A Study on the Evaluation Index System for the Operation and Development of Electricity Wholesale Markets Based on FAHP-DEMATEL: A Case Study of Henan Province

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Abstract. The healthy development of the power spot market is of great significance to the power economic system. To achieve long-term stable operation of the spot market, it is necessary to improve market construction from multiple aspects. This paper selects indicators from eight aspects: compliance, participation, supply-demand relationship, price distribution, electricity distribution, bidding behavior, operational risks, and personnel organization management risks of the wholesale power market, using the Delphi method and sensitivity analysis. A two-level index system of primary and secondary indicators is established. The Decision Making Trial and Evaluation Laboratory (DEMATEL) method is used to analyze the influence between indicators. Combined with the Fuzzy Analytic Hierarchy Process (FAHP), the indicator weights are determined, key influencing factors for the healthy operation of the spot market are identified, and decision references are provided for the construction and development of the spot market.

Keywords: electricity market, power trading center, electricity wholesale market, operation management, development evaluation, Delphi method, sensitivity analysis, decision making trial and evaluation laboratory, fuzzy analytic hierarchy process

1 Introduction

After decades of large-scale development, China's electric power industry has laid a solid foundation for the rapid development of China's economy and the improvement of people's living standards. The installed capacity of power generation increased from 1.8486 million kilowatts in 1949 to 2,200.58 million kilowatts in 2020. The annual power generation ranking jumped from the 25th in the world to the first in the world. However, under the advantage of total scale, China's energy consumption per unit GDP is still higher than the world average. With the continuous rapid increase in the proportion of new energy in recent years, the utilization hours of various power generation equipment continue to decrease. In order to improve system operation efficiency, enhance industrial transformation capabilities, and accelerate the construction of competitive power markets, in 2015, the State Council officially issued the "Several Opinions on Further Deepening the Reform of the Power System", starting

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a new round of power system reform. The construction of spot power market is an important way to promote this power system reform.

In 2021, Henan became a pilot province for the construction of spot power markets under the background of China's power system reform. Exploring the establishment of power spot trading mechanisms, changing planned dispatching methods, discovering electricity commodity prices, forming a market-based power balance mechanism, and gradually building a power market system combining medium-and long-term transactions with spot transactions are conducive to Henan giving full play to the decisive role of the market in allocating power resources and further releasing reform dividends.

The wholesale power market refers to the market for electricity transactions such as direct transactions between power generation enterprises and power users and power sales companies, and is a market for large transactions of electricity. With the continuous advancement of spot power market construction, how to quantify the operation indicators of the wholesale power market, monitor the operation of the wholesale power market, and judge the future development trend of the wholesale power market is particularly important. Since the construction of China's spot power market started late, the evaluation index system for the operation of wholesale power markets under the spot background has not yet formed a unified framework at the national level, and relevant research is also lacking. Reference [1] analyzes the evaluation index system for market power regulation in the power market through the analysis of market models, measures and regulatory frequencies in foreign power markets, and provides recommendations for the construction of market power regulation in the power market. Reference [2] mainly constructs a comprehensive evaluation system based on the development status of power enterprises and market environment under the power market, and obtains the operating conditions and economic performance of each regional grid, providing references for the healthy operation of power companies under the power market background. Reference [3] takes the market service performance of power producers as the main research object, and constructs a comprehensive evaluation index system for the market service performance of power producers. Reference [4] constructed a comprehensive evaluation model of environmental impacts during construction using the hierarchical analysis method, and based on this method, it was applied to a construction example to investigate the appropriate evaluation of environmental impacts during the construction period. Existing studies utilizing the hierarchical analysis method mainly reflect the evaluation of business processes related to a single participant in the market, and there are fewer studies evaluating the overall operation and development of the wholesale electricity market in the context of the spot.

This paper focuses on the construction of operation and development evaluation models for wholesale power markets under the spot market background. Based on the business chain of wholesale power markets, considering the business chain of wholesale power markets under the spot background, the author selected an appropriate index system, and formed a set of evaluation index systems for the operation and development of wholesale power markets under the spot background through analytic hierarchy process and fuzzy comprehensive evaluation method. On this basis, combined with the actual situation in Henan Province, case analysis is given. Finally, corresponding operation and management measures are proposed based on the evaluation results of the indicators.

2 Research Methodology

This paper mainly uses the principles of fuzzy analytic hierarchy process (FAHP) and decision making trial and evaluation laboratory (DEMATEL) to establish an evaluation index system. The characteristics of the two methods are as follows:

2.1 Fuzzy Analytic Hierarchy Process (FAHP)

The fuzzy analytic hierarchy process is a multi-criteria decision analysis method that combines analytic hierarchy process (AHP) with fuzzy mathematical theory. It constructs a hierarchical index system, uses expert judgment to form fuzzy comparison matrices, and utilizes mathematical operations on fuzzy matrices to obtain weights of indices at each level, thereby evaluating and prioritizing alternatives. Compared with the traditional AHP, FAHP uses fuzzy linguistic variables to express experts' judgments on the relative importance of indices, which can better deal with uncertainties in the decision making process.

2.2 Decision Making Trial and Evaluation Laboratory (DEMATEL)

The decision making trial and evaluation laboratory method is a decision analysis method that can identify the interactions between factors and analyze the intrinsic relationships between factors. Through expert surveys, this method constructs a direct influence matrix of factors, and applies matrix operations to extract causal relationships and degrees between factors, distinguishing the degree of influence and being influenced of factors, and establishing a network relationship diagram of factors. DEMATEL can clarify the influence directions between factors in complex systems, which is conducive to identifying core and induce factors and providing support for identifying system constraints in decision making.

3 Construction of Evaluation Index System for the Operation and Development of Wholesale Power Markets

The evaluation index system for the operation and development of wholesale power markets monitors market operations in multiple dimensions and comprehensively evaluates market operations. It can both discover problems existing in market operations to provide a basis for regulatory authorities to strengthen supervision and promote standardized development and formulate targeted improvement measures. Based on the scientific, comprehensive, instructive and adjustable principles of index selection, this study constructs an evaluation index system for the operation and development of wholesale power markets from eight aspects: compliance, participation, supply-demand relationship, electricity price distribution, electricity distribution, bidding behavior, operational risks, and personnel organization management risks, as shown in the following Table 1:

Table 1. Evaluation Indicators for the Operation and Development of Wholesale Power Markets

Primary Indicator	Secondary Indicator	Indicator Category
	Completeness of Trading Rules R_{11}	Qualitative

Compliance Indicators of Wholesale Power Market Construction R_1	Implementation of Trading Rules R_{12}	Qualitative
Participation Indicators of Wholesale Power Market R_2	Participation Degree of Power Generation Side in Wholesale Power Market R_{21}	Quantitative
	Participation Degree of User Side in Wholesale Power Market R_{22}	Quantitative
Supply-Demand Indicators of Wholesale Power Market R_3	Supply Capability of Wholesale Power Market R_{31}	Quantitative
	Supply-Demand Relationship of Power Generation and User Sides in Wholesale Power Market R_{32}	Quantitative
Electricity Price Distribution Indicators of Wholesale Power Market R_4	Electricity Price Fluctuation Indicator in Wholesale Power Market Transactions R_{41}	Quantitative
	Peak-Valley Price Indicator in Wholesale Power Market R_{42}	Quantitative
Electricity Distribution Indicators of Wholesale Power Market R_5	Deviation Degree of Power Generation Side Settlement Electricity in Wholesale Power Market R_{51}	Quantitative
	Deviation Degree of User Side Settlement Electricity in Wholesale Power Market R_{52}	Quantitative
Bidding Behavior Indicators of Wholesale Power Market R_6	Self-reported Rate of Power Generation Side R_{61}	Quantitative
	Self-reported Rate of User Side R_{62}	Quantitative
Operational Risk Indicators of Wholesale Power Market R_7	Scale of Imbalance Funds R_{71}	Quantitative
	Dispersion Degree of Surplus and Shortage Fund Costs R_{72}	Quantitative
Personnel Organization Management Risk Indicators of Wholesale Power Market R_8	Integrity of Power Trading Center Organizational Structure R_{81}	Qualitative
	Talent Team Quality Indicators R_{82}	Quantitative

The evaluation index system for market operation and development constructed in this study consists of 8 first-level indicators R1~R8 and 16 corresponding second-level indicators. The second-level indicators include both qualitative and quantitative indicators.

Compliance Indicators of Wholesale Power Market Construction

This indicator describes the compliance of power wholesale market institutions, reflecting whether the market supervision rules and systems are complete, clear, and operable, and whether the internal control system is sound.

Completeness of Trading Rules

This indicator mainly evaluates whether the trading rules themselves are fully formulated, clear, operable, and whether the rules system is in place. It is a qualitative indicator.

Implementation of Trading Rules

This indicator describes whether each institution carries out its market operations in strict accordance with the market rules or relevant national regulations, and evaluates the effectiveness of compliance and implementation of the rules in actual execution. It is a qualitative indicator.

Participation Indicators of Wholesale Power Market

This type of indicator is mainly used to describe the participation of power market supply and demand sides, reflecting the competition levels of supply and demand sides in the wholesale power market.

Participation Degree of Power Generation Side in Wholesale Power Market

Mainly describes the direct participation degree of power generation entities in the power market, as formula (1) shows.

$$R_{21} = \frac{N_{\text{market-based}}}{N_{\text{centrally dispatched}}} \tag{1}$$

Where $N_{\text{market-based}}$ is the number of market-based units, and $N_{\text{centrally dispatched}}$ is the number of centrally dispatched units.

Participation Degree of User Side in Wholesale Power Market

Mainly describes the direct participation degree of wholesale power users in the power market, as formula (2) shows.

$$R_{22} = \frac{N_{\text{direct power purchase}}}{N_{\text{direct power purchase users}}} + \frac{N_{\text{power sales companies in the spot market}}}{N_{\text{power sales companies}}} \tag{2}$$

Where $N_{\text{direct power purchase}}$ is the number of direct power purchase users participating in the spot market, $N_{\text{direct power purchase users}}$ is the total number of direct power purchase users, $N_{\text{power sales companies in the spot market}}$ is the number of power sales companies participating in the spot market, $N_{\text{power sales companies}}$ is the total number of power sales companies.

Supply-Demand Indicators of Wholesale Power Market

This indicator describes the supply and demand conditions of the supply and demand sides in the spot market, and evaluates the performance of the power market in balancing supply and demand, ensuring transactions, and reasonable pricing.

Supply Capability of Wholesale Power Market

This indicator mainly describes the supply capability, supply potential, and supply security of the supply side entities in the spot market, as formula (3) shows.

$$R_{31} = \frac{P_{\text{market-based}}}{P_{\text{maximum grid load}}} \tag{3}$$

Where $\boldsymbol{P}_{\text{market-based}}$ is the total capacity of market-based units, and $\boldsymbol{P}_{\text{maximum grid load}}$ is the maximum grid load.

Supply-Demand Relationship of Power Generation and User Sides in Wholesale Power Market

This indicator mainly describes the load supply-demand relationship between the power generation side and user side entities in the spot market, as formula (4) shows.

$$R_{32} = \frac{P_{\text{generation side}}}{P_{\text{user side}}} \quad (4)$$

Where $P_{\text{generation side}}$ is the total capacity of the generation side participating in the spot market, and $P_{\text{user side}}$ is the total demand of the user side participating in the spot market.

Electricity Price Distribution Indicators of Wholesale Power Market

This indicator describes the price formation and transmission in the spot market[6].

Electricity Price Fluctuation Indicator in Wholesale Power Market Transactions

This indicator describes the overall volatility of transaction prices in the spot market, providing a basis for electricity price supervision.

Peak-Valley Price Indicator in Wholesale Power Market

This indicator describes peak and off-peak prices in the spot market, examines the effects of peak-valley regulation strategies, and optimizes resource allocation.

Electricity Distribution Indicators of Wholesale Power Market

This indicator describes the distribution of traded electricity volume in the spot market, reflecting the rationality of the power supply structure[5].

Deviation Degree of Power Generation Side Settlement Electricity in Wholesale Power Market

This indicator describes the distribution of deviation degrees of power generation side settlement in the spot market, reflecting the operating conditions and peak shaving capabilities of power generation companies, as formula (5) shows.

$$R_{51} = \delta\_(Day - ahead\ deviation,\ \ generation\ side) \quad (5)$$

Deviation Degree of User Side Settlement Electricity in Wholesale Power Market

This indicator describes the distribution of deviation degrees of user side settlement in the spot market, reflecting the electricity usage patterns and response capabilities of the user side, as formula (6) shows.

$$R_{52} = \delta\_(Day - ahead\ deviation,\ user\ side) \quad (6)$$

Bidding Behavior Indicators of Wholesale Power Market

This indicator describes whether the bidding behavior of participating entities in the wholesale power market is standardized and transparent, and whether there are abnormalities and violations.

Self-reported Rate of Power Generation Side

This indicator describes the self-reporting of power generation side entities, as formula (7) shows.

$$R_{61} = \frac{N_{\text{self-reported power generation units}}}{N_{\text{power generation side entities}}} \quad (7)$$

Where $N_{\text{self-reported power generation units}}$ is the number of self-reported power generation units, and $N_{\text{power generation side entities}}$ is the total number of power generation side entities.

Self-reported Rate of User Side

This indicator describes the self-reporting of user side entities, as formula (8) shows.

$$R_{62} = \frac{N_{\text{self-reported users}}}{N_{\text{user side entities}}} \quad (8)$$

Where $N_{\text{self-reported users}}$ is the number of self-reported users, and $N_{\text{user side entities}}$ is the total number of user side entities.

Operational Risk Indicators of Wholesale Power Market

This mainly reflects the operational risks in all aspects from organization, clearing to settlement of the spot market under the power spot market system.

Scale of Imbalance Funds

This indicator describes the scale of imbalance funds, reflecting the internal imbalance of the market. By statistically calculating the total imbalance funds of the power generation side and user side, it reflects the internal supply and demand deviations and peak shaving capabilities of the market, as formula (9) shows.

$$R_{71} = \frac{\Sigma M_{\text{fund surplus and shortage}}}{\Sigma M_{\text{spot market settlement cost}}} \quad (9)$$

Where $\Sigma M_{\text{fund surplus and shortage}}$ is the total cost of fund surplus and shortage, and $\Sigma M_{\text{spot market settlement cost}}$ is the total spot market settlement cost.

Dispersion Degree of Surplus and Shortage Fund Costs

This indicator describes the dispersion degree of the settlement ratios of various imbalance fund varieties, reflecting the capital regulation pressures faced by market participants. By calculating the differences in the capital surplus and shortage statuses and corresponding cost levels of different market entities, it reflects the difficulty degree of capital regulation faced by entities.

Personnel Organization Management Risk Indicators of Wholesale Power Market

This indicator describes risks that may exist in aspects such as organization management, personnel capabilities and team building of the wholesale power market.

Integrity of Power Trading Center Organizational Structure

This indicator measures whether the organizational functions of the market operating agency are complete, whether the functional departments are complete, whether the responsibilities and boundaries between relevant departments are clarified and rationalized, whether there are phenomena of some departments acting on duties and powers, etc. It is a qualitative indicator.

Talent Team Quality Indicators

This indicator comprehensively evaluates the quality of the market agency's team by the proportion of senior professional title personnel and the proportion of full-time undergraduate and above educational personnel, as formula (10) shows.

$$TQ = k_1 \times \frac{N_{bac}}{N_{s-total}} + k_2 \times \frac{N_{snr}}{N_{s-total}} \ (k_1 + k_2 = 1) \tag{10}$$

Where TQ is the talent team quality score, N_{bac} is the number of full-time undergraduate and above educational personnel, N_{snr} is the number of senior professional title personnel, and $N_{s-total}$ is the total establishment number of the trading center. k_1 and k_2 are weighting coefficients.

4 Analysis of Indicator Correlation and Weight Determination

4.1 Analysis of Influencing Relationships Between Indicators Based on DEMATEL

The steps for influence relationship analysis using the DEMATEL method are as follows:

1. Perform system analysis on the model to be evaluated, and determine the goal and criteria.
2. Construct a direct relation matrix D. This matrix evaluates the direct influence relationships between indicators through expert scoring.
3. Calculate the normalized direct relation matrix N. The constant k is calculated by a formula $N = k * D$ to make the column sums of the matrix equal to 1.
4. Calculate the total relation matrix T. $T = N * (I - N)^{-1}$ I is the identity matrix. The elements t_{ij} in T represent the total influence degree of the indicators on each other.
5. Calculate the influence degree R and influenced degree of each indicator C. R is the column sum of the matrix T, representing the influence of this indicator on other indicators. C is the row sum, representing the influence degree of other indicators on this indicator.
6. Based on R and C, the nature of the indicators can be determined. If $R - C > 0$, the indicator is a causal variable; if $R - C < 0$, it is a result variable. The larger $R + C$ is, the higher the importance of the indicator.
7. Plot the influence relation diagram. The horizontal axis is influenced degree C, and the vertical axis is influencing degree R. Indicators with high importance will be concentrated in the upper right corner of the graph.
8. Based on the causal relationships between indicators, modeling of the index system can be performed to determine the hierarchical relationships and weights of the indicators.

4.2 Determination of Indicator Weights Based on FAHP-DEMATEL

The basic steps of the fuzzy analytic hierarchy process (FAHP) are:

1. Invite several experts, issue evaluation survey questionnaires, and make pairwise comparisons and scoring between indicators of the same level and affiliation on their relative importance, using a 0.1-0.9 nine-level scale for dimensional breakdown.
2. Establish a fuzzy complementary matrix. The scoring results of the pairwise indicator comparisons should satisfy the basic requirements of the fuzzy complementary matrix. Record the final scoring matrix that satisfies the fuzzy complementary matrix as T.

As formula (11) shows, the definition formula of the fuzzy complementary matrix is:

$$0 \leq S_{ij} \leq 1,\ S_{ji} = 0.5\ and\ S_{\mathrm{ij}} + S_{\mathrm{ji}} = 1,\ (i,\ j = 1,\ 2,\ \dots,\ n) \tag{11}$$

The matrix T is shown as formula (12):

$$T = \begin{pmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & \cdots & t_{2\mathrm{n}} \\ \vdots & \vdots & \vdots & \vdots \\ t_{n1} & t_{\mathrm{n}2} & \cdots & t_{\mathrm{nn}} \end{pmatrix} \tag{12}$$

3. Derive the weight coefficients R_i combined with the following formulas (13)-(15).

$$t_i = \sum_{k=1}^{n} t_{ik},\ (i,\ k = 1,\ 2 \cdots n) \tag{13}$$

$$r_i = \frac{t_i - n - 2}{n(n-1)} \tag{14}$$

$$R_i = \begin{pmatrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{pmatrix} \tag{15}$$

4. Perform consistency test on the fuzzy judgment matrix, first fuzzily standardize it as formula (16) shows, and obtain the fuzzy consistent matrix *A* as formula (17) shows after processing.

$$r_{ij} = \frac{(n-1)(r_i - r_j)}{2} + 0.5 \tag{16}$$

$$A = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{pmatrix} \tag{17}$$

5. Perform consistency test on the fuzzy judgment matrix A, and the consistency test process can be expressed by Formula (18):

$$CI(T,\ A) = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} |A_{ij} - T_{ij}|}{n^2} \tag{18}$$

6. Finally, compare and judge the magnitude of the calculated CI values. According to the consistency of the fuzzy analytic hierarchy process, when the CI value is smaller, the consistency of the data group is better. When $CI < 0.1$, it indicates that the data group meets the fuzzy consistency requirement and the initial weights W_1 are obtained.
7. Multiply the influence degree and influenced degree, normalize them, and calculate the influence weight of the indicator W_2 based on DEMATEL. Multiply it by the initial weight W_1, to obtain the comprehensive weight of the evaluation indicator for Henan's power spot market.

4.3 Case Analysis

Data Collection and Processing

This study takes Henan Province as the evaluation object. The data required for quantitative evaluation comes from the National Bureau of Statistics, the National Energy Administration, and the Henan Provincial Power Grid Company. The qualitative evaluation results come from experts from various departments of the trading center and third-party agencies.

Quantitative indicator processing

The quantitative indicators in this study adopt the linear evaluation method and implement the percentage system. The specific calculation method is as follows:

When the indicator value is positively correlated with the evaluation score, it means that as the indicator increases, the score increases and the risk level decreases, as shown in formula (19):

$$S_i = \frac{v_i - v_{min}^i}{v_{max}^i - v_{min}^i} \times 100 \tag{19}$$

Where S_i is the score of indicator i, v_i is the indicator value of indicator i, v_{min}^i is the theoretical minimum value of indicator i, and v_{max}^i is the theoretical maximum value of indicator i.

When the indicator value is negatively correlated with the evaluation score, it means that as the indicator increases, the score decreases and the risk level rises, as shown in formula (20):

$$S_i = \frac{v_{min}^i - v_i}{v_{max}^i - v_{min}^i} \times 100 \tag{20}$$

Qualitative indicator processing

Based on fuzzy comprehensive analysis, the evaluation set of the secondary evaluation indicators is determined as:

$$V = \{V_1, V_2, V_3, V_4, V_5\} = \{\text{Excellent, Good, Average, Pass, Needs Improvement}\}$$

The mapped scores of the evaluation set are $H = [90, 80, 70, 60, 50]$. By collecting expert opinions through questionnaires, the weighted average score of single-factor expert evaluation is taken as the evaluation result of the secondary indicator. Then the final compliance risk evaluation result is determined according to the weights of the primary indicators obtained by ANP.

Calculation of Indicator Weights Based on ANP

Experts from the trading center and third parties are invited to make pairwise comparisons of indicators at each level based on the nine-level scale, and form an indicator importance judgment matrix. After passing the consistency test, the judgment matrix is entered into the Yaanp decision software to solve the limit super matrix and obtain the weights of each indicator as shown in Table 2:

Table 2. Evaluation Indicators for the Operation and Development of Wholesale Power Markets

Primary Indicator	Weight	Secondary Indicator	Weight
Compliance Indicators of Wholesale Power Market Construction R_1	0.106120	Completeness of Trading Rules R_{11}	0.021932
		Implementation of Trading Rules R_{12}	0.084189
Participation Indicators of Wholesale Power Market R_2	0.046510	Participation Degree of Power Generation Side in Wholesale Power Market R_{21}	0.033487
		Participation Degree of User Side in Wholesale Power Market R_{22}	0.013023
Supply-Demand Indicators of Wholesale Power Market R_3	0.133348	Supply Capability of Wholesale Power Market R_{31}	0.092455
		Supply-Demand Relationship of Power Generation and User Sides in Wholesale Power Market R_{32}	0.040893
Electricity Price Distribution Indicators of Wholesale Power Market R_4	0.081321	Electricity Price Fluctuation Indicator in Wholesale Power Market Transactions R_{41}	0.018704
		Peak-Valley Price Indicator in Wholesale Power Market R_{42}	0.062617
Electricity Distribution Indicators of Wholesale Power Market R_5	0.039587	Deviation Degree of Power Generation Side Settlement Electricity in Wholesale Power Market R_{51}	0.033366
		Deviation Degree of User Side Settlement Electricity in Wholesale Power Market R_{52}	0.006221
Bidding Behavior Indicators of Wholesale Power Market R_6	0.026750	Self-reported Rate of Power Generation Side R_{61}	0.021617
		Self-reported Rate of User Side R_{62}	0.005134
Operational Risk Indicators of Wholesale Power Market R_7	0.259033	Scale of Imbalance Funds R_{71}	0.225009
		Dispersion Degree of Surplus and Shortage Fund Costs R_{72}	0.034024
Personnel Organization Management Risk Indicators of Wholesale Power Market R_8	0.307331	Integrity of Power Trading Center Organizational Structure R_{81}	0.202326
		Talent Team Quality Indicators R_{82}	0.105005

Arranging the weights of the secondary indicators in descending order as shown in the Fig. 1, it can be seen that the importance of imbalance fund scale and integrity of power trading center organizational structure ranks ahead, and their impact on the evaluation of wholesale power market operation and development is also the greatest.

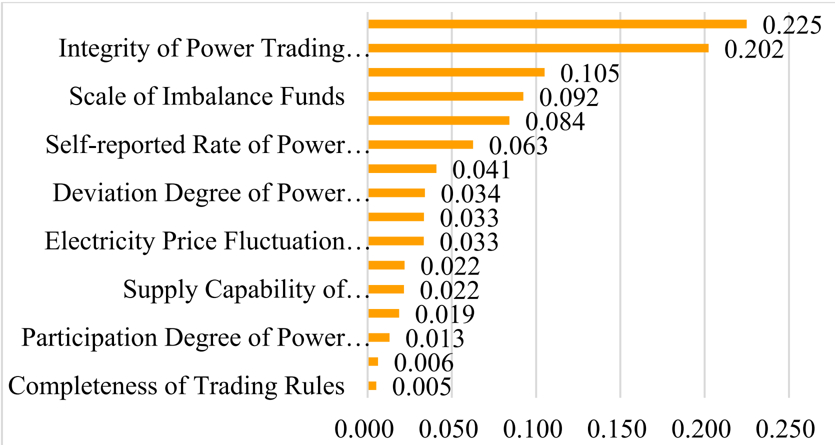

Fig. 1. Ranking of Weights for Evaluation Indicators of Wholesale Power Market Operation and Development

Determining the Final Evaluation Result Based on Fuzzy Comprehensive Analysis

The expert questionnaire surveys are statistically summarized to obtain the evaluation results of the qualitative indicators among the secondary indicators; at the same time, the scores of the quantitative indicators among the secondary indicators are calculated according to formulas (19) and (20). According to the fuzzy evaluation matrix obtained from formula (17) and the weight vector of each factor set, the comprehensive evaluation result of the trading center's compliance risk is calculated, as shown in Table 3.

Table 3. Comprehensive Evaluation Results of Wholesale Power Market Operation and Development

Comprehensive Evaluation Results of Wholesale Power Market Operation and Development	
Compliance Indicators of Wholesale Power Market Construction	72.13
Participation Indicators of Wholesale Power Market	72.96
Supply-Demand Indicators of Wholesale Power Market	85.00
Electricity Price Distribution Indicators of Wholesale Power Market	81.15
Electricity Distribution Indicators of Wholesale Power Market	80.00
Bidding Behavior Indicators of Wholesale Power Market	94.18
Operational Risk Indicators of Wholesale Power Market	82.61
Personnel Organization Management Risk Indicators of Wholesale Power Market	79.08
Total Score	**80.37**

Based on the scores of each primary indicator, a visualized radar chart is formed as Fig. 2 shown.

Fig. 2. Radar Chart for Evaluation of Wholesale Power Market Operation and Development

It can be seen from the evaluation results that the current advantages of Henan's wholesale power market operation and development are reflected in aspects of market bidding behavior, supply-demand relationship between power generation and user sides, and operational risks. Henan's wholesale power market has demonstrated relatively outstanding professional competence in implementing market bidding behavior, optimizing supply-demand relationships between power generation and user sides, and effectively reducing market operational risks. The insufficient parts are market trading rules and market participation. Follow-up work needs to implement trading rules and increase the participation of power generation side and user side market entities.

5 Conclusions

With the continuous advancement of China's power market reform, the openness and complexity of market operations will gradually increase. The wholesale power market urgently needs to promote the construction of an operation and development evaluation system to maintain its own advancement. To adapt to the needs of power market development, we must focus on the long-term development of the market, and start from improving the openness and transparency of market trading, enhancing the efficiency of market operations, and maintaining the fairness of market trading, to construct a systematic, scientific and dynamic evaluation index system for the operation and development of wholesale power markets.

This paper constructed an evaluation model for the operation and development of wholesale power markets based on 8 primary operation and development categories: compliance, participation degree, supply-demand relationship, electricity price distribution, electricity distribution, bidding behavior, operational risks, and personnel organization management risks, covering the basic business chain of wholesale power markets. Using analytic hierarchy process and fuzzy comprehensive method, a comprehensive evaluation of the 8 first-level indicators and 16 second-level indicators was carried out, forming an evaluation system for the operation and development of wholesale power markets, which can assist wholesale power markets to complete risk self-checks during operation and management, promptly discover defects and deficiencies in market operation and development, provide guidance for proposing targeted improvement measures, and promote the sustainable development of wholesale power markets.

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