the operation risk of electricity retailing company from four dimensions: policy risk, market risk, internal risk, and security risk. Huang et al constructed a competition evaluation index system for electricity retailing entities from seven dimensions: business hall service, electricity payment, fault repair, telephone and website services, power demand management, power supply quality, and other service indicators.

At present, many scholars have adopted different credit risk evaluation methods, including multiattribute decision making, analytic hierarchy process, fuzzy comprehensive evaluation method, and gray theory. Gebrezgabher et al used AHP to identify the key risk evaluation indicators for decision makers and ranked them. According to the survey information of expert scoring, Opitz et al selected the most representative risk evaluation indicators by AHP. Li et al combined the entropy weight method with the analytic hierarchy process to determine the weight of risk assessment indicators. Chen et al combined Dempster-Shafer evidence theory with failure mode and effects analysis (FMEA) to quantify uncertainty risk indicators and prioritization issues. Samantra et al divided risk into two parts, the possibility and impact of occurrence, and proposed a comprehensive risk evaluation method based on fuzzy set theory. Wu et al identified key risk factors using the extended hesitant fuzzy linguistic term sets (HFLTS)-DEMATEL fuzzy comprehensive assessment method. However, the above-mentioned credit risk evaluation methods rely too much on the subjectivity of experts. Even if the uncertainty and ambiguity of expert judgment are considered to some extent, it is impossible to express the hesitation of experts on the evaluation of various credit risk evaluation indicators. Based on this, the hesitation of decision makers is introduced into the decision system, and the theory of intuitionistic fuzzy sets is proposed and widely applied. Xu et al proposed an intuitionistic fuzzy analytic hierarchy process (IFAHHP) with fuzzy analytic hierarchy process (FAHP). However, the above-mentioned various credit risk assessment methods rely too much on the subjectivity of experts. Even if the uncertainty and ambiguity of expert judgment are considered to some extent, it is impossible to express the hesitation of experts on the evaluation of various credit risk evaluation indicators. On this basis, the hesitation of decision makers is introduced into the decision system, and the theory of intuitionistic fuzzy sets is proposed and widely applied. Yu et al identified key risk factors using intuitionistic fuzzy analytic hierarchy analysis. Ouyang et al proposed an intuitionistic fuzzy analytical hierarchical process through multicriteria decision making in the case that the optimal scheme is uncertain. Naraynamoorthy et al proposed interval intuitionistic fuzzy entropy and determined the importance of standard and interval intuitionistic fuzzy number VIKOR methods for sorting alternatives. Mohammad Yazdi et al proposed a hybrid intuitionistic fuzzy TOPSIS method to prioritize risk indicators. In order to overcome the shortcomings of intuitionistic fuzzy interval, Chen et al proposed a multiattribute decision-making (MADM) method based on information entropy, nonlinear programming, and interval intuitionistic fuzzy. Liao et al introduced simple intuitionistic fuzzy-weighted geometric (SIFWG) intuitionistic fuzzy preference relations (IFPRs). Fei et al proposed a new vector-valued similarity measure based on OWA. Deng
et al.\textsuperscript{35} proposed the AHP method extended by D-number preference relation for the MADM problem of D-number extended fuzzy preference relation, which was called D-AHP. In order to determine the key success factors of system feasibility, Han et al.\textsuperscript{36} proposed a multicriteria decision-making (MCDM) approach. Based on the preference relationship between the difficult solutions of the pairwise comparison matrix (PCM), affinity diagram, Zhou et al.\textsuperscript{37} proposed a decision-making and trial evaluation laboratory (DEMATEL) method, which has ability to derive the total relation matrix from direct relation matrix.

In summary, many achievements have been made in the research on credit risk of electricity retailing companies. However, the current research pays more attention to the electricity retailing company itself and does not analyze the credit risk of the company's transaction process from the perspective of sustainable development. Besides, many existing credit risk evaluation methods cannot accurately reflect the "hesitation" and "abstention" of each expert in the credit risk decision-making process of the electricity retailing company, which may lead the credit risk evaluation results of the electricity retailing company to deviate from the actual situation. Therefore, combined with the characteristics of the company itself, it is necessary to objectify subjective factors scientifically and deal with qualitative and fuzzy information quantitatively. The innovations are as follows:

1. In order to improve the sustainable development efficiency of the electricity retailing company, combined with the characteristics of the company itself, we establish 22 three-level indicators from the external basic environment, operating credit risk, financial credit risk, and transaction credit risk. The credit risk evaluation index system of the electricity retailing company can evaluate the sustainable development level of the company more comprehensively, objectively, and scientifically.

2. When characterizing the fuzziness and uncertainty of each credit risk indicator of a company, we use the theory of intuitionistic fuzzy set to perform the unconformity test and readjust the expert score, which can fully consider the membership of the decision maker, nonmembership, and hesitation information. The proposed method can further improve the accuracy of subjective judgment and accurately reflect the essential state of credit risk of the company.

3. In order to improve the identification of credit risk assessment of electricity retailing companies, we establish a comprehensive evaluation model of credit risk of electricity retailing companies and introduce a variable weighting mechanism that dynamically adjusts the hesitation. The proposed method can flexibly change the weight of credit risk indicators of electricity retailing companies, and strengthen the recognition degree of the companies' comprehensive evaluation.

The main content and structure of this paper are as follows: Section 2, combined with the characteristics of the electricity retailing company itself, constructs the credit risk evaluation index system from the four dimensions of external basic environment, operating credit risk, financial credit risk, and transaction credit risk. Detailed explanations are given. Section 3 elaborates the basic theory of intuitionistic fuzzy evaluation, namely definition, characteristics, and calculation flow. Section 4 establishes the credit risk evaluation model of electricity retailing company by introducing the variable weight mechanism of dynamic hesitation. Section 5 selects a typical electricity retailing company for a case study and makes a comparative discussion. Section 6 summarizes the research results and directs the subsequent research.

## 2 THE CREDIT RISK EVALUATION INDEX SYSTEM OF ELECTRICITY RETAILING COMPANIES

With the new round of electric power system reform occurring, it is of great significance to establish a credit risk index system for electricity retailing companies and improve the overall level of sustainable development. From the perspective of the sustainable development of electricity retailing companies, this paper constructs a credit risk evaluation index system for electricity retailing companies, including four criteria: the external basic environment, operational credit risk, financial credit risk, and transaction credit risk. Moreover, the four criteria contain multiple subcriteria. The specific process of selecting subcriteria is as follows:

1. Based on the meaning, characteristics, and business model of the electricity retailing company, we collect and organize the relevant academic literature to determine the initial subcriteria.

2. According to relevant experts and experienced persons of the electricity retailing company, namely electricity retailing company management personnel, economic, social, and environmental protection policymakers, and academic professors, we review the initial subcriteria and select the most important ones.

3. By utilizing the opinions of the relevant experts to remove unimportant subcriteria, we can determine the final subcriteria of the credit risk evaluation index system for the standard of the company.

Therefore, the credit risk index system of electricity retailing companies includes four first-level indicators, nine second-level indicators, and 22 third-level indicators, as shown in Figure 1.
2.1 External basic environmental indicators

The external basic environment is the guarantee for the sustainable development of electricity retailing companies and also an important support for the strategic transformation of electricity retailing companies under the new round of power system reform in China. Credit risk evaluation of the external infrastructure of electricity retailing companies based on the two dimensions of policies and regulations and industry operation identified five three-level indicators.

1. Macrocontrol policies refer to the policy directives issued by the state on the reform of the power system, which affect electricity retailing companies, and environmental protection and energy-saving policies refer to the policies, laws, and regulations that affect electricity retailing companies in the country. Industry-related policies refer to reform policies and other guiding policies issued within the power industry. Macrocontrol policies, environmental protection and energy-saving policies, and industry-related policies all have an impact on electricity retailing companies,
and experts can determine the level of support for the policy environment.

2. The proportion of technical talents determines the competitive environment of an electricity retailing company and directly affects its profitability. For a power sale company, the transaction volume is very important, so an indicator that reflects the change in trading power must be selected. The month-on-month increase in the trading volume of electricity retailing companies will increase their profit, thereby increasing their profitability and solvency.

2.2 | Production and operation risk indicators

The risks of production and operation are the driving force for the sustainable development of electricity retailing companies, and the key to improving their core competitiveness. A credit risk evaluation of electricity retailing companies was carried out based on the two dimensions of operational risk and production management and four three-level indicators.

1. Market share refers to the proportion of the electricity sold by the electricity retailing company in the total transaction power, reflecting the position and importance of the electricity retailing company in the industry. With the advancement of the new round of power system reform, the number of electricity retailing companies established in various provinces and cities in China has been increasing, and their social impact reflects the acceptance of power companies in society.

2. The reliability of power transmission is the main indicator of the safe and reliable transmission of electric energy by an electricity retailing company. When considering the ratio of the actual total transmission energy from the power generation side to the user side and the total expected transmission energy, the larger the ratio, the higher the safety and reliability rate. The success rate of the supply and demand side signing refers to the quotation of the power generation enterprise and the electricity customer to the power trading center, and finally the success rate of the supply and demand side signing.

2.3 | Financial credit risk indicator

Financial credit risk is the basis for the sustainable development of electricity retailing companies and the core embodiment of their overall efficiency. A credit risk evaluation of an electricity retailing company was carried out based on three dimensions, profitability, solvency, and development capability, and eight three-level indicators were determined.

1. The rate of return on total assets is the proportion of profits in total assets. The higher the rate of return on total assets, the stronger the ability of the electricity retailing company to create profit. The net profit of sales is the ratio of net profit to sale revenue, reflecting the profitability of the electricity trading company's energy trading. The higher the net profit, the higher the solvency of the electricity retailing company. The cost–cost profit rate is the ratio of the total profit to the total cost, which reflects the operating cost. Operating cost management expenses account for the main business ratio, which reflects the control of the periodic expenses of different power-selling companies in the operation process. The smaller the indicator, the stronger the cost control ability of the electricity retailing company, and the stronger the profitability.

2. The current ratio is the ratio of current assets to current liabilities. It mainly measures the ability of a company's current assets to become cash for repayment of liabilities before the short-term debt expires. The higher the current ratio of the electricity retailing company, the stronger the company's liquidity, the stronger the short-term solvency, and vice versa. The asset-liability ratio refers to the ratio of total liabilities to total assets, which mainly measures the important index of the debt level, and the risk degree of the electricity retailing company.

3. The main business income growth rate refers to the ratio of the main business income of the current period to the increase in the main business income of the previous period. The growth rate of the main business income reflects the declaration period of the electricity retailing company and further reflects the important indicators of the development capability of the electricity retailing company. When the cash flow growth rate increases, the ratio of the current cash flow growth value to the previous year's cash flow is expressed by the ring ratio. The faster the indicator growth, the better the normal sustainable development capability of the electricity retailing company.

2.4 | Trading credit risk indicators

Trading credit risk is a necessary condition for the sustainable development of electricity retailing companies, and also an important factor to enhance their overall image and social influence. This paper conducts a credit risk evaluation of electricity retailing companies based on the two dimensions of the energy trading status and supply and demand transaction response, and determines five third-level indicators.

1. The performance rate of the transaction contract is the ratio of the number of contract performances to the total number of transaction contracts when the
power generation side and the user side trade electricity through the electricity retailing company. This indicator mainly reflects the performance willingness of the power generation side and the user side in the electricity trading process. The power load forecasting ratio is the ratio of the actual power load to the contracted load in the current period. This indicator reflects the ability of the power company to sign various users and avoid punishment caused by the deviation evaluation. Inaccurate load forecasting will affect the long-term effective development of electricity retailing companies. The transaction deviation evaluation rate is the ratio of the actual power consumption to the total amount of electricity contracted, which mainly reflects the completion of the contracted power during the electricity trading process.

2. The contract rate of power sale contract is the ratio of the number of contracts for sale of electricity to the total number of contracts for the electricity retailing companies, mainly reflecting the performance of contracts in the trading methods of power generation companies and power consumers through electricity retailing companies. The interruptible load contract performance rate refers to the proportion of interruptible load contract performances in the total number of interruptible contracts, mainly reflecting the electricity retailing company’s willingness to act as a link between the power generation side and the user side.

3 | METHODOLOGY

3.1 | Intuitionistic fuzzy set theory

On the basis of fuzzy theory, Bulgarian scholar Atanassov et al.38-40 proposed the definition of intuitionistic fuzzy sets and the basic algorithm, as follows:

**Definition 1:** Set $X$ to be a nonempty set, then:

$$A = \{(x, \mu_A(x), v_A(x)) \mid x \in X\}$$

(1)

is an intuitionistic fuzzy number, where $\mu_A(x)$ and $v_A(x)$ are respectively the membership and nonaffiliation of the element belonging to $A$:

$$\mu_A : X \to [0, 1], x \in X \to \mu_A(x) \in [0, 1]$$

(2)

and meet the conditions:

$$0 \leq \mu_A(x) + v_A(x) \leq 1, x \in X$$

(4)

**Definition 2:** The degree of hesitation or uncertainty of the element $x$ in $X$ belonging to $A$ is given by:

$$\pi_A(x) = 1 - \mu_A(x) - v_A(x), x \in X$$

(5)

In addition, when $\pi_A(x) = 0$, it becomes a traditional fuzzy set, which will be a special case of the intuitionistic fuzzy set.

**Definition 3:** Let $\alpha = (\mu_a, v_a), \alpha_1 = (\mu_{a_1}, v_{a_1})$ and $\alpha_2 = (\mu_{a_2}, v_{a_2})$ be intuitionistic fuzzy numbers, where $\lambda$ is a real number and $\lambda \geq 0$, then the basic algorithm of intuitionistic fuzzy numbers is given by:

$$\alpha_1 + \alpha_2 = (\mu_{a_1} + \mu_{a_2}, \mu_{a_1} - \mu_{a_2}, v_{a_1} + v_{a_2})$$

(6)

$$\lambda \alpha = (\lambda (1 - \mu_a)^{1/\lambda}, \lambda v_a)$$

(8)

$$\alpha^\lambda = (\mu_a^\lambda, 1 - (1 - v_a)^{1/\lambda})$$

(9)

The theory of intuitionistic fuzzy sets is an extension of fuzzy theory. Fuzzy theory can only describe the two states of “affirmative” and “negative,” while the intuitionistic fuzzy set also takes into account the state of hesitation, which is more flexible and practical in describing fuzzy information and uncertain information.

3.2 | Constructing an intuitionistic fuzzy judgment matrix

Based on the meaning, characteristics, and business model of electricity retailing companies, from the perspective of sustainable development, a credit risk evaluation index system of electricity retailing companies is constructed, which will cover the external basic environment, business credit risk, financial credit risk, and transaction credit risk (see Figure 1 for details). However, in the credit risk evaluation system of electricity retailing companies, the four first-level indicators establish an intuitionistic fuzzy judgment matrix and compare the same-level indicators subordinate to each index of the upper layer to establish an intuitionistic fuzzy judgment matrix:

$$R = (r_{ij})_{n \times n}$$

(10)
Among them, $i$ and $j$ represent the rows and columns of the intuitionistic fuzzy judgment matrix, respectively; in $r_{ij} = (\mu_{ij}, v_{ij})$, $\mu_{ij}$ represents the degree of membership; that is, the degree of the $i$ index is more important than the $j$ index; $v_{ij}$ indicates the degree of nonmembership; that is, the degree of the $i$ index is more important than the $j$ index; and $\pi_{ij}$ means hesitation; that is, $\pi_{ij} = 1 - \mu_{ij} - v_{ij}$.

In addition, in the intuitionistic fuzzy judgment matrix, the IFPR data are scored by the peer-invited experts, and the average is calculated to obtain the final score. Therefore, in order to quantify the importance of describing the credit risk evaluation indicators of electricity retailing companies, the corresponding scoring scale,\(^{31}\) namely the intuitionistic fuzzy number, is defined as shown in Table 1.

### 3.3 Consistency test and correction

Based on the distance measure of the intuitionistic fuzzy set,\(^{31}\) the consistency test formula of the intuitionistic fuzzy judgment matrix is obtained\(^{27, 42}\):

$$d(R, R) = \frac{1}{2(n-1)(n-2)} \sum_{i=1}^{n} \sum_{j=1}^{n} \left( |\bar{\mu}_{ij} - \mu_{ij}| + |\bar{v}_{ij} - v_{ij}| + |\bar{\pi}_{ij} - \pi_{ij}| \right)$$

(11) where $R$ represents the intuitionistic fuzzy judgment matrix; that is, $R = (r_{ij})_{n \times n}$, which is obtained by comparing each layer of indicators according to the relative importance degree, and $\bar{R}$ represents the intuitionistic fuzzy consistency judgment matrix; that is, $\bar{R} = (\bar{r}_{ij})_{n \times n}$. It is calculated based on the intuitionistic fuzzy judgment matrix, and its construction method is as follows:

1. When $j > i$, let $\bar{r}_{ij} = (\bar{\mu}_{ij}, \bar{v}_{ij})$, then

$$\bar{\mu}_{ij} = \frac{\sqrt{j-1} \prod_{t=i+1}^{j-1} \mu_{ti} \mu_{ij} + \sqrt{j-1} \prod_{t=i+1}^{j-1} (1 - \mu_{ti}) (1 - \mu_{ij})}{\sqrt{j-1} \prod_{t=i+1}^{j-1} v_{ti} v_{ij} + \sqrt{j-1} \prod_{t=i+1}^{j-1} (1 - v_{ti}) (1 - v_{ij})}, \quad j > i + 1$$

(12)

$$\bar{v}_{ij} = \frac{\sqrt{j-1} \prod_{t=i+1}^{j-1} v_{ti} v_{ij} + \sqrt{j-1} \prod_{t=i+1}^{j-1} (1 - v_{ti}) (1 - v_{ij})}{\sqrt{j-1} \prod_{t=i+1}^{j-1} \mu_{ti} \mu_{ij} + \sqrt{j-1} \prod_{t=i+1}^{j-1} (1 - \mu_{ti}) (1 - \mu_{ij})}, \quad j > i + 1$$

(13)

2. When $j = i + 1$, then

$$\bar{r}_{ij} = (\mu_{ij}, v_{ij})$$

(14)

### Table 1 Evaluation scale and its meaning

| Meaning | Scale |
|---------|-------|
| Factor $i$ is exceedingly superior to factor $j$ | (0.90, 0.10, 0.00) |
| Factor $i$ is strongly superior to factor $j$ | (0.80, 0.15, 0.05) |
| Factor $i$ is obviously superior to factor $j$ | (0.70, 0.20, 0.10) |
| Factor $i$ is slightly superior to factor $j$ | (0.60, 0.25, 0.15) |
| Factor $i$ is equivalent to factor $j$ ($i \neq j$) | (0.50, 0.30, 0.20) |
| Factor $j$ is slightly superior to factor $i$ | (0.40, 0.45, 0.15) |
| Factor $j$ is obviously superior to factor $i$ | (0.30, 0.60, 0.10) |
| Factor $j$ is exceedingly superior to factor $i$ | (0.20, 0.75, 0.05) |
| Factor $j$ is strongly superior to factor $i$ | (0.10, 0.90, 0.00) |

### 3.4 Calculating indicator weights

According to the intuitionistic fuzzy consistency judgment matrix, each indicator is calculated for the weight of the upper layer.\(^ {27, 42}\)
\[
\omega_i = \frac{\sum_{j=1}^{n} \bar{\mu}_{ij} - \sum_{j=1}^{n} (1 - \bar{v}_{ij})}{\sum_{i=1}^{n} \sum_{j=1}^{n} (1 - \bar{v}_{ij}) - \sum_{i=1}^{n} \sum_{j=1}^{n} \bar{\mu}_{ij}}, \quad i = 1, 2, \ldots, n
\]  

(19)

### 3.5 Dynamic adjustment mechanism of hesitation

In order to improve the adaptability of the IFAHP, considering the actual situation of electricity retailing companies and various credit risk indicators, a penalty mechanism is proposed to adjust the hesitation in the intuitionistic fuzzy judgment matrix.

Suppose \( n_\pi \), when \( n_\pi > 1 \), let:

\[
\pi_{ij}^* = \left( 1 - \frac{n_\pi}{N_\pi} \right) \pi_{ij}
\]

(20)

In the formula, \( N_\pi \) is the total number of indicators that are expected to affect the credit risk of the company, and \( n_\pi \) is the number of indicators that actually affect the credit risk of the company. Moreover, the larger the \( n_\pi \), the worse the credit of the electricity retailing company, and the higher the risk level. According to the adjusted hesitation degree value \( \pi_{ij}^* \), combined with the hesitation degree distribution of Table 1, the \( \mu_{ij} \) and \( \bar{v}_{ij} \) grading levels are automatically adjusted, thereby flexibly changing the index weight and improving the comprehensive evaluation of the electricity retailing company.

### 3.6 Integrated credit risk evaluation

According to the algorithm of intuitionistic fuzzy numbers, that is:

\[
\omega_1 \otimes \omega_2 = \left( \mu_{a1} \mu_{a2}, v_{a1} + v_{a2} - v_{a1} v_{a2} \right)
\]

(21)

\[
\omega_1 \oplus \omega_2 = \left( \mu_{a1} + \mu_{a2} - \mu_{a1} \mu_{a2}, v_{a1} v_{a2} \right)
\]

(22)

The weights of the secondary indicators and the corresponding primary indicator weights are aggregated and weighted.

\[
\omega \left( C_i \right) = \omega_{b_i} \otimes \omega_{C_i}, k = 1, 2, \ldots, m; i = 1, 2, \ldots, n
\]

(23)

\[
W = \bigoplus_{i=1}^{n} \omega \left( C_i \right), i = 1, 2, \ldots, n
\]

(24)

After the above calculation steps are completed, the ranking function, based on the intuitionistic fuzzy set, is used to perform a final comprehensive evaluation of the credit risk level of the electricity retailing company, and the calculation formula is:

\[
\rho \left( W \right) = 0.5 \left( 1 + \sigma \right) \left( 1 - \mu \right)
\]

(25)

\( \pi_\omega \) and \( \mu_\omega \) represent the hesitation degree and membership degree of \( W \) obtained by the weight calculation, respectively.

### 4 THE CREDIT RISK EVALUATION MODEL OF ELECTRICITY RETAILING COMPANIES: THE VARIABLE WEIGHT MECHANISM OF HESITATION AND IFAHP

In order to further improve the overall efficiency and sustainability of electricity retailing companies, the dynamic
The adjustment factor is introduced in the hesitation degree, and the scoring function of the credit risk of electricity retailing companies is improved as a whole, by becoming more flexible. However, in the actual credit risk evaluation process, the more indicators affecting the credit risk of the sale company, the more dangerous the credit risk status. The specific calculation steps are as follows.

**Step 1:** Determine the target layer, the criterion layer, and the indicator layer for evaluating the credit risk of the electricity retailing company, and construct a hierarchical structure model of the problem from the perspective of sustainable development. Calculate the index values and standardize the processing.

**Step 2:** Compare the importance of each factor in the same layer with respect to a certain criterion in the previous level, and construct an intuitionistic fuzzy judgment matrix.

**Step 3:** Perform a consistency check on each intuitionistic fuzzy judgment matrix. If consistency is met, go to step 5, otherwise go to step 4.

**Step 4:** Correct the nonuniform intuitionistic fuzzy judgment matrix.

**Step 5:** Calculate the relative weight vector of the compared factor for the upper layer criterion according to the intuitionistic fuzzy judgment matrix.

**Step 6:** Calculate the combined weight of each layer factor to the total target of the system through the intuitionistic fuzzy number operator.

**Step 7:** Dynamically adjust the degree of hesitation in the intuitionistic fuzzy judgment matrix according to the penalty mechanism.

**Step 8:** Conduct a comprehensive evaluation of credit risk.

Based on the above calculation steps, from the perspective of sustainable development, the specific process of credit risk evaluation of electricity retailing companies is shown in Figure 2.

### 5 | EMPIRICAL ANALYSIS

In order to verify the validity and feasibility of the proposed method, five electricity retailing companies (A, B, C, D, and E) are selected to conduct credit risk assessment. The specific discussion is as follows:

#### 5.1 | Credit risk evaluation of different electricity retailing companies

##### 5.1.1 | Basic IFAHP method

On the basis of the IFAHP, this paper invited peer experts to obtain the initial data of the electricity retailing companies A, B, C, D, and E, according to the scoring scale given in Table 1. Then, after calculating the arithmetic average, the intuitionistic preference relationship between the layers of A, B, C, D, and E is obtained. Due to space limitations, the paper only gives the intuitionistic fuzzy preference relationship between the first-level indicators of electricity retailing company A, as shown in Tables 2-5.

Tables 2-5 use (12)-(14) to transform, allowing the intuitionistic fuzzy consistency judgment matrix to be obtained.

### Table 2 First-level index intuition preference relationship

|          | (0.50, 0.50) | (0.42, 0.46) | (0.54, 0.38) | (0.54, 0.36) |
|----------|--------------|--------------|--------------|--------------|
| (0.46, 0.42) | (0.50, 0.50) | (0.52, 0.35) | (0.64, 0.25) |
| (0.56, 0.35) | (0.48, 0.39) | (0.50, 0.50) | (0.38, 0.48) |
| (0.44, 0.45) | (0.46, 0.42) | (0.56, 0.33) | (0.50, 0.50) |

### Table 3 Second-level index intuition preference relationship

|          | (0.50, 0.50) | (0.62, 0.26) |
|----------|--------------|--------------|
| (0.34, 0.54) | (0.50, 0.50) |

### Table 4 Third-level index intuition preference relationship

|          | (0.50, 0.50) | (0.48, 0.37) | (0.58, 0.28) |
|----------|--------------|--------------|--------------|
| (0.40, 0.45) | (0.50, 0.50) | (0.52, 0.35) |
| (0.28, 0.63) | (0.28, 0.63) | (0.50, 0.50) |

### Table 5 Third-level index intuition preference relationship

|          | (0.50, 0.50) | (0.48, 0.37) | (0.48, 0.37) | (0.50, 0.50) |
|----------|--------------|--------------|--------------|--------------|
| (0.42, 0.37) | (0.50, 0.50) |

\[
\tilde{R}_A = \begin{bmatrix}
(0.5000, 0.5000) & (0.4200, 0.4600) & (0.4396, 0.3145) & (0.4904, 0.2861) \\
(0.4600, 0.4200) & (0.5000, 0.5000) & (0.5200, 0.3500) & (0.3990, 0.3320) \\
(0.3145, 0.4396) & (0.3500, 0.5200) & (0.5000, 0.5000) & (0.3800, 0.4800) \\
(0.2861, 0.4904) & (0.3320, 0.3990) & (0.4800, 0.3800) & (0.5000, 0.5000)
\end{bmatrix}
\]
Calculate the distance between $R_A$ and $\tilde{R}_A$ to get $d(\tilde{R}_A, R_A) = 0.2148 > 0.1$, failing the consistency test. If there is a need to further set the parameters, let $\sigma = 0.45$, use (16)-(18) to adjust, and get:

$$\tilde{R}_A = \begin{bmatrix}
(0.5000, 0.5000) & (0.4200, 0.4600) & (0.4947, 0.3498) & (0.5177, 0.3257) \\
(0.4600, 0.4200) & (0.5000, 0.5000) & (0.5200, 0.3500) & (0.5330, 0.2852) \\
(0.4457, 0.3894) & (0.4200, 0.4477) & (0.5000, 0.5000) & (0.3800, 0.4800) \\
(0.3672, 0.4681) & (0.4006, 0.4105) & (0.5241, 0.3521) & (0.5000, 0.5000)
\end{bmatrix}.$$  

After this calculation, $d(\tilde{R}_A, R_A) = 0.0985 < 0.1$, then the matrix $\tilde{R}_A$ passes the consistency test, and $\tilde{R}_A$ is substituted into (19) to calculate the weight:

$$\omega_A = (0.2086, 0.6932).$$

Similarly, based on the weight of each indicator, the total weight of each indicator is calculated as follows:

$$\omega_1 = A_1 \otimes B_1 \otimes C_1 = (0.2086, 0.6932) \otimes (0.5283, 0.5319) \otimes (0.3107, 0.6396) = (0.0342, 0.9482).$$

The total weight of electricity retailing company A can be obtained (see Table 6). For the total weights of electricity retailing companies B, C, D, and E, see Tables A1-A4.

Then, for electricity retailing company A to carry out information assembly by substituting (24), we get:

$$W_1 = \bigoplus_{j=1}^{32} \omega_j = (0.0342, 0.9482) \oplus (0.0316, 0.9441) \oplus (0.0241, 0.9324) \oplus (0.0324, 0.8815) \oplus (0.0304, 0.8744)$$
$$\oplus (0.0466, 0.9155) \oplus (0.0316, 0.8810) \oplus (0.0448, 0.9093) \oplus (0.0388, 0.8957) \oplus (0.0158, 0.9730)$$
$$\oplus (0.0162, 0.9738) \oplus (0.0103, 0.9632) \oplus (0.0119, 0.9660) \oplus (0.0237, 0.9261) \oplus (0.0217, 0.9207)$$
$$\oplus (0.0186, 0.9146) \oplus (0.0131, 0.8853) \oplus (0.0293, 0.9387) \oplus (0.0195, 0.9157) \oplus (0.0256, 0.9301)$$
$$\oplus (0.0399, 0.8999) \oplus (0.0288, 0.8673)$$
$$= (0.4502, 0.1605)$$

Similarly, the information aggregation for electricity retailing companies B, C, D and E can be obtained:

$$W_2 = \bigoplus_{j=1}^{32} \omega_j = (0.0378, 0.7517) \oplus (0.0347, 0.7284) \oplus (0.0296, 0.6896) \oplus (0.0418, 0.8428) \oplus (0.0600, 0.8906)$$
$$\oplus (0.0481, 0.8990) \oplus (0.0393, 0.8765) \oplus (0.0342, 0.8961) \oplus (0.0472, 0.9246) \oplus (0.0148, 0.9738)$$
$$\oplus (0.0151, 0.9743) \oplus (0.0143, 0.9730) \oplus (0.0130, 0.9710) \oplus (0.0282, 0.9348) \oplus (0.0260, 0.9293)$$
$$\oplus (0.0219, 0.9255) \oplus (0.0179, 0.9088) \oplus (0.0264, 0.9336) \oplus (0.0316, 0.9434) \oplus (0.0307, 0.9417)$$
$$\oplus (0.0470, 0.9175) \oplus (0.0597, 0.9351)$$
$$= (0.5197, 0.0862)$$

$$W_3 = \bigoplus_{j=1}^{32} \omega_j = (0.0537, 0.8200) \oplus (0.0430, 0.7633) \oplus (0.00315, 0.7026) \oplus (0.0456, 0.8505) \oplus (0.0655, 0.8960)$$
$$\oplus (0.0453, 0.8948) \oplus (0.0370, 0.8712) \oplus (0.0308, 0.8709) \oplus (0.0442, 0.9102) \oplus (0.0089, 0.9547)$$
$$\oplus (0.0093, 0.9565) \oplus (0.0113, 0.9648) \oplus (0.0083, 0.9522) \oplus (0.0244, 0.9269) \oplus (0.0191, 0.9068)$$
$$\oplus (0.0256, 0.9295) \oplus (0.0228, 0.9217) \oplus (0.0279, 0.9394) \oplus (0.0381, 0.9550) \oplus (0.0350, 0.9502)$$
$$\oplus (0.0546, 0.9281) \oplus (0.0503, 0.9220)$$
$$= (0.5265, 0.0913)$$

$$W_4 = \bigoplus_{j=1}^{32} \omega_j = (0.0562, 0.8432) \oplus (0.0424, 0.7699) \oplus (0.0265, 0.6857) \oplus (0.0354, 0.8332) \oplus (0.0513, 0.8811)$$
$$\oplus (0.0464, 0.9090) \oplus (0.0411, 0.8943) \oplus (0.0257, 0.8696) \oplus (0.0355, 0.9054) \oplus (0.0162, 0.9772)$$
$$\oplus (0.0204, 0.9834) \oplus (0.0146, 0.9748) \oplus (0.0098, 0.9677) \oplus (0.0265, 0.9312) \oplus (0.0310, 0.9413)$$
$$\oplus (0.0168, 0.9083) \oplus (0.0231, 0.9312) \oplus (0.0340, 0.9498) \oplus (0.0290, 0.9435) \oplus (0.0460, 0.9648)$$
$$\oplus (0.0562, 0.9318) \oplus (0.0459, 0.9165)$$
$$= (0.5250, 0.1042)$$
### TABLE 6  Total weight table

| First-level indicators | Second-level indicators                  | Third-level indicators                                      | Total weight               |
|------------------------|------------------------------------------|-------------------------------------------------------------|-----------------------------|
| External Basic         | Policies and Regulations                 | Macroeconomic Regulation Policy C1                           | (0.0342, 0.9482)            |
| Environment A1         | B1                                        | Environmental Protection and Energy Conservation Policy C2     | (0.0316, 0.9441)            |
| (0.2086, 0.6932)       |                                           | Industry-Related Policy C3                                   | (0.0241, 0.9324)            |
|                        | (0.5283, 0.5319)                          |                                                             |                             |
| Operations Status of   | Operations Status of Industry B2          | Technical Talent Ratio C4                                    | (0.0324, 0.8815)            |
| Industry B2            | (0.3585, 0.3404)                          | Trading Volume Month-On-Month Increase C5                    | (0.0304, 0.8744)            |
|                        | (0.4338, 0.4142)                          |                                                             |                             |
| Operational Credit Risk| Management Risk B3                        | Market Share C6                                              | (0.0466, 0.9155)            |
| A2                     | (0.2274, 0.7051)                          | Social Influence C7                                          | (0.0316, 0.8810)            |
|                        | (0.4225, 0.4118)                          | Power Transmission Reliability C8 (0.4714, 0.4632)           | (0.0448, 0.9093)            |
|                        |                                           | Supply and Demand Side Signing Success Rate C9 (0.4086, 0.3826) | (0.0388, 0.8957)            |
|                        | (0.5283, 0.5319)                          |                                                             |                             |
| Financial Credit Risk A3| Profitability B5                          | Rate of Return on Assets C10                                 | (0.0158, 0.9730)            |
| (0.1885, 0.6655)       | (0.3679, 0.7102)                          | Net Profit Margin C11                                        | (0.0162, 0.9738)            |
|                        |                                           | Cost Profit Margin C12                                       | (0.0103, 0.9632)            |
|                        |                                           | Management Costs Account for the Main Business Ratio C13    | (0.0119, 0.9660)            |
| Solvency B6            | Current Ratio C14                         | (0.2274, 0.7210)                                            | (0.0158, 0.9730)            |
| (0.5283, 0.5319)       | (0.2343, 0.7299)                          | Net Profit Margin C11                                        | (0.0162, 0.9738)            |
| Development Ability B7 | Assets Liability Ratio C15               | Cost Profit Margin C12                                       | (0.0103, 0.9632)            |
| (0.2015, 0.5006)       | (0.4552, 0.4542)                          | Management Costs Account for the Main Business Ratio C13    | (0.0119, 0.9660)            |
|                        | (0.1715, 0.6493)                          |                                                             |                             |
| Transaction Credit Risk A4| Power Trading Status B8                  | Transaction Contract Performance Rate C18                   | (0.0293, 0.9387)            |
| (0.1935, 0.6723)       | (0.4714, 0.4632)                          | Transaction Deviation Assessment Rate C19                   | (0.0195, 0.9157)            |
|                        |                                           | Actual Power Completion Rate C20                            | (0.0256, 0.9301)            |
|                        |                                           | Contract Rate of Power Sale Contract C21                   | (0.0399, 0.8999)            |
| Supply and Demand      | Supply and Demand Transaction Response B9| Interruption Load Contract Performance Rate C22             | (0.0288, 0.8673)            |
| Transaction Response B9| (0.4086, 0.3826)                         | (0.3209, 0.6514)                                            | (0.0293, 0.9387)            |
| (0.2809, 0.6025)       |                                           | Transaction Deviation Assessment Rate C19                   | (0.0195, 0.9157)            |
|                        |                                           | Actual Power Completion Rate C20                            | (0.0256, 0.9301)            |
|                        |                                           | Contract Rate of Power Sale Contract C21                   | (0.0399, 0.8999)            |
|                        |                                           | Interruption Load Contract Performance Rate C22             | (0.0288, 0.8673)            |

\[
W_S = \bigoplus_{j=1}^{22} \omega_j = (0.0450, 0.8321) \bigoplus (0.0348, 0.7689) \bigoplus (0.0253, 0.7100) \bigoplus (0.0216, 0.8098) \bigoplus (0.0386, 0.8903) \\
\bigoplus (0.0526, 0.9053) \bigoplus (0.0271, 0.8237) \bigoplus (0.0263, 0.8732) \bigoplus (0.0487, 0.9313) \bigoplus (0.0129, 0.9718) \\
\bigoplus (0.0215, 0.9844) \bigoplus (0.0134, 0.9725) \bigoplus (0.0135, 0.9726) \bigoplus (0.0382, 0.9602) \bigoplus (0.0265, 0.9427) \\
\bigoplus (0.0348, 0.9574) \bigoplus (0.0622, 0.9754) \bigoplus (0.0303, 0.9587) \bigoplus (0.0334, 0.9614) \bigoplus (0.0509, 0.9764) \\
\bigoplus (0.0918, 0.9678) \bigoplus (0.0750, 0.9607) = (0.5704, 0.1272)
\]
From substituting the above-aggregated results into (25), the results are shown in Table 7.

In comparing the credit risk scores of the five electricity retailing companies, electricity retailing company A scored highest. Next, we see the direct impact of the external basic environment, operating credit risk, financial credit risk, and transaction credit risk on the credit risk of the sustainable development of electricity retailing companies, as shown in Table 8.

It is obvious from Table 8 that electricity retailing companies A and C are more focused on the financial credit risk indicators, which fully conforms to the new round of power system reform ideas and the overall description of sustainable development from the perspective of “open at both ends, to hold the middle.” When assessing the credit risk of a power company, this means more focus on financial credit risk indicators. Electricity retailing companies B, D, and E are more focused on external basic environmental indicators. Although they are regulated, they lack professionalism.

Specifically, the electricity sale market is released in an orderly manner, and multiple power-selling entities are built, with more independent choices and on the basis of a fully liberalized market structure of buyers and sellers. C11, C14, C16, C17 and other indicators directly affect electricity retailing company A and C’s sustainable credit risk evaluation results, while electricity retailing companies B, D, and E focus more on the relevant policies issued by the state, such as indicators, while ignoring the sustainability of credit risk capabilities. This has greatly weakened the ability of these electricity retailing companies to withstand risks and improve credit levels, as shown in Figure 3.

### 5.1.2 The IFAHP of changing the degree of hesitation

After calculation and analysis, although the credit risk comprehensive scores of companies B, D, and E are not the largest, the main reason for their low level of resistance to various types of risks is caused by external basic environmental indicators. That is, the electricity retailing companies B, D, and E focus more on the guidance of their policies in the country or related industries, thus reducing the sustainability of the credit risk of these electricity retailing companies. Therefore, by adopting the dynamic adjustment hesitation strategy proposed in this paper, these companies can be re-evaluated and found to have better adaptability, as follows:

\[ \rho \left( W_B^1 \right) = 0.3304 < \rho \left( W_B \right) = 0.3348, \]

\[ \rho \left( W_D^1 \right) = 0.3312 < \rho \left( W_D \right) = 0.3356, \]

\[ \rho \left( W_E^1 \right) = 0.3397 < \rho \left( W_E \right) = 0.3352. \]

After the dynamic adjustment of the hesitation of B, D, and E, the credit risk results of these electricity retailing companies are worse than the initial hesitation, and the credit risk evaluation values of A and C are different. The recognition is therefore enhanced.

### 5.2 Comparative analysis of different methods

In order to further verify the flexibility and practicability of the IFAHP, based on the same information set, the author used the basic IFAHP, the dynamic variable hesitation degree IFAHP (D-IFAHP), and the FAHP to evaluate the credit risk of the five electricity retailing companies. The results of the comprehensive evaluation are shown in Table 9:

Table 9 shows the credit risk evaluation results of the five electricity retailing companies under the three evaluation methods. The basic changes in the threefold lines

| Electricity retailing company | A   | B   | C   | D   | E   |
|------------------------------|-----|-----|-----|-----|-----|
| Credit risk score result     | 0.3819 | 0.3348 | 0.3772 | 0.3356 | 0.3397 |
| Sort                         | 1   | 5   | 2   | 4   | 3   |

| A               | B               | C               | D               | E               |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| A1              | 0.5047          | 0.6204          | 0.6971          | 0.5952          | 0.6412          |
| A2              | 0.5193          | 0.5001          | 0.7885          | 0.5228          | 0.5325          |
| A3              | 0.5924          | 0.5166          | 0.8233          | 0.5026          | 0.4110          |
| A4              | 0.4924          | 0.4534          | 0.7332          | 0.4301          | 0.3402          |
| Sort            | A1 > A2 > A3 > A4 | A1 > A2 > A3 > A4 | A1 > A2 > A3 > A4 | A1 > A2 > A3 > A4 | A1 > A2 > A3 > A4 |

Table 7 Credit risk score results of different electricity retailing companies

Table 8 The direct impact of the primary indicator on the electricity retailing company
are very similar, indicating that the relative rankings of the credit risk levels of different electricity retailing companies are different. However, after the dynamic adjustment of the method of intuition fuzzy evaluation, the resolution of D-IFAHP and IFAHP is higher, and the evaluation result of FAHP obviously does not show the weak link of the credit risk of the electricity retailing companies’ sustainable development. In addition, since the weight value is directly given by experience without considering the uncertainty of the peer expert’s own judgment, it is easy for the actual change of some index values to be inconsistent with the expert experience, resulting in critical information being flooded. Therefore, it is difficult to be objective and accurate. Specifically,

1. The lines of A and C are raised close to the surroundings, indicating that the credit rating of these electricity retailing companies is relative to the front, and the credit risk is low, suggesting high-quality sale companies.
2. The fold lines of B, D, and E are all inward and close to the center of the circle, indicating that the credit ratings of these electricity retailing companies are relatively low, and the credit risk is relatively high. Whether this reflects the power generation side or the user side, users should focus on such electricity retailing companies to avoid causing greater losses. At the same time, the regional power trading center should adopt a coping strategy for this type of electricity retailing company and urge the “power generation side-sales side-user side” to dynamically improve their performance in terms of trading behaviors and trading capabilities, thereby improving their credit risk level.

### 6 | CONCLUSION

In order to improve the sustainability of the credit risk of electricity retailing companies, this paper developed a credit risk evaluation index system for these companies based on existing research and the actual situation of the sustainable development of electricity retailing companies. We analyzed the direct or indirect impact of different indicators of electricity retailing companies, and carried out a case analysis to reach the following conclusions.

1. We systematically sorted out and summarized the research relating to electricity retailing companies, and identified 22 credit risk evaluation indicators to build an electricity retailing company credit risk evaluation index system, considering the external basic environment, production and operation risk, financial credit risk, and transaction credit risk.
2. We proposed a comprehensive evaluation model of the credit risk of electricity retailing companies based on the IFAHP, and introduced a variable weighting mechanism for dynamically adjusting hesitation. The sustainability of the credit risk of electricity retailing companies was comprehensively evaluated. Therefore, our method contributes to electricity retailing company credit risk evaluation becoming more flexible and effective overall.
3. We selected five electricity retailing companies for empirical analysis and found that the credit risk levels of A and C are higher than those of B, D, and E, which is consistent with the new round of power system reform and further validates the feasibility of the improved IFAHP. The proposed model can help comprehensively improve the sustainable development level of electricity retailing companies, and their ability to resist risk.

### TABLE 9 Comprehensive evaluation value of different evaluation methods

| Sale company | Comprehensive evaluation value | Comprehensive evaluation value |
|--------------|--------------------------------|--------------------------------|
|              | IFAHP  | D-IFAHP | FAHP  |          |
| A            | 0.3819 | 0.3819  | 0.3886| 1        |
| B            | 0.3348 | 0.3304  | 0.3544| 5        |
| C            | 0.3772 | 0.3772  | 0.3840| 2        |
| D            | 0.3356 | 0.3312  | 0.3553| 4        |
| E            | 0.3397 | 0.3352  | 0.3596| 3        |
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ORCID

Gejirufu De https://orcid.org/0000-0002-2443-3113

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## APPENDIX

### TABLE A1  B electricity retailing company total weight table

| First-level indicators | Second-level indicators | Third-level indicators | Total weight          |
|------------------------|-------------------------|------------------------|-----------------------|
| (0.1507, 0.6079)       | (0.8134, -0.7195)       | (0.3081, 0.6317)       | (0.0378, 0.7517)      |
|                        |                         | (0.2832, 0.5971)       | (0.0347, 0.7284)      |
|                        |                         | (0.2416, 0.5396)       | (0.0296, 0.6896)      |
|                        |                         | (0.3695, 0.3374)       | (0.0418, 0.8428)      |
|                        |                         | (0.5313, 0.5390)       | (0.0600, 0.8906)      |
|                        |                         | (0.4870, 0.3923)       | (0.0481, 0.8990)      |
|                        |                         | (0.3978, 0.2563)       | (0.0393, 0.8765)      |
|                        |                         | (0.3752, 0.4233)       | (0.0342, 0.8961)      |
|                        |                         | (0.5176, 0.5818)       | (0.0472, 0.9246)      |
|                        |                         | (0.1803, 0.6873)       | (0.0148, 0.9738)      |
|                        |                         | (0.1835, 0.6924)       | (0.0151, 0.9743)      |
|                        |                         | (0.1740, 0.6773)       | (0.0143, 0.9730)      |
|                        |                         | (0.1385, 0.6529)       | (0.0130, 0.9710)      |
|                        |                         | (0.4564, 0.4423)       | (0.0282, 0.9348)      |
|                        |                         | (0.4207, 0.3950)       | (0.0260, 0.9293)      |
|                        |                         | (0.2015, 0.5006)       | (0.0219, 0.9255)      |
|                        |                         | (0.4870, 0.4831)       | (0.0179, 0.9088)      |
|                        |                         | (0.3978, 0.3675)       | (0.0179, 0.9088)      |
|                        |                         | (0.2633, 0.7690)       | (0.0264, 0.9336)      |
|                        |                         | (0.4213, 0.3958)       | (0.0316, 0.9434)      |
|                        |                         | (0.2769, 0.5954)       | (0.0316, 0.9434)      |
|                        |                         | (0.2015, 0.5006)       | (0.0219, 0.9255)      |
|                        |                         | (0.4558, 0.4415)       | (0.0470, 0.9175)      |
|                        |                         | (0.4975, 0.4968)       | (0.0597, 0.9351)      |
### TABLE A2  C electricity retailing company total weight table

| First-level indicators | Second-level indicators | Third-level indicators | Total weight |
|------------------------|-------------------------|------------------------|--------------|
| (0.1727, 0.6434)      | (0.8739, -0.6654)       | (0.3558, 0.6969)       | (0.0537, 0.8200) |
|                        |                         | (0.2849, 0.6013)       | (0.0430, 0.7633) |
|                        |                         | (0.2089, 0.4993)       | (0.0315, 0.7026) |
|                        |                         | (0.7139, 0.3675)       | (0.0456, 0.8505) |
|                        |                         | (0.3695, 0.3374)       | (0.0655, 0.8960) |
| (0.1963, 0.6760)      | (0.4740, 0.4656)        | (0.4870, 0.3923)       | (0.0453, 0.8948) |
|                        |                         | (0.3978, 0.2563)       | (0.0370, 0.8712) |
|                        |                         | (0.3886, 0.3660)       | (0.0398, 0.8709) |
|                        |                         | (0.5588, 0.5589)       | (0.0442, 0.9102) |
| (0.1877, 0.6640)      | (0.2829, 0.5965)        | (0.1670, 0.6657)       | (0.0089, 0.9547) |
|                        |                         | (0.1755, 0.6793)       | (0.0093, 0.9565) |
|                        |                         | (0.2136, 0.7403)       | (0.0113, 0.9648) |
|                        |                         | (0.1558, 0.6477)       | (0.0081, 0.9522) |
|                        |                         | (0.2598, 0.5644)       | (0.0244, 0.9269) |
|                        |                         | (0.3925, 0.3633)       | (0.0191, 0.9068) |
|                        |                         | (0.4739, 0.4709)       | (0.0256, 0.9295) |
| (0.2653, 0.7711)      | (0.4339, 0.4142)        | (0.2423, 0.5476)       | (0.0279, 0.9394) |
|                        |                         | (0.3313, 0.6640)       | (0.0381, 0.9550) |
|                        |                         | (0.3040, 0.6284)       | (0.0350, 0.9502) |
|                        |                         | (0.4564, 0.4423)       | (0.0546, 0.9281) |
|                        |                         | (0.4207, 0.3950)       | (0.0503, 0.9220) |

### TABLE A3  D electricity retailing company total weight table

| First-level indicators | Second-level indicators | Third-level indicators | Total weight |
|------------------------|-------------------------|------------------------|--------------|
| (0.1423, 0.6084)      | (1.0009, -0.5546)       | (0.3944, 0.7424)       | (0.0562, 0.8432) |
|                        |                         | (0.2973, 0.6220)       | (0.0424, 0.7699) |
|                        |                         | (0.1858, 0.4837)       | (0.0265, 0.6857) |
|                        |                         | (0.6664, 0.3331)       | (0.0354, 0.8332) |
|                        |                         | (0.3732, 0.3613)       | (0.0513, 0.8811) |
| (0.1860, 0.6658)      | (0.5318, 0.5396)        | (0.4693, 0.4088)       | (0.0464, 0.9090) |
|                        |                         | (0.4155, 0.3325)       | (0.0411, 0.8973) |
|                        |                         | (0.3752, 0.4116)       | (0.0257, 0.8696) |
|                        |                         | (0.5176, 0.5733)       | (0.0355, 0.9054) |
| (0.2227, 0.7141)      | (0.3758, 0.7213)        | (0.1937, 0.7138)       | (0.0162, 0.9772) |
|                        |                         | (0.2440, 0.7918)       | (0.0204, 0.9834) |
|                        |                         | (0.1744, 0.6939)       | (0.0146, 0.9748) |
|                        |                         | (0.1170, 0.5951)       | (0.0098, 0.9677) |
|                        |                         | (0.2945, 0.6168)       | (0.0265, 0.9312) |
|                        |                         | (0.4733, 0.4647)       | (0.0310, 0.9413) |
|                        |                         | (0.3810, 0.3684)       | (0.0168, 0.9085) |
|                        |                         | (0.5238, 0.5263)       | (0.0231, 0.9512) |

(Continues)
### Table A3 (Continued)

| First-level indicators | Second-level indicators | Third-level indicators | Total weight |
|------------------------|-------------------------|------------------------|--------------|
| (0.2743, 0.7819)       | (0.4564, 0.4423)        | (0.2715, 0.5870)       | (0.0340, 0.9498) |
|                        |                         | (0.2317, 0.5356)       | (0.0290, 0.9435)  |
|                        |                         | (0.3673, 0.7105)       | (0.0460, 0.9648)  |
|                        |                         | (0.4870, 0.4831)       | (0.0562, 0.9318)  |
|                        |                         | (0.3978, 0.3675)       | (0.0459, 0.9165)  |
| (0.4207, 0.3950)       |                         | (0.2835, 0.6008)       | (0.0348, 0.7689)  |
|                        |                         | (0.2066, 0.4992)       | (0.0253, 0.7100)  |
|                        |                         | (0.3415, 0.3333)       | (0.0216, 0.8098)  |
|                        |                         | (0.6098, 0.6154)       | (0.0386, 0.8903)  |

### Table A4  
E electricity retailing company total weight table

| First-level indicators | Second-level indicators | Third-level indicators | Total weight |
|------------------------|-------------------------|------------------------|--------------|
| (0.1016, 0.5870)       | (1.2075, −0.4021)       | (0.3666, 0.7106)       | (0.0450, 0.8324) |
|                        |                         | (0.2835, 0.6008)       | (0.0348, 0.7689) |
|                        |                         | (0.2066, 0.4992)       | (0.0253, 0.7100) |
|                        |                         | (0.3415, 0.3333)       | (0.0216, 0.8098) |
|                        |                         | (0.6098, 0.6154)       | (0.0386, 0.8903) |
| (0.1854, 0.6791)       | (0.4564, 0.4423)        | (0.6214, 0.4706)       | (0.0526, 0.9053) |
|                        |                         | (0.3204, 0.0147)       | (0.0271, 0.8237) |
|                        |                         | (0.3374, 0.3467)       | (0.0263, 0.8732) |
|                        |                         | (0.6245, 0.6460)       | (0.0487, 0.9313) |
| (0.2849, 0.7884)       | (0.2980, 0.6210)        | (0.1523, 0.6485)       | (0.0129, 0.9718) |
|                        |                         | (0.2529, 0.8008)       | (0.0215, 0.9844) |
|                        |                         | (0.1579, 0.6573)       | (0.0134, 0.9725) |
|                        |                         | (0.1584, 0.6580)       | (0.0135, 0.9726) |
|                        |                         | (0.6352, 0.6173)       | (0.0382, 0.9602) |
|                        |                         | (0.4408, 0.4487)       | (0.0265, 0.9427) |
|                        |                         | (0.3415, 0.3333)       | (0.0348, 0.9574) |
|                        |                         | (0.6098, 0.6154)       | (0.0622, 0.9754) |
| (0.3548, 0.8651)       | (0.3695, 0.3374)        | (0.2311, 0.5381)       | (0.0303, 0.9587) |
|                        |                         | (0.2552, 0.5684)       | (0.0334, 0.9614) |
|                        |                         | (0.3886, 0.7362)       | (0.0509, 0.9764) |
|                        |                         | (0.4870, 0.4831)       | (0.0918, 0.9678) |
|                        |                         | (0.3978, 0.3675)       | (0.0720, 0.9607) |